


REPORT OF COMMITTEE

ON

TECHNOLOGICAL PREPAREDNESS FOR DEALING WITH NATIONAL DISRUPTIONS




Indian National Academy of Engineering

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Chief Mentor: Dr. Prem Shanker Goel

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INTRODUCTION

India is a country with large variations in geological conditions, covered with ocean on three sides, and the third pole, Himalayas in the north, north of equator with highly variable climate over a year, thus facing all possible natural disasters. Also, the geopolitical situation is so complex that it is vulnerable to many man-made disasters. The 2004 Tsunami caught the country with a total surprise, thousands of people lost their life as the possibility of Tsunami was totally forgotten. Today, the country is better prepared with a functional, state of the art Tsunami Warning Centre and a mechanism for responding to a Tsunami. This preparedness can also be seen in the case of various cyclones that hit the country every year. On science side the India Meteorology Department has developed techniques for forecasting the rout and intensity a cyclone is likely to take and on response side, the National Disaster Management Authority has equipped itself to provide relief to the people along with the preparedness at the state governments

However, there is a lot to be done with respect to engineering interventions for various disasters the country is facing/likely to face. Indian National Academy of Engineering (INAE) decided to conduct an in-depth study with respect to what engineering interventions are needed to forecast (to the extent possible) and to mitigate the impact of each type of national disaster and prepared a white paper (Annexure #1). INAE constituted a peer committee (Annexure #2) to carry out this task. The following six domain were identified and expert committees were constituted (Annexure #3);

1. **Weather and climate related disasters**
2. **Ocean related disasters**
3. **Geological related disasters**
4. **Health related disasters**
5. **Cyber security related disasters**
6. **Fire related disasters**

Each expert committee had several meetings within themselves and across the expert committees as some of them have overlapping activity. Peer committee had several interactions with each expert committee primarily to steer the studies towards what kind of engineering preparedness the country needs to create in terms of basic science, tools & gadgets, instruments, equipment, communication & connectivity etc. The expert committees were also advised to address policy issues and any new mechanism or bodies that need to be set up in the country.

This report is an outcome of this exercise. The recommendations outlined in each expert committee report have focused on implementable aspect and create additional mechanisms, where needed. There is no claim that these will solve all problems related to disasters, but certainly, if accepted and implemented, the country will be better prepared to face the national disasters in the future.

This report is organized in two parts. The part I gives this the consolidated recommendations emerging from the 6 expert committees and the discussions in the Peer committee, organized as per the agencies responsible for the engineering preparedness, namely the agencies and departments of the GoI. Some of the recommendations have been repeated against more than one agency. It is because one agency may be user while other may be provider. It is recognized that NDMA is the prime body responsible for providing immediate relief on the ground, however we need additional mechanism(s) to organize the engineering preparedness and practically all S&T agencies are involved in this activity.

Part II of the report gives the study and recommendations of the 6 expert committees. These studies are the basis of this report, but should not be seen in isolation. A lot of interaction has taken place, where necessary, within the expert committees and the peer committee. Finally, the overall recommendations have attempted to provide an integrated approach to the engineering preparedness for Disaster Management in the part #1.

The Annexure #1 gives the white paper generated by the INAE, which is the genesis of this report. Annexure #2 is the constitution of the Peer Committee. Annexure #3 is the constitution of the six expert committees. Annexure #4 is the recommendations of the INAE forum on Engineering interventions in Disaster mitigation in 2015.

ACKNOWLEDGEMENT

This report is a voluntary effort of a large number of experts in different fields and in different agencies, many retired but worked for a national cause. Most of these scientists who have contributed are not fellows of INAE as they are not engineers but, they are experts in their respective area. INAE gratefully acknowledges the contribution of each of the scientist who are members of the peer committee and the expert committees.

INAE Contributions to Disaster Management in the Past

INAE recognized the importance of engineering interventions in Disasters Management early and created an INAE forum on "Engineering Intervention for Disaster Mitigation in 2013 with Dr R K Bhandari as its Chairman. The forum organized Round Table meetings on Engineering interventions in Landslide Risk Reduction in New Delhi on May 11th, 2015 and November 4th, 2015. Recommendations of these meetings are appended in Annexure #4.

Dr Bhandari also played an important role as member of a High Power Committee on Disaster Management by Ministry of Agriculture, committee report for National Centre for Disaster Management, Oct, 2001(Reference #1). Dr Bhandari has been associated with the activity of Disaster management in individual capacity and as an INAE fellow for over two decades.

PART 1

CONSOLIDATED RECOMMENDATIONS

1. Ministry of Earth Sciences

1.1 Atmosphere Related Hazards

1.1.1 Most of the scientific and technology inputs for forecast and mitigation of National Disasters come from MoES, it is suggested that MoES may create a think tank on Engineering Preparedness for disasters, task teams to review the latest developments across the globe, with participation of all stakeholders viz., NDMA, ISRO, DRDO, CSIR, DST, INAE and the Office of the PSA.

1.1.2 Related to Cyclones

(i) Space based observations

- Improve microwave imaging coverage and resolution over oceans and Indian land mass.
- To operationalize radio occultation technique for atmospheric profiling in cooperation with ISRO.

(ii) Improve high resolution coastal bathymetry and topography

(iii) UAVs for generation of DEM, 3D GIS mapping all along the coast

(iv) Continuous coastal Doppler Weather Radar coverage along all the Indian coast on priority and full India coverage in 5 years, in suitable combination of S, C and Ku bands.

- Development of multi-institutional mechanism for exchange of Radar Meteorology data between IMD, IAF, IISc and ISRO and other research and operational bodies and a central data base at IMD.

(v) Establishment of National Weather Radar operating Centre at IMD and to build capacity in the industry for operational maintenance of all the Radars of IMD on contract basis rather than in house maintenance.

- Development of software tools for contemporary Radar meteorology.

(vi) To have a coastal network of wind profilers covering all the coast.

(vii) To create a network of microwave radiometer along the coast.

(viii) Sustenance of 6 nos. of high-quality GPS based systems –WMO GUAM standard Network.

(ix) Surface observation Network of IMD

- To have at least one Agro-AWS in each district of India
- Installation of at least one HIWR station in each coastal district of India
- Part time observations to be replaced with AWS

- IMD to create an operational maintenance body on contract basis for all surface observation network of IMD.

(x) Strengthen cyclone forecasting research through multi organization participation including ISRO and academia.

(xi) Cyclone warning dissemination system -- Though there is an appropriate system to warn the authorities at district level, public outreach needs improvement in view of emerging IT technologies like 5G. Every concerned citizen should have information about possible cyclones and how will it affect him (personalized information) through mobile and other broadcast mechanisms, particularly the Sea going communities like fishermen.

1.1.3 Related to Storm Surge.

(i) There should be a network of automated tide gauges all along the coast at least one in 100 kms and all the data to be available in real time at a Central station.

(ii) Realtime assessment of coastal inundation is necessary for future warnings and hence UAV/Aerial survey system should be in place as satellite imagery is not available due to clouds. SAR mapping from satellites can be utilized.

(iii) Coastal DEM has to be improved via CARTO Satellites/Aerial survey using ALTM.

(iv) The storm surge modeling has to be improved using coupled land, ocean and atmosphere model, and using rainfall, river discharge and wind data.

1.1.4 Heavy Rain and Floods

(i) The network of dual polarized Doppler Weather Radar has to cover the complete country on priority to enhance the capability of now-casting and extreme weather events.

(ii) The global and regional models need to be scaled up to resolve the regional heterogeneity and topography. The needed resolution is about 6 km global and 1 km for mesoscale regional model.

(iii) Land-Ocean-Atmosphere coupled model needs to be developed for realistic forecast of heavy rainfall and floods.

There is an urgent need for engineering solution to drain water from heavy rainfall for most of the cities and flood prone areas, as such events would be on increase due to global warming.

1.1.5 Cloud bursts

Cloud bursts are intense precipitation events with rain rates greater than 100 mm per hour for a few hours over a relatively small geographical area. The numerical models are sufficiently developed to capture cloud bursts, however, isolated local events in hilly regions are difficult to forecast. Cloud bursts cause extensive damage, particularly in hilly regions. While various mitigation steps have been identified, the following engineering preparedness steps have been recommended:

(i) Airborne Early Warning Systems (AEWS): Four specialized Aircraft fitted with Doppler Weather Radar to be kept at four different stations prone to cloud bursts, available at short notice to monitor any intense connective system. During non-active periods these aircrafts can be used for other parameters like DEM using ALTM and coastal bathymetry etc.

(ii) ISRO may develop a satellite that will monitor stable water isotopologues in the atmosphere via making use of occultation technique with special focus on intense convective cells.

(iii) Conduct experiments with High power microwave and laser beams in collaboration with DRDO to induce initial triggering of precipitation (similar to cloud seeding, this can also be tried for cloud seeding for areas where rain bearing clouds are there but with no sufficient rains).

(iv) High Altitude Platforms can provide severe weather monitoring. NAL/CSIR is developing one such platform that can be fitted with optical and IR sensors which can be steered towards weather active regions.

1.1.6 Urban Floods

(i) For better forecast heavy rain in urban areas, there is a need for the city to have a X-band dual pole Doppler weather radar with global model and high-resolution local data will be able to provide better forecast of heavy rains in a region of city in short term and now-casting basis using mesoscale modes. Also need sufficient number of AWS in cities.

(ii) There is a need for geo referencing and impact based forecast and risk based warning generation utilizing a digital DSS for a particular area. For this purpose, a digital data base has to be created for each city on meteorological data, socio economic indicators, geo spatial data including drainage data and associated hazards like coastal flooding due to storm surge, astronomical tides, riverine flooding, landslides etc. An appropriate agency has to be identified for each of the above, as there is no identified agency for any City. The Corporations do not have such a modeling capability, though they may be a primary source of city specific data. (MoES, NDMA, State Govts, City Civil authorities may identify a body). Digital data base of a city can be prepared using private industry also.

1.1.7 Thunder storms/Lightning/Hailstorm

(i) Comprehensive weather observation system as described earlier will be need to have a warning of the active atmospheric conditions described above. The observation system includes dual polarization Doppler Weather radars, AWS, HAP and Satellite based occultation sensors.

(ii) Some experiments are being conducted to dissipate Hailstorms as they cause very extensive damage to crops etc. using anti-hail gun. Once found successful, these need to be deployed at large scale in hail prone areas like Uttarakhand and Maharashtra, and an operational agency need to be identified.

(iii) Some advanced countries have set up a very exhaustive thunderstorm monitoring system. However, it is only a monitoring system and does not help in forecast. The socio-economic benefit of such a system needs to be evaluated to ascertain whether such a system is needed.

1.1.8 Heat wave and cold wave

(i) The current observation system is not adequate to forecast heatwave and cold wave, though IMD is doing its best with the existing observation system. The observation system needs to be improved.

(ii) IMD need to fine tune modeling on region basis and disseminate deterministic forecast for target region, rather than vague region definition like northern India.

1.1.9 Global Warming and Related Impact on Agriculture, Health and Disasters etc.

(i) The agriculture may be affected as the temperature in the planes will increase and specific cultivation like Apple may shift northwards. It needs appropriate mechanism to advise farmers accordingly.

(ii) Since extreme weather events will increase in number, separated by dry spell, more water storage capacity like check dams need to be created to store water more often and avoid sudden floods.

(iii) Chronic obstructive pulmonary diseases and Asthma are likely to flare up, better preparedness with outreach to villages is needed.

(iv) Vector Borne Diseases (VDB) caused by faster growth of bacteria like Malaria are likely to increase. Extra research effort in this direction is needed.

(v) In view of the vulnerability due to heat wave, heat action plan for all vulnerable districts should be developed.

(vi) Collaborating research between institutes like ICMR, Vector Born Disease control program, local state governments, NCDO, IMD and MPCCHH for development of tools of early warning of outbreaks of malaria and dengue should be encouraged.

(vii) The global warming will lead to more frequent and more intense extreme events, needing better infrastructure and quicker response to situations like floods, landslides and cyclones.

1.1.10 Global warming and impact on coastal region submerging.

Climate change induced changes in the coast could give serious repercussions on the coastal infrastructure, primarily ports and cities and villages along the coast.

(i) A comprehensive study is needed to model the coastal erosion processes at all vulnerable locations and to come up with solutions and place suitable structures well in advance. NIOT/MoES has the expertise but to conduct studies all along the coast and come up with solutions is a big and time-consuming task, however it has to be done.

1.1.11 Droughts in regional and national level

In India, nearly 68% of net sown area is vulnerable to drought. It is envisaged that global warming would increase in this area, and drought would be more severe and frequent.

(i) Country needs to improve its infrastructure for better monitoring of the drought through satellite imagery and IT infrastructure.

(ii) Bring more farmers under crop insurance cover, so as to minimize individual impact.

(iii) Agro-Advisory service needs to be improved at village or individual land holding level and precision farming to be introduced at village level.

(iv) Better water management at local levels, more check-dams and river dams to be created to store rainwater and not to let it flow to sea through rivers.

1.2 Ocean Related Hazards

1.2.1 TSUNAMI

The present Tsunami Warning System operational at INCOIS/MOES takes care of Tsunami generated only from earthquakes. But Tsunami can also be triggered by submarine landslides, under sea volcanic eruptions and meteoritic impacts. This needs considerable enhanced observations system surrounding the Indian Ocean Rim to be comprehensive.

1.2.2 Tropical cyclones and Storm Surges.

(i) Improve the monitoring network by enhancing the existing sensors and integrating new platforms such as GNSS, Ocean Bottom Seismometers, infrasound and InSAR and Altimeters in space.

(ii) Develop natural barriers (sand dunes, mangroves, coral reefs, grass beds and coastal forest etc.)

(iii) Erect vertical evacuation shelters and warning towers with sirens along the coastline of vulnerable areas.

(iv) Mapping the inter-tidal zones, coastal topography and bathymetry with centimeter level accuracy to improve the accuracy of inundation models.

1.2.3 Oil Spills

(i) SAR is an important sensor for detecting oil spills. Hence, space-based SAR imaging is very necessary on continuous basis for detecting oil spills in time.

(ii) While Indian coastguard is the responsive/mitigating agency, the role for an early detection is not defined. INCOIS may be assigned this responsibility from SAR satellite data detection and generating alert, modeling the spread with time etc., through a DSS.

1.2.4 Harmful Algal Blooms

Harmful Algal Blooms (HAB) detection is very important for advising the fishermen.

(i) The detection of HAB is from the OCEANSAT satellite imagery. ISRO may maintain the continuity of the OCEANSAT data.

(ii) INCOIS may be identified as operational agency for generating alert for HAB with data from OCEANSAT satellite to be available in real time.

(iii) Further research is required to improve algorithms for detection of bloom and a collaborating research/coordination is needed between INCOIS, SAC, CMLRE, NRSC, NIO and NAVY.

1.2.5 Sea Level Rise and Climate change

(i) There is a need to develop multi-hazard vulnerability maps under different scenarios of sea level rise for the Indian coasts.

(ii) Ocean climate change Advisory services to be developed by INCOIS under the Deep Ocean Mission to include dynamic Ocean modeling, statistical down scaling and detailed impact on Ocean climate change.

1.2.6 Coral bleaching/Ocean acidification

(i) Insitu observations should be enhanced with bio chemical sensors at all critical eco systems such as coral reefs.

(ii) More research is needed to improve retrieval of geophysical parameters for coastal waters from Ocean Sat data.

(iii) Numerical model would be developed integrating heat and CO2 flux to generate Ocean circulation models.

(iv) Coral bleaching alerts generated by INCOIS should be enhanced with additional environmental parameters.

1.2.7 Marine Plastics/debris

Plastics waste thrown into the sea is a major ecological hazard for the coastal region.

(i) Detailed guidelines need to be evolved to control the waste plastic flow to the Oceans (MoEF)

(ii) An in-depth study is needed to understand pathways of plastic pollutants through eddies and coastal currents.

1.2.8 High waves along west coast of Indian and Makran Swells

The high waves activity associated with Makran Swells in the months October to May influence marine operations and coastal processes in the west coast of India.

A comprehensive study is required on wind wave characteristics in a changing climate scenario. Needed observation systems to be provided.

1.2.9 Marine Heat waves

Marine heat waves over Indian Ocean Region play a vital role in the governing the Ocean currents and hence the weather system.

(i) Integrate Marine Observations through insitu and satellite platforms in the coupled models for understanding the marine heat waves and their impact on weather. An operational system needs to be set up for forecasting marine heat waves.

2. ISRO/DOS

(i) Improve microwave coverage and resolution by satellites over ocean and land mass

(ii) To develop radio occultation payload and associated data processing algorithms so that radio occultation payload can be accommodated in many LEO satellites.

(iii) Coastal DEM to be improved using CARTO satellites and airborne ALTM

(iv) ISRO in participation with other space agencies should create a constellation of Fire Detection LEO satellites with a repeativity of any area with less than 6 hours. It could also complement it by using thermal sensors on GEO satellites.

(v) ISRO may develop a satellite that will monitor stable water isotopologues in the atmosphere via making use of Occultation technique, with special focus on intense convective cells.

(vi) Improve the monitoring network by enhancing existing sensors and integrating with new platforms such as GNSS, Infrasound, InSAR and altimeters in space.

(vii) SAR provides an effective method of detecting oil spills. Hence, ISRO should plan availability of satellite SAR data on continuation basis in collaboration with international coordination to reduce the revisit time in the Indian Ocean and Bay of Bengal.

(viii) OCEANSAT data is very important for providing Potential Fishing Zone (PFZ) advisories to fishermen, about 7 lakhs of them are using now. OCEANSAT data is also used for identification of Harmful Algal Bloom. The continuity of the data should be ensured and it should be regularly available at INCOIS.

(ix) ISRO to launch microwave interferometry satellites (formation flying in LEO) for creating centimeter level accuracy DEM of all vulnerable landslide/snow avalanche vulnerable locations.

3. Ministry of Home and C S I R

3.1 NAL is developing a High-Altitude Platform to be tested in 2024. This can be equipped with optical and IR Sensors to monitor severe weather events by steering towards weather active regions.

3.2 Earthquake Disaster Mitigation

(i) Conduct microzonation studies of all major cities to assess the earthquake vulnerability and generate design guidelines based on worst case earthquake intensity probability and the soil conditions.

(ii) Introduce earthquake safety of built environment as mandatory part of Technical Educational under graduate civil engineering and architecture degree programs.

(iii) Licensing of civil engineers for competence that design and built are meeting requisite standards as per zone.

(iv) Revise building bye-laws of all states and UTs of India to ensure mandatory earthquake resistant features in the design and construction

(v) Prioritize seismic retrofit of critical and lifeline structures.

3.3 Landslide and snow avalanche disaster mitigation

(i) Establish an Indian Centre for Landslide and snow avalanche mitigation as a single national operational body, assessing vulnerable locations, managing landslide hazard through an institutional mechanism by following systematic approach that includes short term and long-term planning.

(ii) The Indian Centre of Landslide and sow avalanche mitigation centre to create a library of all vulnerable sites, create DEM model of each side and study impact of rain/snowfall on all sites.

(iii) The centimeter level DEM can be created using aircraft based ALTM/SAR images. ISRO may launch a microwave interferometry satellites, formation flying with three satellites in LEO to create the DEM library of all landslide/avalanche vulnerable sites in about a decade.

4. NDMA

(i) For fighting fire at congested places like lanes of Chandini chowk Delhi, NDMA should task industry to develop special firefighting stations and ensure that all major cities to have these.

(ii) NDMA may host two aircraft with the operational support from Airforce for fighting disasters in cooperation with MoES as follows:

a) Carrying meteorological equipment to image with high resolution the cyclone formation, flying above the cyclone, in co-operation with MoES (IMD, NCMRF and IITM)

b) Same aircraft could carry ground mapping camera in case of an earthquake for damage assessment.

c) Same aircraft could map in high resolution inundation in case of Tsunami storm surge or floods.

d) Same aircraft could be used for forest fire spread assessment to plan the extinguishing strategy.

e) Same aircraft could be used for transporting hail gun when IMD expects hail to occur in a region.

f) Same aircraft with an Ocean color monitor could be used for mapping Algae bloom in finer details.

g) Same aircraft could be used to destroy locust at the entry point to the country or even before in cooperation with Pakistan as locust first enter Pakistan and then enter India after devastating crops in Pakistan.

5. DRDO

(i) Conduct experiments with high power microwave and laser beams in collaboration with MoES to induce initial triggering of precipitation (similar to cloud seeding, this can also be tried for cloud seeding in areas where rain bearing clouds are there but no sufficient rains)

(ii) CFEES/DRDO should introduce latest equipment such as water mist to all state firefighting agencies and ensure development/production of these equipment in the Indian Industry.

(iii) DRDO may join IMD to experiment with laser gun as anti-hail gun. If successful, it could save a few thousands of crores worth of crop every year.

7. ICMR

The COVID-19 pandemic has taught many lessons and India has succeeded well in tackling the disease. It is known fact that Covid 19 caught us by a surprise and we had to learn a lot while facing it. Once corona is gone and we are back to normal, dismantling all the infrastructure created. Already, the oxygen plants have been dismantled as there is no space to keep them functioning and the emergency beds have been removed. Some other virus like monkeypox may emerge and we may repeat the story from developing vaccine in one year, augmenting medical infrastructure and impose lockdowns under the National Disaster Act.

(i) MoHFW/ ICMR/NHSRC should create a mechanism to keep emergency infrastructure alive for all time to come.

(ii) MoHFW/ICMRNHSRC to create a mechanism to keep a watch on any such virus emerging anywhere else in the world and warn the government well before it enters India, with actionable recommendations.

(iii) ICMR should fund developments related to facing such pandemics like (a) Capacity building for vaccine R&D in the country, (b) Development of medical equipment that we still import, in consultation with DBT, DST and private industry.

(iv) While we developed very effective state of the art vaccines, we import their ingredients in large numbers and large quantities. Efforts should be made under directed research programs to develop and manufacturing in India as a part of Atmnirbhar Bharat.

(v) Stake holders such as MoHFW/ICMR/NHSRC/ Department of pharma should develop a list of dependable suppliers who can provide a bulk of quantity to the government. Vulnerable places for medical emergencies could be identified and a geo-location database for such places should be created.

(vi) The National Healthcare Innovation Portal (https:nhinp.org)developed by NHSRC may be harnessed for reviewing and deploying indigenous solutions to help in mitigating the disaster.

7. Ministry of Agriculture

7.1 Rising temperatures because of Global Warming will need;

(i) Developing varieties that are tolerant to higher temperatures. 1 degree rise in temperature in February causes 2% loss of wheat yield in the planes. An R&D effort is needed for all agriculture crops.

(ii) Shifting of crops like APPLE to the north. As trees take time to bear fruits, it is needed to take some actions in advance.

8. DIETY / Ministry of Home Affairs (Cyber Security)

Cyber Warfare is considered as one of the most potent instruments of warfare, a fifth dimension after Army, Airforce, Navy and Space.

(i) The national cyber security policy, 2013 needs to be revised in line with the technological innovations, emerging technologies, the emerging threats, open and unmanaged networks.

(ii) The CERT-IN and NCIIPC may be merged into one agency as National Agency for Cyber Security and Policy and a Hub and spoke model may be used for coordinating between different sectorial regulators. The agency needs significant empowerment through legislation so as to enforce cyber policies to prevent cyber events.

(iii) The cyber and ICT infrastructure of critical, sensitive and strategic sectors be thoroughly audited prior to commencement of their (Banking, Airlines, Railways, Power, Space, DAE, DRDO etc.) operations.

(iv) Cyber security be introduced in the IT courses at BE/ME level so as to create awareness in the students, when they take up jobs.

(v) The platforms like National Resilience Centre for cyber, centralized malware analysis platforms, centralized Dark Web Monitoring platform and centralized standard body be strengthened and brought under the overall umbrella of the "National Agency for Cyber Security and Policy."

(vi) The National cyber security coordinator (NCSC) be empowered and his role be expanded to coordinate all sectors and regulators including space and defence. All regulators must get their policies vested, prior to their notification form NCSC.

(vii) The cyber capabilities of the security agencies be enhanced considerably, particularly the forensic capabilities. Security agencies be allowed to do research on offensive capabilities as well to really understand the potential of adversaries. This may include offensive tools development.

(viii) All state police agencies must enhance their cyber forensic capabilities and infrastructure. These be supported by NCSC.

(ix) NCSC must create mechanism to test and certify the infrastructure and equipment as user agencies.

(x) Cyber security law be framed on priority basis.

(xi) Cyber security law be framed outlining the legal responsibilities and accountability of organizations and individuals to enhance the cyber security of the country as a whole.

9. Ministry of Home Affairs/Ministry of Environment and Forest

9.1 Forest Fires

(i) ISRO in participation with international agencies should create a constellation of fire detection LEO satellites with repeativity of any area less than 6 hrs. It could also utilize a thermal sensor on an Indian Geo satellite.

(ii) Forest fire too will increase with global warming. MoEF, the Forest Protection Division, to create a cell for forest fires, that should log all minor or major forest fires and coordinate with local agencies, NDMA etc., for taking steps to quench the forest fires in the beginning itself, before it reaches uncontrollable state. Early detection and response to put off fire are important for this.

(iii) The capability for fighting forest fire developed by Forest Research Institute (FRI) Dehradun to be shared with state firefighting departments of vulnerable states like Andhra Pradesh.

(iv) Vulnerable states to keep helicopters with firefighting material ready for operation the vulnerable summer months for quick response.

(v) Any equipment that are imported currently to be listed and indigenized.

(vi) New fire retardants like foam, gel, chemicals should be introduced.

9.2 Industrial Fire.

(i) About 70% of the industry fire are caused by short circuits. This is also mostly because of negligence by not following the industry standard wiring practices. Current mechanism of inspection and certification has proved to be inefficient. It is time to create trustworthy professional inspection and certification agencies.

(ii) Many MSMEs function in congested and residential areas. All such industries should be relocated to identified industrial areas that are equipped with firefighting stations.

(iii) A mandatory annual fire safety audit by an independent certification body should be introduced for all industries.

(iv) CFEES/DRDO suggest latest firefighting equipment to state governments/fire fighting forces and develop those in the country.

9.3 Fires in congested areas

(i) The municipal corporations should ensure that there is access to all areas for fire tenders to reach and take necessary actions in a time bound schedule.

(ii) Latest technology such as water mist should be utilized. CFEES/DRDO should create awareness of such equipment and ensure that these are produced in the Indian industry.

(iii) A special all terrain small fire fighting stations should be developed in India, that can enter thickly populated lanes, NDMA should act as a coordination agency.

(iv) Fire safety should be an integral part of the town/urban planning an such a clearance should be mandatory from firefighting department/certifying agency.

(v) Motorbikes based fire tenders with water mist back pack system should be developed and made available in congested areas in all major cities.

(vi) Provision of a Fire Post a every 3 kms and a Fire Station at every 7 kms should be ensured at all metropolitan cities.

(vii) Provision should be made for dedicated underground water reservoirs in areas of high risk for replenishment of fire tenders.

10. State Governments and Local bodies

(i) The most devastating effect of global warming is going to be the occurrences of extreme weather events like heavy rain/cloud bursts, though the overall monsoon rain over the season may not change much. This will result in more severe floods and landslides followed by water scarcity as most water will flow in to the ocean as there would not be enough time for land to absorb. The only solutions are;

a) to doubling the water storage capacity as quickly as possible, by creating new dams even in so called dry states like Rajasthan and Telangana, increasing dam height where ever possible,

b) increase drainage capacity in all cities and towns to avoid flooding the houses.

11. Recommendations to create standing mechanisms

(i) In the prevailing situation of global warning and consequent more frequent occurrences of extreme weather events, there is need to implement the above recommendations in a time bound manner. This would need attention and monitoring at a very high level. It is noted that while NDMA is primarily the response body, the scientific inputs largely come from Ministry of Earth Sciences, NGRI/CSIR, ISRO, ICMR and DST. It is proposed to create an overseeing body on Technology preparedness for addressing disasters (both forecast and mitigation) that may meet on National Disaster Management Day, Oct. 29 each year.

The suggested committee is as follows:

1.	Principal Scientific Advisor	:	Chairman
2.	Director General MDMA	:	Member
3.	Secretary, MoES (or rep)	:	Member
4.	DG, CSIR (or his rep.)	:	Member
5.	Chairman, ISRO (or rep.)	:	Member
6.	D.G., DRDO (or rep)	:	Member
7.	D.G. ICMR (or rep.)	:	Member
8.	Secretary, DST (or Rep)	:	Member
9.	President, INAE (or rep)	:	Member
10.	D.G. IMD/Scientific Secretary, MoES	:	Member Secy.

The Committee will review the technology preparedness toward National disasters vis-à-vis technology adopted elsewhere in the world and proposed new initiatives to the respective department/agency.

(ii) The role of satellite-based observations is ever increasing in the forecast and advance warning of National Disaster and some of these have been detailed section 2 of this chapter. Being an evolutionary technology as the technology and science progress, data in visible, IR, microwave and Radar Imaging, Interferometry in Microwave etc. It is recommended to create a committee to address needs of space-based observations for technology preparedness for disasters mitigation, as follows:

1.	Secretary, MoES	:	Chairman
2.	Secretary DOS (or Rep.)	:	Member
3.	DG. NDMA	:	Member
4.	Director, NGRI/CSIR	:	Member
5.	Director, SASE/DRDO	:	Member
6.	Scientific Secretary, MoES	:	Member- Secretary.

Secretary, MoES may create an Office for coordination with various Users engaged in dealing with disasters and consolidate the requirement, that may be projected to ISRO, once in a year in the month of September, prior to National Disaster Management Day.

The suggested office, at MoES will act as overall coordination office for all scientific and engineering needs towards Engineering Preparedness for National Disasters.

PART 2

EXPERT COMMITTEES REPORTS

CHAPTER - 1

ATMOSPHERE RELATED DISASTERS

Subcommittee on
Technology Preparedness for
dealing with National Disruptions:
Atmosphere Related Disasters

Contents

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Section 5 : Urban floods

Section 8: Global Warming and related impact on agriculture, health and diseases etc.

Section 9: Global Warming and impact on coastal region submersing Drought on regional or national level

Section 10: Drought on regional or national level

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New Delhi ***Mrutyunjay Mohapatra***
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Executive Summary

The meteorological and hydrological services have significant soci-economic impact. Demands of Public/private/government sectors for accurate prediction of weather and climate at various temporal and spatial scales is increasing due to impacts of global climate variability and change. Continuous improvements are being done to develop and disseminate forecasts, warnings and alerts to protect life and property and to support efforts to reduce the adverse impacts of weather, climate, water and related environmental natural hazards.

The primary hazards leading to national disruptions are cyclone, floods, droughts, heat & cold waves, thunderstorms and associated weather (lightning, squall, and hailstorm), cloudburst, snow and avalanches. It also leads to secondary hazards like landslides, health hazards, food scarcity etc. Many of the weather and climate hazards are also multi-hazard type in nature with their simultaneous occurrence over a region like cyclones being associated with heavy rain leading to flood, winds leading structural damage and storm surge leading coastal inundation.

The disaster risk reduction basically includes (i) Hazard Monitoring, détection and assessment, (ii) early warning, (iii) vulnerability analysis, risk assessment, (iv) preparedness, prevention and mitigation through adequate response actions. The early warning is a major component which includes monitoring and detection, analysis, prediction, early warning generation and dissemination. Hydro-Meteorological informations are also used in management of natural resources from disasters (Agriculture/Water resources, Energy Resources etc). In the recent years, there have been significant improvements in early warning system (EWS) of the country, especially by the Ministry of Earth Sciences including IMD and also by Ministry of Water Resources (Central Water Commissions) and SASE, DRDO. Though it has been possible to minimize the loss of lives due to weather and climate related hazards like cyclones, heavy rainfall, heat wave and cold waves, there is still large loss of lives due to floods (Riverine flood, urban flood, flash flood, Glacial Lake outburst flood (GLOF)) and lightning. Further, there is huge loss of property due to these hazards. Hence, there is still scope to improve the EWS and other aspects of disaster risk reduction.

The focus of the report is to study all possible disruptions and to examine technology preparedness for dealing with National Disruptions: Atmosphere and Climate related disasters in the country, identify the gaps and recommend the areas for further scientific research and technology solutions. In this regard it has been decided to address possible disasters through an Expert Committee in each sectoral discipline to address all aspect related to preparedness for cyclones, floods, global warming and related like impact on agriculture, coastal region submersing, health and diseases etc., heavy rain / cloud burst like Mumbai deluge, drought on regional or national level, impact of adverse weather on agriculture output and any other related disaster

During the first meeting of Expert Committee on Technology Preparedness for dealing with National Disruptions: Atmosphere and Climate related disasters it was decided to form Subcommittees to address different major disasters.

The brief summary of the reports of Subcommittees on Technology Preparedness for dealing with National Disruptions: Atmosphere and Climate related disasters as presented on subsequent ten chapters as described below:

Cyclone

There has been significant improvement in tropical cyclone monitoring, forecasting and warning services by IMD in recent years which enabled disaster managers and general public to minimase the loss of life and property. However, there are still gaps and challenges to improve further the early warning system and response mechanism based on improvement in hazard, vulnerability and risk analysis, preparedness, prevention and mitigation measures.

The hazards associated with a tropical cyclone (TC) include strong winds, heavy rain, storm surge, high to phenomenal waves, flooding (coastal inundation, pluvial and fluvial), landslides and occasionally tornadoes. There is a rising trend in frequency of extremely severe cyclonic storm (ESCS) and above intensity storms over the Arabian Sea (AS) since 1990 and no significant trend over the Bay of Bengal (BoB). Accurate forecasting of both track and intensity of a TC is critical to mitigation of disasters caused by an approaching TC.

Though we have developed a set of Risk atlases, we still lack a national repository of risk mapping considering all-hazard events associated with cyclones and loss data, thereby reducing our ability to make informed decisions about where and how to prioritize their resilience investments. Comprehensive and viable policies on coastal protection based on the latest data set from improved coastal mapping to enhanced weather and impact forecasting need to be developed. Gearing up the disaster management forces with advanced technological equipment for search and rescue operations is also very much essential to reduce the loss of life and property due to TCs.

Making use of such Geo-Spatial information, INAE with the support of Government, coastal managers, property owners and the general public should work towards developing a long-term plan for ensuring the sustainable development goals (SDGs). All observational, modelling and analytical TC research groups in India may be brought under a single umbrella of **National Centre for Tropical Cyclone Research.** IMD could be the nodal agency for a concerted research activity with specific objectives and goals for each group associated with this centre.

Storm surge

Storm surge is the sudden rise in sea level above the astronomical tide due to an approaching Tropical Cyclone (TC). It depends primarily on pressure drop at the centre of the cyclone, radius of maximum wind and the elevation of coast at landfall. Due to the occurrence of high sea waves, phase of astronomical tide, rainfall, river run off, bathymetry, coastal geometry etc the destruction caused by storm surge further amplifies. The coastal inundation due to storm surge depends on the surge height, vegetation characteristics prevalent over the affected regions, and onshore topography of the hinterland. Through accurate prediction and timely dissemination, the disastrous effect of this natural geo-hazard can be minimized.

Regional Specialized Meteorological Centre, India Meteorological Department (IMD), New Delhi is the nodal agency for providing cyclone and storm surge forecast with the details on track, intensity and location of landfall of TCs developing in north Indian Ocean (NIO) region to 13 WMO/ESCAP Panel Member Countries that include Thailand, Myanmar, Bangladesh, India, Sri Lanka, Maldives, Pakistan, Iran, Saudi Arabia, United Arab Emirates, Sultanate of Oman, Qatar and Yemen.

To improve the forecasting of TCs and storm surges a multi pronged approach with technology intervention is necessary to acquire real time in situ data, improve the model physics, model forcing, model numeric, enhancing the preparedness, risk assessment, mitigation and capacity building of coastal population.

In the numerical model the computation of coastal inundation is very tricky as it requires accurate data on near shore bathymetry, topography of the coast and configuration of river systems. The land topography is provided by various data sets like CARTOSAT, SRTM, ALTM, etc.

In case of cyclone passing over the riverine system, storm surge model a coupled with a hydraulic model to include precipitation and outflow from the river, is necessary to better simulate the scenario of coastal inundation. In addition, inclusion of information on land use-land cover (LULC) bottom and surface friction in the model are vital for accurate computation of inundation.

For further improvement in storm surge forecasting, some of the areas require immediate attention viz., enhancement in tide gauge network, direct and accurate observation mechanisms of the meteorological forcing and the parameterization of air-sea-land interactions, integration of river discharge in the storm surge model, maps of inter tidal zones are to be made available, customization of forecasts based on the existing infrastructure and land use-land cover (LULC) mapped on geospatial information system, planned infrastructure development in the coastal areas, to improve shelter belt plantation in coastal areas, to develop probabilistic storm surge model and land, ocean & atmosphere coupled model, to flag off the surge prone areas and to create mass awareness, to build check dams to channelize and regulate excess water from rainfall and river outflows.

There should be a formal coordination between the researchers who are engaged with storm surge observations and modelling through the establishment of a Cyclone Warning Research Centre under Ministry of Earth Sciences to further improve the accuracy of cyclone & storm surge forecasts and associated inland inundation and to device better forecasting and dissemination modalities taking advantage of the changing information technology and communication means.

Heavy rain and Floods

India experiences heavy rainfall induced floods & landslides in association with southwest monsoon, northeast monsoon and cyclonic disturbances. The increase in frequency of extreme weather events including heavy precipitation, riverine flooding etc making public and society vulnerable in recent years.

For strengthening and enhancing the skill of short to medium range forecast and nowcast of extreme weather events like heavy rainfall the number of dual polarized Doppler weather RADARs needs to be enhanced along with availability of high resolution spatio-temporal rainfall data at hourly or three hourly intervals at ~4km resolution over the vulnerable hotspot areas of India.

The numerical weather prediction models also need to be scaled up to resolve the regional heterogeneity particularly the topography, with a target resolution of ~5km for global model and ~1km for the regional mesoscale model. By utilizing all modern technology, the hazard impact modelling is essential to evaluate the risk and ensure timely response. The warning dissemination mechanism has also to be strengthened on priority following common alert protocol (CAP).

Cloud bursts

Cloudbursts leading to associated disasters frequently occur over the Himalayan region during monsoon seasons. They can also occur in deserts and interior regions of continental landmasses and along western & eastern Ghats of India.

Forecasting of cloudbursts are still in a very nascent stage and current status of the numerical weather prediction models are still not developed to capture such events in terms of exact location and timing and hence is a challenge for the generation of localized specific warnings for these highly micro scale and spontaneous events.

Some measures suggested to mitigate the impact of cloudbursts are,

- Radar and satellite products need to be integrated with existing NWP products and utilized effectively for the monitoring and early warning of the cloudbursts.
- Climatological records should be analysed to identify the possible hot spots for the cloudburst and flash flood occurrences.
- Establishment of linkages with possible glacial lake outbursts by understanding the process, gathering hydro-meteorological and geological information.
- Establishment of high-density observation networks which is most essential components of an extreme rainfall nowcasting system
- Strengthening of embankments, barrages and dams
- Localized planning involving the local communities by considering the ecologically fragile nature of the region
- Regulation of infrastructure projects and preservation of the sanctity of eco-sensitive zones
- To develop satellites for monitoring “stable water Isotopologues” in the Atmosphere
- Possible use of High-power Microwave & Laser beams, special focus on “free convective cells” that form along the fringes of intense cyclones, that many a time is not captured well in the Global Models.
- setting up “moisture trapping nets” (extracting water from atmosphere) in the Indo-Gangetic plane to extract water from the atmosphere and use it for agriculture/household needs

Urban floods

Management and operation of lakes and dams especially at times of flooding is extremely critical as many of our cities are located downstream of these storage structures. Urban floods have extensive effects on the lives and livelihoods of individuals, components of their vulnerability should be comprehended. Small-scale variability of rainfall often failed to represent by models, satellite and reanalysis datasets due to limited understanding of underlying physical processes responsible for such variability. Therefore, analysis of rainfall observations obtained with the MESONET is very much require to understand diurnal variability and sub-grid scale spatial variability of rainfall. The location specific flash flood guidance up to watershed level also to be made available for the urban locations. Development of hazard/risk maps for urban area within the context of its larger river basin is required to prepare action plans. To develop structural and non-structural measures like improvement in drainage network, planning or control on new developments in flood prone areas, pumping stations etc. Also, indigenous development may be taken up for sensor systems, network & communication system, modelling platforms and operational guidance systems for better understanding of urban floods.

There is need for geo referencing and impact-based forecast and risk based based warning generation at granular manner for the cities utilizing a digital DSS. For this purpose, there is need for digital database on meteorological & hydrological data, socio economic indicators, geospatial data including drainage data as secondary & tertiary hazards and associated hazards like coastal flooding due to storm surge, astronomical tides, riverine flooding, landslides etc. The ultimate objective should be to develop high spatial & temporal resolution urban specific flood depth, its impact & risk assessment and real time communication to public & disaster managers for timely response actions.

Thunderstorm/Lightning/ Hailstorm

There are three thunderstorm maximum regions (a) northwest Himalaya and adjoining Pakistan, (b) east India, and (c) extreme south peninsular India. The emerging technological advances are likely to have on huge impact on monitoring, numerical modelling, visualization of the various observations, forecasting, risk assessment and dissemination of final warnings of these localized severe weather phenomena. While there is need for augmentation of observational network at mesoscale with AWS/ ARG & DWR a suitable visualization platform is necessary to combine all the observations obtained from various platforms to reach an informed decision about the thunderstorm and associated weather. Though there has been remarkable improvement in mesoscale modelling in recent years, it still needs improvement with better resolution, physical process representation & data assimilation in models so as to improve the accuracy of forecast as well as hazard & impact modelling.

The Gap areas in dissemination of Alerts have been largely covered by the initiative of NDMA. However, penetration of Terrestrial GSM/Telecom network to sparsely populated regions which have poor/no GSM/Telecom network, resilience of telecom infrastructure to natural disasters for un interrupted dissemination of subsidiary alerts/instructions and relief and rescue activities, use of satellite communication for dissemination of alerts, integration with social media with the CAP being deployed by NDMA also need to be addressed .

Heat Wave and Cold Wave

The heat waves, periods of sustained high temperature and high humidity, have long been recognized as a significant weather hazard. An abnormal heat results from the increase of temperature can impose severe physiological stress and can adversely affect the life, health and well-being of human society. Maximum frequency of heat waves over most of the states is found to be in the month of May. However, the number of heat waves over Bihar, Rajasthan and Uttar Pradesh (UP) is more during the month of June compared to other months. The causalities due to heat waves are more over the regions where the normal maximum temperature itself is more than 40°C.

Cold wave is a condition of air temperature which becomes fatal to human body when exposed. The precise criterion for a cold wave is determined by the rate at which the temperature falls. Like the humidity in the heat wave case, the wind speed in case of cold wave further compounded the effect of wind chill. It is distinguished by a marked cooling of the air, or with the invasion of very cold air, over a large area. In the case of heat wave, it is highly recommended to consider minimum temperature, humidity and wind speed & direction to issue the impact-based warning for heat wave, UHI effect also to be considered while issuing the impact-based heat wave warnings. Similarly, in the case of cold wave it is recommended to consider the wind & humidity for issuing impact of the cold wave.

There is also is need of issuing special impact of heat/cold wave on agriculture, animal husbandry, wildlife and energy sector with development and implementation of heat/cold action plans at district & city/town levels.

Global Warming and related impact on agriculture, health and diseases etc

The assessment of the impacts of global warming and climate change related disruptions on agriculture, health and diseases over India highlights the role of technological preparedness and solutions. There is unequivocal evidence that the warming is occurring not only through natural variations but also due to human activities.

A robust weather forecast led agricultural management through enhancement of observational datasets and improvement in climate models is very important to minimize the climatic risk related losses to farmers which have been ever increasing. The impacts of land-use and land-cover change, irrigation practices, urbanization on the regional climate, water resources and crop production also need to be addressed.

The dissemination of knowledge about vulnerability, preventive measures and 'when to take action' is needed at ground level as a part of heat action plans are still required for several vulnerable cities.

District level action plans in terms of when and what is to be done should be implemented to avert the adverse impacts Vector Borne Diseases (VBDs). Collaborative research between research institutes for piloting of implementation of tools of early warning of outbreaks of malaria and dengue should be encouraged. System of drought, flood and other climatic stress monitors are required. Establishment for observation, identification of hotspots and forecast systems is needed to minimize the adverse effect of hailstorm. A join project on online platform DSS may be developed by linking the seamless inflow of weather forecast into the model for providing the automated advisory to farmers and for use by different stakeholders.

Advancement is very much required in various aspects of agriculture activities viz., water availability and its use efficiency, energy use efficiency, nutrient use efficiency; seed use efficiency, soil health, post harvesting & post processing Technology.

Some concerns related to security issues of Ex m-krishi fisheries (developed jointly by CMFRI, IARI and TCS and INCOIS) need to be addressed. It is recommended to Integrate simulation models, weather forecast, remote sensing and expert systems for improved management of agriculture.

Further, a panel of technical experts may be constituted for pre and post evaluation, periodical validation and monitoring of the BS/BC (Biosafety / Biocontainment) facilities throughout country.

It is important to bring the intuitions with expertise and capabilities to bring together to develop such systems/platforms for the benefit of farmers, agriculture and Nation. An institution for hosting health data needs to be established. Inter institutional collaboration with advanced research and training should be developed to attract global talent to find solution of impact of global warming on agriculture, health and diseases etc and creating trained manpower. In order to identify animal pathogens and other vector borne diseases of zoonotic importance at ICAR-NIHSAD existing facility needs modernization of the structural / Bio engineering components. Considering emergence of certain exotic animal diseases like CCHF and Nipah, there is urgent need of establishing a new Bioengineering infrastructure in form of a BSL2+BSL4 integrated laboratory with most modern facilities. Considering the geographical area and risky sample transportation from all the part of the country to Bhopal, it is essential to have two additional BSL4 labs exclusively for animal diseases. One of these can be established in South and second one in NEH region. Including all the estimated cost for these labs may come to Rs 250 to 300 crores each.

Global Warming and impact on coastal region submersing Drought on regional or national level

Oceans play a central role in regulating the Earth’s climate by the uptake and redistribution of anthropogenic heat and carbon dioxide and also regulating the hydrological cycle. Indian Ocean Sea level rise exhibit high spatial and temporal variability and is dominated by the ocean thermal expansion.

Methodologies for development of high-resolution climate change scenarios of sea level rise and the associated impacts on coastal regions and islands needs to be improved. There is a need to have a detailed shoreline monitoring and in particular the changes in Island morphology in context to climate change.

There is a need to downscale the output from Global Circulation Models to finer-resolution on regional scale for the Indian Ocean region and Sea-level rise estimation along the coast should be carried out based on downscale models validated with tide gauge data. Continuous monitoring of sea level along the coastline is needed to understand the long-term changes in regional and extreme sea level along Indian Ocean coastline. Coastal topography and near shore bathymetry should be mapped for analysing impact of sea-level rise on coast. Modern technologies like UAV etc., should be adopted for mapping.

By adopting soft engineering or hybrid solutions, the negative effects of hard solutions can be avoided. Green solutions can also be adopted for better sustainable management based on site conditions.

A plant may be established through Industry – Institute participation for Ocean Thermal Energy Conversion (OTEC) on a large scale.

Drought on regional or national level

Drought is a stochastic and creeping natural disaster caused by significant and persistent deviation of precipitation relative to the statistical multi-year average for a region. Though precipitation is the dominant factor in triggering drought, but its occurrence is also associated with other factors such as timing of precipitation, distribution within the season, high temperature, and high wind speed. In general, arid and semi-arid areas are more drought-prone than humid areas.

In India, nearly 68% of net sown area is vulnerable to drought. More than 100 districts, which receive less than 750 mm rainfall are officially "chronic drought-affected", while 35% of the area, falling in 750-1, 125 mm rainfall zone is classified as 'drought-prone.

The use of science and technology has made considerable improvement in the processes of planning, implementing preventing and mitigation of droughts. But there is scope for intensifying use of the existing technologies, further refinement and innovations in technologies; and the supporting institutions and policies.

The report includes all the aspects of drought and their management viz., extent and frequency of droughts and impacts in India, Evolution of drought management framework, growing role of science and technology in drought management, objectives of current exercise, future projections of droughts and their impacts, future drought scenarios and its impact, data and analysis gaps, how the drought has been addressed in the recent past, National Agricultural Drought Assessment and Monitoring System (NADAMS), National Drought Manual, Drought monitoring systems by States – some successful examples with analysis of gap areas.

Section 1 Cyclone

1.1 Introduction

Tropical cyclones (TCs) are intense low-pressure systems that form over warm tropical Oceans, in which the winds (speed ≥62 kmph) rotate in an anti-clockwise direction in the northern hemisphere. It is a large-scale weather system with a horizontal size (diameter) of 100 to 1000 km and vertical extension of 10-15 km. They are one of the most destructive meteorological phenomena around the world, with their associated hazards and impacts extending over a wide area. The hazards associated with a tropical cyclone include strong winds, heavy rain, storm surge, high to phenomenal waves, flooding (coastal inundation, pluvial and fluvial), landslides and occasionally tornadoes. These often occur simultaneously in space and time, either in the same location or over the same broad area, leading to complexities in emergency preparedness, response and recovery programmes. These are the best example of multi-hazard phenomena.

The destructive winds, storm surges and very heavy rainfall accompanying the cyclonic storms, each one of them has its own impact on human and livestock and their activities. Of these, storm surge is responsible for 90% of the loss of lives associated with cyclone disaster. Since 1737, 21 of the 23 major cyclone disasters (in terms of loss of lives) in the world have occurred over the Indian subcontinent (India and Bangladesh). Though only 7% of the world's total number of cyclones develop over the north Indian Ocean (NIO) basin, the unique bathymetry of the Bay of Bengal (BoB) produces much larger storm surge and take a very heavy toll of life as compared to other basins.

Table1: Major damaging Cyclones over the NIO (1970-2021)

Sl. No	System	Year	Country affected	Death toll
1	Bhola Cyclone	1970	Bangladesh	3,00,000
2	Cyclone	1991	Bangladesh	1,38,866
3	Cyclone Nargis	2008	Myanmar	1,38,366
4	Cyclone	1985	Bangladesh	15,000
5	Cyclone	1977	India	14,204
6	Odisha Super cyclone	1999	India	9,843
7	Cyclone	1971	India	9,658

The soon to be released WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes 1970-2019 states that in the past 50 years, three of the top 10 disasters worldwide in terms of deaths were attributed to TCs. The deaths recorded in these three events accounts for 43% of the combined deaths of the top ten disasters. In addition, the Atlas records that seven of the top ten disasters in terms of economic losses were attributed to TCs, which account for 82% of the total economic losses of the combined top ten disasters. A list of some of the past cyclones (since 1970) over the NIO which caused major damage to life & property is given in Table 1.

Accurate forecasting of both track and intensity of a TC is critical to mitigation of disasters caused by an approaching TC. During recent years there has been significant improvement in genesis, track, landfall, intensity and associated adverse weather prediction. It is mainly attributed to improvements in observations, especially the satellite and Buoy data; improvements in dynamical & statistical models and improvements in understanding of physical processes. But still the damage associated with TCs is on the rise, due to a continuously growing coastal population and urbanisation. Hence, technological intervention is required to improve the resilience of coastal areas to combat the disastrous impacts of TCs. Comprehensive and viable policies on coastal protection based on the latest data set from improved coastal mapping to enhanced weather and impact forecasting need to be developed. Making use of such Geo-Spatial information, INAE with the support of Government, coastal managers, property owners and the general public should work towards developing a long-term plan for ensuring the sustainable development goals (SDGs).

Natural disasters and shoreline erosion are two of the main threats that coastal communities face. Coastal population is particularly vulnerable to Cyclone, associated Storm surge, Sea level Rise and Tsunamis. Shoreline erosion, a worldwide phenomenon that is often exacerbated by cyclonic storms, is also increasing due to a number of factors, including Sea level rise and loss of wetland buffer areas.

New scientific & technological innovations are required to help the government agencies and local communities deal with coastal hazards more effectively and develop long-term hazard management plans.

1.2 Climatology of cyclones affecting India

Climatologically, there are two peak cyclone seasons over NIO region namely April-May-June and October-November-December. On the average about 5 Cyclones form over the NIO. More cyclones develop in the BoB than in the Arabian Sea with a ratio 4:1. Out of 5 TCs developing over the NIO, about 3 to 4 TCs make landfall (Tyagi et al, 2010) causing loss of life and property. Though the number of such TCs is less as compared to other Ocean basins like north Pacific and north Atlantic Ocean, the impact is felt more in the region due to poor socio-economic conditions. The tropical warm NIO, like the tropical north Atlantic, the south Pacific and the northwest Pacific, is a breeding ground for the disastrous TC phenomenon. Low lying coastal belts of West Bengal, Odisha and Andhra Pradesh have borne the brunt of the fury of these very severe TCs (IMD, 2003, 2008 & 2021; Mohapatra et al, 2012a; Mohapatra et al, 2013, Mohapatra, 2015). Though the number of deaths due to TCs have decreased significantly (Mohapatra and Sharma, 2019), still there is huge loss to property.

A study by Mohapatra etal, 2021 on the recent trends of frequency of genesis and landfall of cyclones over various coastal states in the region indicate that there is a decreasing trend in landfalling cyclonic storms (CS), severe cyclonic storms (SCS), very severe cyclonic storms (VSCS) and there is no significant trend in the frequency of extremely severe cyclonic storms (ESCS) and above intensity storms over the BoB. Thus, the coastal vulnerability due to ESCS continues over the BoB region. There is an increasing trend in the frequency of landfalling TCs over AS in the categories of VSCS and CS. Considering the SuCS category, its frequency has increased during the recent years since 1990 both over the BoB and AS and hence over the NIO. There is a rising trend in frequency of ESCS and above intensity storms over the AS since 1990 and no significant trend over the BoB.

1.3 Cyclone hazard proneness

A study by Mohapatra etal, 2012 and Mohapatra, 2015 indicate that 96 districts including 72 touching the coast and 24 not touching the coast, but lying within 100 km from the coast are prone to disaster due to TCs. Out of these 96 districts, 12 are very highly prone, 41 are highly prone, 30 are moderately prone, and the remaining 13 are less prone (Fig.1). Twelve very highly prone districts include South and North 24 Praganas, Medinipur, and Kolkata of West Bengal, Balasore, Bhadrak, Kendrapara, and Jagatsinghpur districts of Odisha, Nellore, Krishna, and east Godavari districts of Andhra Pradesh and Yanam of Puducherry. The remaining districts of Odisha and Andhra Pradesh, which touch the coast are highly prone districts. The north Tamil Nadu coastal districts are more prone than the south Tamil Nadu districts (south of about 10^{0}N latitude). Most of the coastal districts of Gujarat and north Konkan are also highly prone districts. The remaining districts in the west coast and south Tamil Nadu are either moderately prone or less prone districts.

Hazard analysis has been carried out by various agencies and vulnerability analysis on project mode is being carried out by the National Disaster Management Authority (NDMA). Communities can also play a major role in performing risk analysis for all key infrastructure systems, assessing the full range of likely hazards and the severity of risk. When assessing risk from Cyclone hazards, it is imperative that the hazard risks are effectively evaluated and understood in order to formulate a comprehensive approach to resilient infrastructure. Risk assessment for resilience should take future conditions into consideration. In addition, all the resources of the community should be leveraged in preparing for, protecting and mitigating against, responding to and recovering from natural hazard's impact to infrastructure and communities.

	Very highly prone
	Highly prone
	Moderately prone
	Less prone

Fig. 1: Cyclone hazard prone districts of India based on frequency of total cyclones, total severe cyclones, actual/estimated maximum wind strength, PMSS associated with the cyclones and PMP for all districts

Here it may be stated that, though we have carried out certain vulnerability analysis generated a set of Risk atlases, we still lack a national repository for all-hazard event (associated with Cyclones) and loss data, thereby reducing our ability to make informed decisions about where and how to prioritize their resilience investments.

The Policy decisions that can aid local communities to increase their resilience include:

- Adopting suitable land-use planning practices; and
- Adopting and enforcing building codes and standards appropriate to existing hazards.
- Building levees and dams in disaster prone areas

- Nonstructural (non-construction-related) measures include development of natural defenses, insurance, zoning ordinances and economic incentives.
- Improvements in various early warning components including augmentation of observational network, enhancement of modeling capabilities, enhancement of research & capacity building

1.4 How these have been addressed in the past

(Hazard mitigation measures and Early Warning System)

Reduction of cyclone disasters depends primarily on several factors including

a) Hazard analysis,

b) Vulnerability analysis,

c) Preparedness & planning,

d) Early warning.

However, due to poor socio-economic conditions in the region, early warning plays an important role in mitigating disaster due to TCs. The components of early warning system are presented in Fig.2. These components primarily include:

i) Skill in monitoring and prediction of cyclone,

ii) Effective warning products generation and dissemination,

iii) Coordination with emergency response units and

iv) The public perception about the credibility of the official predictions and warnings.

Until the 1950s, IMD relied on ship and coastal observations for cyclone monitoring as data over the oceanic region where cyclones form was rather sparse. With the advent of technological applications in weather forecasting such as weather satellites in 1960s, cyclone detection radars along the coast in 1970s, implementation of computer based numerical weather prediction (NWP) techniques in 1980s, advancements in telecommunication networks for data exchange in 1980s & 90s and their upgradation from time to time, IMD's cyclone forecasting and early warning capabilities have improved leaps and bounds. Yet, location specific peculiarities of the NIO basin and recent advances in scientific and technological fronts, offer tremendous scope for further improvements in observational and analytical aspects as well as in warning dissemination and last mile connectivity.

The Ministry of Earth Sciences (MoES) through the Indian National Center for Ocean Information Services (INCOIS) and National Institute of Ocean Technology (NIOT) established the Ocean Observing Network (OON) in the Indian Ocean and the marine-meteorological and oceanographic data from OON are being transmitted in real-time through Global Telecommunication System (GTS) for operational weather forecasting. The OON comprises Argo Floats, Ship-based Automatic Weather Stations, Drifting Buoys, Wave Rider Buoys, Tide Gauges, Bottom Pressure Recorders maintained by INCOIS; and the Moored Buoy Network in the northern Indian Ocean and 5 pairs of HF Radar Network along the coast maintained by

NIOT. The data from OON are vital for monitoring the cyclones at different stages e.g., from cyclogenesis to landfall and its impacts along the coast.

Currently, IMD has got a high end decision support system to analyse and a vast observational network including Automated Weather Stations, Automated Rain Gauges, High Wind Speed Recorders, GPS based upper air observation system, buoys & ships, satellites based observations from INSAT, METSAT, EumetSat, Ocean Sat, Doppler Weather Radars and an array of short and medium range global & regional numerical weather prediction (NWP) models (including Global Forecast System (GFS), Hurricane Weather Research & Forecast (HWRF), Statistical Dynamical Model for cyclone genesis & intensity prediction, Multi Model Ensemble, Ensemble Prediction System (EPS), other global & regional models (including European Centre for Medium Range Weather Forecasting (ECMWF), United Kingdom Meteorological Office (UKMO), Japan Meteorological Agency (JMA), National Centre for Environment Prediction (NCEP)) under bilateral arrangement. The Tropical Cyclone Module installed in this forecasting system is utlised to analyse all synoptic, satellite and NWP model products for genesis, intensity & track monitoring and prediction, prepare past & forecast tracks upto 120 hrs, depict uncertainty in track forecast and structure forecast around the centre along four geographical quadrants. This system has resulted in reducing time of analysis, improving timeliness of the warning and visibility of warning products leading to reduction in loss of lives as the outcome.

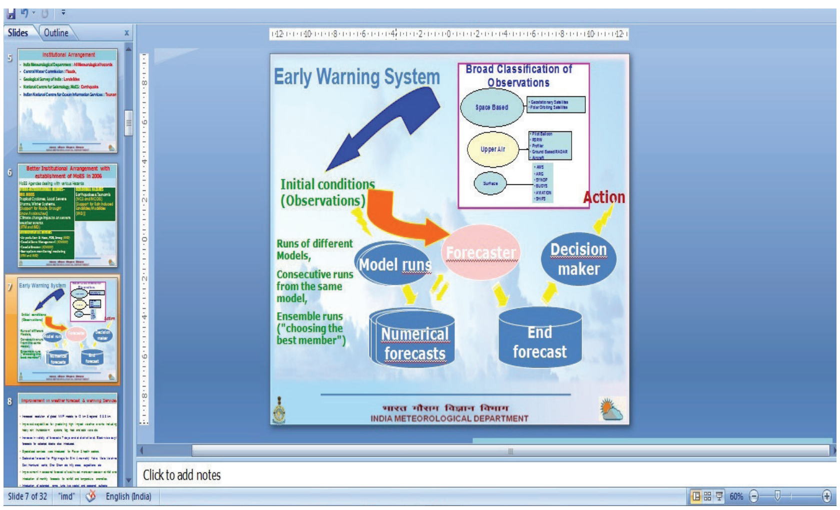


Fig.2: Components of Early Warning System

1.4.1 Current status of observational network:

TCs are monitored by satellite-based observations when, it is over sea. As it comes closer to coast, the observations from radar followed by coastal observations play a significant role in monitoring of TCs. The current status of observational network is discussed below:

(i) Satellite based observations

With advancement of technology, satellite remote sensing is considered as one of the efficient tools to monitor and manage the oceanographic disaster. The various parameters retrieved from satellite data can act as an environmental indicator for disaster management related to cyclone. The details of some of the parameters are as follows

a) Sea Surface Temperature: Sea surface temperature (SST) is a key climate and weather measurement obtained by satellite infrared (IR) and microwave radiometers. These measurements can be combined to create daily spatially-complete global SST maps used for weather prediction and ocean forecasts during cyclones. While IR SSTs have a higher resolution than microwave SSTs (1 – 4 km as compared to 25 km), their retrieval is prevented by clouds giving microwave SSTs improved coverage since they can be measured through clouds. This has proven especially important in tropical cyclone forecasting as the clouds surrounding a cyclone prevented adequate SST measurements until microwave instruments became available.

b) Sea Surface Height: The Sea Surface Height Anomaly (SSHA) products derived from satellite altimetry are used for understanding the basin scale dynamic variability of the sea level. Altimeter data are also utilized to derive ocean heat content, geostrophic currents and variability of eddies. SSHA is used for studies related to upwelling and intensification of cyclones based on the movement of cyclone over a cold or warm core eddies. However, the altimetry methods are unable to monitor the sea level changes in the coastal zone.

c) Winds: Wind products (wind speed, direction, cloud motion vectors) derived from satellite scatterometer and imagery products (microwave (MW), infrared (IR), visible (VIS)) are used extensively for the study of both local and remotely-forced Ocean phenomena. The wind products are also used to force wave and circulations models. This is an important application for forecasting risk associated with natural disasters such as cyclones and storm surges.

d) Waves: Sea surface wind-waves can be inferred from the satellite altimetry. However, the altimetry methods suffer from the limitations in the coastal zone. Synthetic Aperture Radars monitor the wave directions and periods. These observations too suffer with the limitations on accuracy of waves near the coast.

e) Tropical Cyclone Heat Potential: Satellite derived Sea Surface Temperature and Sea Surface Height are used to estimated the Tropical Cyclone Heat Potential (TCHP). The TCHP data provide qualitative and quantitative information about the areas where Tropical Cyclones may intensify by identifying the location and thermal characteristics of the oceanic upper layer, warm eddies and frontal regions etc.

f) Rainfall: Rainfall derived from satellite imagery (MW, IR and VIS) products (e.g., TRMM (Tropical Rainfall Measurement Mission), GSMAP (Global Satellite Mapping of Precipitation) etc are used to estimate rainfall over Oceans. These products are very useful to understand precipitation during cyclone and storm surges.

g) Ocean Longwave Radiation: The Ocean Longwave Radiation (OLR) products derived from the satellite data (e.g., NOAA NCEP/CDC OLR) are used to study convective systems over oceans and are very crucial in understanding coupled atmosphere-ocean phenomena during the different phase of cyclones.

h) Salinity: Salt plays an important role in how the Earth system functions. Salinity have profound effects on how the ocean circulates, how freshwater cycles around Earth and how our climate evolves. The concentration of salt on the Ocean surface — the part of the Ocean that actively exchanges water and heat with Earth's atmosphere — is a critical driver of Ocean processes and climate variability. Salinity from space is recent activity with data from Soil Moisture Ocean Salinity (SMOS) and Aquarius satellites starting from 2009 onwards.

i) Bathymetry: High-resolution bathymetry data products (e.g., GEBCO, ETOPO) over entire Ocean basins are available because of the availability of satellite gravity products. It is one of the key components of the Ocean model setup. Satellite-derived land topography data [SRTM (Shuttle Radar Topography Mission] from synthetic aperture radar on-board US space shuttle program) are used for coastal inundation studies.

j) The Status of the current operational satellites that can be utilized for cyclone and storm surge management from various global agencies are given in the table below:

Table 2: Status of existing Satellites utilized in monitoring

Country	Agency	Revisit time	Parameter
India	ISRO	2 Days	WIND
India	ISRO	35 Days	SSH
USA	NOAA	Daily	SST
USA	NASA	~10 days	SSH, SWH, WIND
EU	ESA-EUMETSAT	~4days ~2days (A&B Combined)	SST
EU	ESA-EUMETSAT	~4days ~2days (A&B Combined)	SSH, SWH, WIND
EU	ESA-EUMETSAT	1.5 Days	WIND
Japan	JAXA	~2-3 days	CHL, TSM, Kd, CDOM, PAR, SST, WIND
China	CAST	-	Wind speed, SST, SSH, SWH
China	CAST	-	Wind speed, SST, SSH, SWH

Gap areas

The space-based observations have largely improved our understanding and precise monitoring of tropical cyclones and its impacts. These observations improved the tropical cyclone forecasts by reducing errors and biases in analyses used to initialize the Ocean component of coupled predictions models. However, there have been limitations which need to be addressed as mentioned below.

- Non availability of satellite observations in visible channels during the cloudy conditions
- Limited coverage and resolution of the microwave satellite observations
- Difficulties in deriving High resolution coastal bathymetry and topography

Recommendations

- High resolution ocean remote sensing data products with enhanced spatio-temporal coverage.
- Blending of high-resolution coastal bathymetry and topographic datasets from aerial survey, UAV, etc. for generation of DEMs, 3D GIS Mapping and the situation analysis during cyclone events are required for impact analysis.
- Satellite products should be easily accessible and available on the daily time-scales.

(ii) RADAR observations

IMD has installed total 26 Doppler Weather Radars (DWRs) all over India. DWR images are also being received from 3 ISRO and 1 IITM DWRs. Out of these, India now has a network of 12 DWRs covering the Indian coast line. It includes 7 radars (Chennai, Kolkata, Machilipatnam, Visakhapatnam, Paradip, SHAR, Karaikal) on the East Coast and 5 radars (Kochi, Goa, Mumbai, Bhuj, and VSSC) on West Coast. IMD also utilize the data input from Doppler weather radars of ISRO located at VSSC, Thiruvananthapuram), Sohra and Sriharikota.

Gap Areas:

- West coast of India does not have sufficient No. of radars. Installation of C-Band DWR at Ahmedabad can improve the situation.
- Further in eastern belt, gap areas are proposed to be covered with C-band DWRs installation at Ranchi, Raipur, Sambalpur, Malda and Balasore.
- Islands of Andaman and Lakshadweep are also proposed to be covered with C-band DWRs at Port Blair and Kavarathi locations.
- In Southern India, gap areas will be covered with C-band DWR installations at Mangaluru, Bangaluru and Ratnagiri. IAF operated radar at SULUR provides additional coverage over central Tamil Nadu.

Recommendations:

- Development of multi-institutional mechanism for exchange of radar data among various institutions including IMD, IAF, IISc Bangalore etc.
- Un-interrupted supply of the information gathered from these radars to the forecasters on near real time basis for issuing timely and dependably accurate forecasts.
- Establishment of National Weather Radar Operating Centre at IMD Headquarters, New Delhi to build-up capacity in operational maintenance of all Radars in IMD, up gradation, procurement of radars, develop alternate technologies, software product design and development, to support the data assimilation for numerical modelling.
- Establishment of Network Control Centre at IMD, New Delhi for optimum utilization of data, operational management and control of the Doppler Weather Radar network countrywide.

(iii) Additional Observations from wind profiles.

During the cyclones there is requirement for higher temporal resolution in the upper air data sets. Additional radiosonde ascents are taken but it is seen that due to high wind speeds it becomes very difficult. To provide an alternate method wind profiler can be utilized which are able to generate observations at intervals of 10 minutes and can be beneficial along the coast line. IMD has also developed in-house, the wind sonde, which is capable of acquiring wind data using GPS and weather balloon. It can be flown using a smaller balloon and is also portable. It can be installed and made operational at a short notice and provides high resolution wind profile data at every second at 5 m resolution in height.

Recommendations:

- To have a coastal network of wind profilers at each of the radiosonde stations for providing the vital wind data.
- The wind profilers provide only wind related information. However, to complement it and to provide the complete data set, the deployment of radiometer can augment the network since it also provides data at a higher temporal resolution. Though the data is available only up to a height of 10 km, it still can be useful to indicate the changing trend in the weather and along with a wind profiler it can become a complete system for generating atmospheric data using ground based remote sensing techniques.

Recommendations:

- To deploy microwave radiometer at all stations having radio sounding facilities such as Kolkata, Bhubaneswar, Visakhapatnam, Machilipatnam, Kavali, Chennai, Karaikal, Thiruvananthapuram, Kochi, Mangalore, Goa, Ratnagiri, Mumbai, Ahmedabad, Bhuj.
- To also include radio occultation techniques used in atmospheric profiling from satellites. The data from radio occultation profiling is more reliable at 10 km and higher altitudes. Also, the added benefit is that they provide data set over the Ocean.

(iv) Current Status of Upper Air Network of IMD:-

Radio sounding / Radio wind (RS/RW) Network: - IMD, has a network of 56 upper air stations taking radio sounding / radio wind (RS/RW) observations twice daily. Out of 56 stations, there are 18 Nos of stations situated along the Sea coast.

Pilot Balloon (PB) Network: - IMD has a network of 62 pilot balloon observatories. At these stations a smaller balloon is tracked for upper air wind data i.e Wind direction and wind speed profiles. Presently these stations are taking manual observations by tracking the balloon using optical theodolites.

Recommendations:

- Sustenance of 6 Nos of high-quality GPS based system- WMO-GUAN standard network.
- Expansion of GUAN standard network from 6 to 12 stations by up-gradation of 6 operational RS/RW stations to GUAN standard.
- Continuation of all 56 RS/RW stations with twice a day observation.
- Further expansion of operational RS/RW stations from 56 to 63 -procurement of GPS radiosondes from Indian sources to promote ‘make in India’ initiative.
- Up-gradation of PB network from manual (optical theodolite based) observations to fully automatic GPS based observations.
- To create an additional buffer stock of consumables for upper air observations dedicated to the cyclone monitoring.

(v) Status of surface observational network

The surface observational network owned and operated by IMD comprises of networks as shown in table below.

a) Manned Surface observatories:

There are 531 manned surface observatories installed across India by IMD. Of these, 226 observatories are manned by IMD staff. 141 out of 226 observatories are called Class – 1 observatories where all 8 synoptic observations are taken and all autographic instruments are available and remaining 65 observatories are called Class – 2 observatories where autographic instruments are not available. There are 325 surface observatories which are manned by non-departmental staff. Such observatories are called Part Time Observatories where 2 synoptic observations are taken daily.

b) Automatic Weather Stations and Automatic Rain Gauge stations

There are 789 automatic weather stations (AWS) installed across India and neighboring countries viz Nepal, Bhutan and Bangladesh. The sensors for parameters, Air Temperature, Relative Humidity, Rainfall, Pressure, Wind and Solar Radiation are interfaced with these stations. In addition to these sensors, 129 AWS are equipped with sensors for Soil Temperature, Soil Moisture at different depths, Leaf Temperature and Leaf wetness. For monitoring of rainfall, IMD has established a network of over 1350 automatic rain gauges (ARG) stations.

c) High Wind Speed Recording Systems:

As on date 27 HWSR systems have been installed along the east and west coast of India.

Gap Areas:

i. Data sparse region especially meteorologically unrepresented districts require densification of AWS and ARG stations. Strengthening of surface observational network along the coast to monitor severe weather phenomena such as cyclones, thunderstorms, extremely heavy rainfall etc.

ii. Part Time Observatories (PTO) provide limited no. of observations. These observatories need to be converted into Full Time Observatories (FTO) by replacing manned observatories with AWS.

iii. Additional HWSR systems are required to be installed along the coast for monitoring of gale force wind during severe cyclonic storms and gusty winds at inland stations during occurrence of severe thunderstorms. Presently west coast of India has only 5 HWSR systems.

iv. Establishment of dense observational network in other mega cities in India as over Mumbai.

v. Augmentation of weather monitoring systems over Highways affected by Severe Weather such as extremely heavy rainfall, fog, landslides etc. Similar systems are also required to be established along the railway routes.

vi. Non-availability of Agro-AWS at each district of India and AWS in each block of India.

vii. 24 X 7 monitoring of AWS and ARG networks through IT tools and strengthening of timely preventive and corrective maintenance of AWS and ARG stations.

viii. Major airports in the country get affected by severe weather in different seasons leading to enormous economical loss. For example, deterioration of visibility at norther airports during winter period leading

Recommendations:

- To have at least one Agro-AWS in each district of India.
- Installation of at least one HWSR station in each coastal district of India.
- Installation of at least two AWS in each coastal district of India.
- Part Time Observatories to be replaced with AWS.
- Human Resource development and competency enhancement by organizing training programmes as per annual training calendar.
- Upgradation of calibration facilities of IMD, Pune along with accreditation of NABL.
- Encouraging engineering college students to contribute in indigenous development of instruments using AI/ML technology.
- In addition, IMD will enter in to Rate Contracts with competent firms/suppliers through tendering process for procurement of spares of AWS, HWSR and Surface Observatories etc. so as to ensure minimal downtime of systems.

1.4.2. Cyclone forecasting & warning process and operational forecasting skill

(a) Cyclone forecasting process:

IMD has one of the best forecasting systems for predicting tropical cyclones using high resolution advanced mathematical models (including global, regional and cyclone specific models) crossing both west and east coast of India and associated adverse weather over India. Ministry of Earth Sciences has also introduced ensemble prediction systems global ensemble forecasting system (GEFS) and

NCMRWF ensemble prediction system (NEPS) for forecasting of cyclones. IMD utilizes an array of various models including global, regional and cyclone specific models for forecasting genesis, track, intensity, landfall and associated adverse weather like heavy rainfall, gale wind and storm surge. To improve the numerical modelling capability for forecasting cyclones, in addition to in-house efforts, collaborative efforts with various Academic and R&D Institutes to improve early warning services have also been undertaken.

INCOIS provides short term forecasts of several oceanographic parameters such as waves, currents, Sea Surface Temperature (SST), Mixed Layer Depth (MLD), tropical cyclone heat potential, depth of 26°C isotherm etc. based on a state-of-the art operational ocean forecast system, the High-resolution Operational Ocean Forecast and reanalysis System, which has very high-resolution Ocean models equipped with data assimilation systems. INCOIS has also configured a storm surge prediction model, which provides detailed forecasts of the extent of inundation due to storm surge. INCOIS is also providing the high wave alerts during the cyclonic events and the information is being provided in the IMD-INCOIS Joint Bulletins. The HYCOM model configuration of INCOIS also provide initial and boundary conditions for the IMD's operational HYCOM-HWRF cyclone forecast system.

(b) Cyclone Warning process

Currently, IMD maintains round the clock watch over the north Indian Ocean and provides extended range outlook every Thursday with probabilistic forecast of cyclogenesis for next 2 weeks. It also provides 5 days probabilistic cyclogenesis forecast on daily basis. On formation of cyclonic disturbance (wind speed 31.5 kmph and above), structured bulletins are issued (6 hourly/ 3 hourly/ hourly) as per Standard Operating Procedure containing information about the current status of system (including location, movement, intensity) and forecast track, intensity, landfall point & time, associated adverse weather (heavy rainfall, gale wind, storm surge), state of Sea, fishermen warning, damage expected and action suggested.

A four-stage cyclone warning system was introduced in IMD from the pre-monsoon season of 1999, for effective management of land falling cyclones:

i) Pre-Cyclone Watch is issued at least about 72 hours prior to commencement of adverse weather over the coastal areas.

ii) Cyclone Alert is issued at least about 48 hours prior to the expected time of commencement of adverse weather over the specific coastal areas.

iii) Cyclone Warning is issued at least about 24 hours in advance of the commencement of adverse weather in order to cover the devastating impact of cyclones over inland areas.

iv) Post Landfall Outlook is issued at least about 12 hours before the expected time of landfall and continues till such time as cyclone force gusty winds are expected to prevail over the interior areas.

(c) Operational Forecasting Skill

There has been significant improvement in operational forecast accuracy of track, intensity and landfall of tropical cyclones.

- The track forecast error during 2017-21 have been 73, 106, 144 km against 97, 149, 203 km during 2012-16 for 24, 48 and 72 hrs lead period respectively (Decrease in error by 25, 30 & 30% for 24, 48 & 72 hrs lead period respectively).
- The intensity forecast error during 2017-21 has been 6.9, 10.2, 13.3 knots against 10.7, 15.5, 16.3 knots during 2012-16 for 24, 48 and 72 hrs lead period respectively (Decrease in error by 36, 35 & 18% for 24, 48 & 72 hrs lead period respectively).
- The landfall forecast error during 2017-21 has been 31, 51, 85 km against 36, 92, 122 km during 2012-16 for 24, 48 and 72 hrs lead period respectively (Decrease in error by 15, 45 & 30% for 24, 48 & 72 hrs lead period respectively).

Recommendations for improvement in models and research on TC physical processes:

(i) The model improvements will need to include clever ways of producing the maximum improvement while minimizing the infrastructure costs.

- Investigate the potential causes of large forecast errors: observations, data assimilation, vortex specification, model resolution, representation of physical processes; inter-comparison exercises should be conducted and synoptic patterns likely to be associated to forecast errors should be documented.
- Improve the vortex specification techniques for initial conditions (develop an enhanced Dvorak-like technique that will incorporate storm structure asymmetries and changes)
- Assimilation of targeted observations in NWP models has demonstrated value in significantly reducing track forecast errors, even at short term.
- High-resolution models can improve track and structure prediction, and resolve intensity changes, wind and rainfall asymmetries and evolution, interaction with the land roughness and topography. It is necessary to develop new methods for initial conditions, model physics and assimilation of related mesoscale data.
- Coupled Ocean-atmosphere models (with high resolution SST and OHC, dedicated initialization schemes, adequate parameterization of air-sea fluxes, vertical mixing schemes).
- Statistical-dynamical models, ensemble (single- and multiple-model) approach and ensemble data assimilation, representation of uncertainty should be improved. Minimum number and optimal

combination of forecast members should be identified and strategies should be defined to deal with "bifurcation scenarios

- Develop objective methods for model verification using "tropical-cyclone related metrics" and document the performance of the forecast models in a common standard format;

(ii) Enhancement of research activities on TC Physical processes

- Determine large-scale steering mechanisms that control TC genesis and track in relation with large scale processes like ENSO, MJO and QBO etc.
- Analyze different modes of genesis (tropospheric circulation in the low and upper levels, convective activity, upper Ocean structure and air-sea fluxes, interaction with the mid-latitudes).
- The role of stochastic processes should be investigated and the spatial resolution of Ocean data that is required to detect effects on cyclogenesis must be determined.
- Determine how different types, spatial and temporal scales of tropical waves and associated synoptic patterns interact with TC activity and evolution and how TCs influence their atmospheric and oceanic environment.
- Determine the influence of upper-level environment ("good" vs. "bad" tropical upper tropospheric troughs (TUTT), mid-latitude Rossby wave breaking, cut-off lows) on TC evolution and track.
- Improve the understanding of internal processes (vortex dynamics and Potential Vorticity redistribution, microphysics, boundary layer, air-sea fluxes, ocean heat content) which contribute to structure and intensity changes. There is a need for further studies in asymmetry in storm structure related to landfall and fine-scale and transient features (e.g., vortex Rossby waves, wind shear effect, boundary layer rolls and vortices);
- Quantitative precipitation forecast (QPF) at high spatial and temporal resolution should be a priority, particularly at landfall; this would assist in forecasting floods, debris flows, landslips and mudslides.
- Improve the understanding of the effects of variability of land roughness and topography on surface wind speed.
- The forecast of storm tide and storm-induced waves and swell, and the associated risks for coastal regions, must be improved as stated in the earlier section.
- Storm scale and synoptic scale processes associated with "extra-tropical transition", "tropical transition", hybrid and sub-tropical storms should also be considered.

1.4.3. Cyclone Warning Dissemination System

IMD has taken various initiatives in recent years for improvement in the dissemination of weather forecast and warning services based on latest tools and technologies.

- Cyclone warnings are disseminated to various users through telephone, fax, email sms, Global Telecom System (GTS), WMO Information System (WIS), All India Radio, FM & community radio, Television and other print & electronic media, press conference & press release. These warnings/advisories are also put on the website www.rsmcnewdelhi.imd.gov.in and of IMD.

- Another means to transmit warning is IVRS (Interactive Voice Response system). It is functioning with effect from July 2000. The requests for weather information and forecasts from the general public are automatically answered by this system. One can access current weather and forecast for major Indian cities by dialing Toll-free number 1800 180 1717. Presently, a centralized IVRS is catering the weather information of major cities.

- Since 2009, IMD has started SMS based weather and alert dissemination system through AMSS (Transmet) at RTH New Delhi.

- To further enhance this initiative, IMD has taken the leverage of Digital India Programme to utilize "Mobile Seva" of Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Govt. of India for SMS based Warnings /Weather information dissemination for a wide range of users. The SMS based cyclone alert to the registered users including public was inaugurated on 25th December 2014.

- General Public can register in RSMC website free of cost for getting SMS on cyclone warnings. The SMS-based alert/warnings are issued to registered farmers through Kisan Portal of Govt. of India (Ministry of Agriculture) and to registered fishermen through Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also.

- Global Maritime Distress and Safety System (GMDSS) message is also put in RSMC, New Delhi website (URL: www.rsmcnewdelhi.imd.gov.in) as well as transmitted through GTS. The WIS Portal –GISC New Delhi is another system for cyclone warning dissemination. The user can access the warning messages through the URL: http://www.wis.imd.gov.in. IMD has also started issuing of NAVTEX bulletins for the coastal region along east as well as the west coast of India for the operation of lightships and fishermen from 30th March 2015.

1.5 Possible impact of the disaster in the future:

Increasing coastal population and urbanization are further increasing our vulnerability to landfalling TCs. Also, impacts of global warming and climate change scenario, such as sea level rise, increased potential for intensification of cyclones to severe cyclones, documented in the recent decades, compound the destructive impacts and warrant more and more scientific and technological solutions for mitigating the disasters due to TCs.

In a Special Report on the Ocean and Cryosphere in a Changing Climate prepared following an IPCC Panel decision in 2016 during the Sixth Assessment Cycle, it has been stated with a medium confidence that the average intensity of tropical cyclones, the proportion of Category 4 and 5 tropical cyclones and the associated average precipitation rates are projected to increase per 2^{o}C rise in global temperature. The study pointed out with high confidence that the rising mean sea (very high confidence). Thus, coastal hazards will be exacerbated by an increase in the average intensity, magnitude of storm surge and precipitation rates of tropical cyclones. However, there is low confidence in changes in the future frequency of tropical cyclones at the global scale.

Study by Reddy etal, 2021 show that all VSCS and ESCS category TCs are likely to further intensify to the next higher category level with respect to their current classification. Hence damage potential of TCs would increase under climate change scenario. Study by Mohapatra etal, 2021 also indicated that there is increasing trend in the frequency of ESCS, CS & above, SCS & above, VSCS & above and ESCS & above during the year as a whole, VSCS, ESCS, VSCS & above and ESCS & above during post-monsoon season and CS & above and SCS & above during pre-monsoon season over the AS. Knutson et al also established the findings that the recent increasing trend in the frequency of intense cyclones (ESCS) over the AS could be attributed to climate change but with low confidence (Knutson et al, 2020). Knutson etal, 2020 also indicate that the intensity of the TCs over the NIO is projected to increase in a warming climate.

Under the above depicted scenario as well as going by the trend, the probability of higher intensity Cyclones making landfall along the Indian coasts is more likely in future. A projected slowing down of the translational motion of the TCs would add to its damage potential via impacting the coastal areas for a longer period of time in terms of heavy rainfall, strong winds and storm surge. The Bay of Bengal cyclones show the decreasing trend in translational; speed in recent years (1990 onwards) according to Chinchole et al (2017)

1.6. Gap areas and challenges in various components of early warning system:

1.6.1 Conduct of special campaigns for improving Cyclone, forecasting: - Aircraft reconnaissance flights:

High resolution data measured from aircraft through dropsondes lead to improved initial conditions of vertical profiles which in turn improve the forecast. An aircraft will fly into the centre of cyclones to gather data to predict where the cyclone will hit. This is one of a series of measures to be undertaken to improve cyclone forecasting. IMD and other key institutes under MoES engaged in weather research need to use aircraft reconnaissance to gather information at the cyclones 'eye'- a calm, cloudless area in the centre, where the pressure is lowest. Data will also be collected from the surrounding 'eyewall', the most destructive part of the cyclone. Balloons fitted with sensors will be released from the aircraft to measure wind speed, pressure and direction, and humidity around the eyewall. These data are fed into forecast models to predict the track, direction and speed of hurricanes. India currently uses data on winds outside the eye region to estimate the conditions inside and run forecast models to indicate a belt of land where the cyclone is likely to hit. Data gathered through aircraft will be of great use to forecast the cyclones more accurately. Since the process to acquire a Reconnaissance aircraft is expensive

& time consuming, aircraft and UAVs may be hired to take observations during the cyclone period in the regions near to India.

Due to absence of aircraft reconnaissance, detailed structural characteristics like wind & temperature distribution along the vertical and horizontal structure of eye and eye wall etc. over the NIO are not yet known. Studies made so far in this respect are mainly based on satellite and radar observations (Raghavan, 2013; Bhatia and Sharma, 2013). In recent years, the microwave imageries from the polar orbiting satellites have helped further to understand the structure of TC as it can provide the imageries in different levels of the TC (Jha et al., 2013). The structure of TC varies with respect to area of genesis, viz., Bay of Bengal and Arabian Sea, season of formation (pre-monsoon and post-monsoon seasons), intensity of TCs (Mohapatra and Sharma, 2015)

1.6.2 Forecasting

According to Mohapatra (2017b) and Heming et al., 2018), there are some difficult situations wherein TC forecasting is still tricky and more challenging (such as recurving and rapidly intensifying/weakening TCs near the landfall point) than in other situations. IMD needs to regularly upgrade its observational and analytical capabilities to meet these challenges and to improve its forecasting skills further in the near future. With proposed ongoing modernisation programme, the error is likely to reduce by about 20% by 2025 from the base year of 2015.

The track forecast errors are higher over the Arabian Sea than over the Bay of Bengal, as Arabian Sea is more data sparse. The error is also higher in case of recurving and looping TCs than in case of straight moving TCs (Mohapatra et al., 2013d).

The track forecast error is more difficult when there is rapid change in track near landfall. Such difficult situations include the (i) recurving TCs, (ii) rapid movement of TCs during landfall, (Slow movement/ stationarity of TC near the coast. It is found that the error is higher by about 5 to 20% for 12 hr to 72 hr lead period of forecasts in case of TCs with rapid track changes as compared to the mean track forecast errors based on the data of 2003-13 (Heming et al, 2018). Comparing the track forecast errors of cyclones with sudden changes in track direction, rapid movement and slow movement, the error is maximum in case of sudden change in direction followed by rapidly moving TCs.

The intensity forecast error is higher for intense TCs than in weaker TCs. Intensity prediction is more difficult over Arabian Sea than over Bay of Bengal as it is more data sparse leading to poor initial conditions in NWP models. There is no DWR in Arabian Sea rim countries. Number of buoys are also very less.

There are cases, when, the TC maintains its intensity with very slow decaying process after landfall. It specially occurs, when the TC moved over a plain surface, especially over deltaic region and during post-monsoon season (October-December). It occurs in post-monsoon season due to availability of moisture over the land surface and atmosphere due to monsoon circulation which prevailed during June-September and may extend to October during its withdrawal phase. A statistics-based decay model for intensity prediction after landfall using the intensity at the time of landfall has been developed by IMD (Bhowmik et al., 2005). The error statistics shows that the model has still limitations. For the cyclone PHAILIN as an example, decay (after landfall) prediction curve (6-hourly up to 30 hr) showed fast decay compared to observed decay. As the model is statistical in nature, it does not take into consideration various dynamical and hydro-dynamical processes governing the decay of a TC after landfall. Hence prediction of decay of intensity of TC after landfall is still a challenge.

Another interesting part is the dissipation/rapid weakening of systems over NIO. It poses a great challenge to a forecaster as it very often leads to wrong/over-warning. The dissipation/rapid weakening over the sea may happen due to various reasons including colder Ocean thermal energy, entrainment of dry and cold continental air into the core of TC and increase in vertical wind shear in the horizontal wind. An example of very severe cyclonic storm, Lehar (23-28 November, 2013) over Bay of Bengal (Sharma and Mohapatra, 2017), which rapidly weakened before the landfall. It rapidly weakened over the sea from the stage of very severe cyclonic storm (75 knots) to depression (25 knots) in 18 hrs. It had landfall near Machillipatnam (Andhra Pradesh) as a depression. It did not cause any significantly heavy rainfall over Andhra Pradesh. The intensity forecast errors were very high. The error in intensity prediction led to large error in prediction of rainfall, wind and storm surge. However, the situation was managed by providing frequent update and immediate revision of forecasts with the sign of weakening envisioned through synoptic analyses. There is a need for development of dynamical statistical model for rapid weakening of TCs over the sea.

Over the past several years, there have been large improvements in track forecast skill (Mohapatra et al., 2013d) and modest improvements in the intensity skill (Mohapatra et al., 2013e) like other Ocean basins. These errors, particularly the intensity errors negatively affect wind radii forecasts. The poor intensity forecast is particularly pronounced when intensity forecast fail to or falsely forecast winds that exceed the 34 kts, 50 kts and 64 kts thresholds.

There is shifting of convection and wind maxima during landfall sometimes leading to error in predicting heavy rainfall and wind over the land regions. To overcome this problem, R&D activities are needed to develop R-CLIPER for prediction of rainfall, QPE estimates based on Radar and INSAT 3D and land-Ocean-atmosphere coupled models etc.

Some of the gaps in prediction of adverse weather in association with cyclone include probabilistic wind forecast, location of specific heavy rainfall forecast, augmentation of coastal inundation model to include all components of total water envelope (Flood depth due to astronomical tide, wave, storm surge, rainfall, river run off), hydrological models and satellite/ radar-based merged data set for TC rainfall etc.

1.6.3 Warning Dissemination

One of the major gaps lie in communication of fishermen warnings to the fishermen at deep Sea. The proposed GAGAN and NavIC system of communication may be helpful in this regard.

There is an urgent requirement of developing a Two-way communication system such as 'Voice mail' in vernacular language which might be able to cover distances beyond 50 kms from the coastline for reaching out to the Fishermen and also to obtain response from them.

1.6.4 Research & development: Proposal for a National Cyclone Warning Research centre

Though the Cyclone early warning services has improved quite significantly in our country, there are still lot of issues to be addressed. Hence an urgent need for the Establishment of a National Cyclone Warning Research Centre is proposed to address the below enlisted gap areas in early warning & Disaster mitigation, viz.,

Location specific peculiarities of the NIO basin, viz., with two cyclones seasons (primary season during October to December and secondary season during April to June) in contrast to a single cyclone season over the other oceanic basins of the world and the smaller areas of the Indian Seas (compared the vastness of the other Oceanic basins) causing lesser lead time for early warnings pose location specific challenges which need to be understood by taking up studies in respect of TCs of NIO.

In the absence of aircraft observations in the TC field over NIO, our present knowledge of TC processes is based on observations in other Oceanic basins. However, it is essential to study the TCs of NIO so as to improve model physics pertaining to dynamics and thermodynamics of TCs of NIO.

High resolution models require dense observations from the TC field, within about 100 km from the centre.

To understand the asymmetry in structure of cyclones, a denser meso-network of observations is essential to collect the vital data essential for determining the landfall intensity and other important parameters required to assess the impact of disastrous weather associated with the landfall.

Further, when a TC nears the coast or when TC forms close to the coast and moves off and parallel to the coast, denser ground-based observations than the present observatory network is required to improve the accuracy in assessing the TC location and intensity as land influences limit the utility of satellite-based observations in such cases.

Mobile Doppler Weather Radars, Mobile Meso-net probe systems, Portable wind towers, house instrumentation systems etc. are implemented for landfalling Atlantic hurricanes in USA. Similar observations are essential for determining the asymmetric wind and precipitation structures and other landfall characteristics of TCs of NIO. Such observational data would also provide more reliable inputs for extreme rainfall warning, location specific gale wind warnings, coastal and inland flood forecasting and other decision support systems for disaster management.

Further vulnerability of the various coastal districts may have to be re-worked out considering the latest status of the following aspects:

Demographic: (a) population density; (b) annual growth rate of population; (c) population at risk due to sea-level rise.

Physical: (a) coast length; (b) insularity (defined as ratio of coastal length to the area of the district); (c) frequency of cyclones (weighted to account for cyclones of different intensities) based on historic data; (d) probable maximum surge height; (e) area at risk of inundation due to sea level rise; (f) number of vulnerable houses—both those at risk of damage and of destruction (based on the latest census).

Economic: (a) agricultural dependency (expressed in terms of population dependent on agriculture and other primary sectors); (b) income and/or infrastructure index.

Social: (a) literacy; (b) spread of institutional set-up

1.7 Recommendations

Considering the above gap areas and challenges, following recommendations are made:

- In order to study and understand the peculiarities of the dynamical processes in the TCs of NIO, aircraft-based drop-sonde observations in the TC inner core region need to be implemented.
- Mobile Doppler radars and mobile wind profilers to be included in the observational set up to collect crucial data pertaining to the eye-wall / inner core region and mobile wind profilers deployed at various strategic locations of the expected landfall area.
- Similar special observations using mobile Doppler Weather Radars, Mobile Meso-net probe systems, portable wind towers, house instrumentation systems etc. need to be implemented for generating crucial observations in the TC field to improve our understanding and modelling of the TCs of NIO.
- Decision support system for determining the likelihood scenario of the impacts due to severe weather associated with landfalling TCs: Automatic decision support system based on the severe weather warnings and vulnerability of the various coastal areas determined using recent geo-physical and socio-economic data has to be developed for effective disaster management.
- Research on TCs of NIO: Realising the need for region specific TC studies, IMD, as per the directives of the Govt. of India, established a research centre dedicated for TC research (Cyclone Warning Research Centre (CWRC) at Chennai in 1972) and this centre is undertaking studies on TC processes over the Indian seas in a modest way. TC studies are also carried out at IMD's sister scientific organizations under MoES and some academic institutions. All these standalone research groups working on observational, analytical and modelling aspects of TCs in the evolving climate change scenario need to be brought under a single umbrella of a National Centre for Tropical Cyclone Research.
- During the recent decades, the CWRC, IMD Chennai has developed the cyclone eAtlas, cyclone rainfall atlas and has conducted studies on TC structural and intensity changes, synoptic scale eddy forcing on TC

development and weakening, heat and moisture budget studies pertaining to rapid intensification cases etc. All observational, modelling and analytical TC research groups in India may be brought under a single umbrella of **National Centre for Tropical Cyclone Research.** IMD could be the nodal agency for a concerted research activity with specific objectives and goals for each group.

- IT based technological solutions for impact based warnings: Based on the severe weather scenario generated by numerical weather models, civic impact scenarios due to storm surge, coastal and inland flooding; damages to infrastructures due to gale force winds etc., rainfall in catchment areas of lakes and other water reservoirs need to be generated automatically by models specially designed for such purposes so that the final impact scenario provides reliable inputs to disaster management authorities to act upon within the short lead time available. Civil administrators, big data analytics and IT professionals need to work hand-in-hand in this project and develop an IT based decision support system and an effective disaster management strategy within the available time frame
- Advanced technological solutions for rescue and relief operations: Gearing up the disaster management forces with advanced technological equipment for search and rescue operations is also very much essential to reduce the loss of life due to TCs.
- Implementation of multi-institutional program: A multi-institutional approach involving all stake-holders such as administrators, scientific and technological communities, media and other outreach channels need to participate in this program for fruitful solutions.

Section 2 Storm Surge

2.1 Introduction

A tropical cyclone (TC) is a multi-hazard event that causes disaster due to heavy rainfall, gale wind and storm surge. Among them, storm surge is the most destructive element which has the history of deaths and destruction, claiming nine out of ten victims. When a TC approaches a coast, it provides an additional force in the form of horizontal pressure gradient which leads to strong surface winds. As a result, sea level continues to rise as TC approaches the coast. This sudden rise in sea level above the astronomical tide due to an approaching TC is called storm surge. The storm surge primarily depends on pressure drop at the centre of the cyclone, radius of maximum wind and the elevation of coast at landfall. The destruction in response to storm surge further amplifies due to the occurrence of high sea waves, phase of astronomical tide, rainfall, river run off, bathymetry, coastal geometry etc. (Dube et al., 2004). The funnel-shape of the Bay of Bengal (BoB) and shallow bathymetry have resulted in large storm surges over the low-lying area at the northern BoB. The severe cyclone of 7th October 1737 crossed near Hooghly River in West Bengal recorded a water level of 13 m which reached 100 km inland up the river Hooghly perishing about 3,00,000 people. Another cyclone on 5th October 1864 that crossed near Contai (West Bengal) produced a storm surge ~ 10 to 13 m. Backerganj Cyclone (Bangladesh) on 31st October/1st November 1876 caused 3-13 m storm surge along the coast. More recently, the Odisha Super Cyclone in 1999 generated a storm surge up to 5-6 m with severe inundation that killed ~ 10000 people and several thousand live stocks.

Designated as WMO's Regional Specialized Meteorological Centre, India Meteorological Department (IMD), New Delhi is the nodal agency for providing storm surge forecast with the details on track, intensity and location of landfall of TCs developing in north Indian Ocean (NIO) region to 13 WMO/ESCAP Panel Member Countries that include Thailand, Myanmar, Bangladesh, India, Sri Lanka, Maldives, Pakistan, Iran, Saudi Arabia, United Arab Emirates, Sultanate of Oman, Qatar and Yemen. The forecast of storm surge includes (i) time of commencement, (ii) duration, (iii) area of occurrence and (iv) magnitude of storm surge. Methods utilized by IMD for the prediction of storm surge include IMD's Ghosh Nomogram (Ghosh, 1977) which is an empirical analytical method and numerical models of IIT Delhi (implemented from cyclone Bijli in April, 2009) and INCOIS (implemented from cyclone Phailin in October 2013) developed based on the AdCirc model (Advanced Circulation) of NOAA, USA. IIT Delhi model provides residual surge while INCOIS model provides the storm tide (combined effect of storm surge, astronomical tide and breaking wave set up) and also the inland extent of inundation. IIT Delhi model has been adopted for all WMO/ESCAP Panel member countries, while INCOIS ADCIRC Model provides storm surge and coastal inundation forecast for Indian coastal states.

The significant reduction in track forecast errors (77km, 117km and 159 km for 24, 48 & 72 hours lead period during 2016-2020) and landfall forecast errors of TCs in recent years (32 km, 62 km and 92 km for 24, 48 & 72 hours lead period during 2016-2020) are limiting the death toll to double digits. However, tropical cyclones being high impact weather events, it is necessary to improve the forecasting of TCs and storm surges further. A review of existing capabilities suggest further improvements are possible by the assimilation of in situ data from the ocean in the numerical models of cyclones, improvements in forecasted TC wind field, central pressure, model physics, forecasting methodology, quick dissemination, etc. Thus, a multi pronged approach with technology intervention is necessary to acquire real time in situ data, improve the model physics, model forcing, model numeric, enhancing the preparedness, risk assessment, mitigation and capacity building of coastal population.

2.2 Impact of landfalling cyclones storm surges

Impact of TC induced storm surges for the Indian coast has been described by several researchers. For example, Murty and Flather (1994), Das (1994), Dube et al. (1997), Madsen and Jakobsen (2004), Rao et al. (2007), etc. The convergence of the Bay (funnel shaped), presence of wide continental shelf encompassing the deltaic environment in the head BoB, densely populated low-lying coastal belt, higher tidal range, presence of numerous riverine systems, tidal creeks, mud-flats, coastal geometry, complex geomorphic environment, etc. are identified as the major factors that enhance the destructive nature of storm surge in the BoB. The coastal inundation that results from storm surge depends on the surge height, vegetation characteristics prevalent over the affected regions, and onshore topography of the hinterland. The disastrous effect of this natural geo-hazard can be minimized through reliable predictions alerting and warnings the coastal communities. Modelling the prevalent hydrodynamics along the coastal environment during tropical cyclone activity is a quite challenging task due to the complex non-linear interaction between various environmental drivers such as tides, wind-waves, currents and storm surges.

2.3 Current status of storm surge modelling for the north Indian Ocean basin

2.3.1 Previous Studies

Earlier studies on storm surges for the Indian coast started with the development of empirical relations. Study by Rao and Mazumdar (1966) developed nomograms that represented the storm surge amplitude as a function of storm intensity and speed. Another study by Janardhan (1967) used empirical formulations considering the static wind setup and assuming a balance between wind stress and sea-surface slope to estimate storm surge height at Sagar Islands located in the head BoB. There were several other studies that relied on empirical models such as Chaudhury and Ali (1974), Rao and Majumdar (1966), Qayyum (1983), Das et al. (1978). It was only during the early 1970′s that numerical studies on storm surge were attempted. Das (1972) developed the first numerical model for storm surge prediction in the BoB. Later Das (1980) introduced the non-linear advective terms in the model equations and proposed that inclusion of tide-surge interaction in the model will advance the arrival of peak surge by about two hours. It was probably for the first time, the study by Murthy and Henry (1983) developed a series of numerical models for tide and surge that used irregular rectangular grid instead of regular rectangular grid. Significant progress has been made in this subject and the study by Johns and Ali (1980), Johns et al. (1981) included the Ganges-Brahmaputra-Meghna River system using the depth integrated non-linear equations of motion and continuity. The SPLASH model of Jelesnianski (1972) was later adopted by Ghosh (1977) for the East coast of India. In another study, Johns et al. (1981) used the full non-linear depth averaged model of Jelesnianski (1976) to investigate storm surge activity for the

1977 Andhra cyclone. Jarrell et al. (1982) used the Hurricane model of US National Weather Service (Murty et al. 1986) to model the BoB cyclone in 1980. Extensive studies on storm surge were carried out by using a finite difference model for the BoB region by Dube and Gaur (1995) also popularly known as IIT-D storm surge model. An elaborate overview of finite difference models is available in Dube et al. (1997). Several case studies were performed using the IIT-D model for the Indian coast. Later Rao et al. (1997), Chittibabu (1999), Chittibabu et al. (2000, 2002), Dube et al. (2000a, 2000b, 2004) and Jain et al. (2006a, 2006b) used the numerical models to study the storm surges that affected the Gujarat, Andhra Pradesh, Odisha, and Tamil Nadu coasts.

2.3.2 Current Status

Recent developments include the implementation of ADCIRC model by Rao et al. (2010) for the Kalpakkam coast located in the Tamil Nadu to evaluate extreme storm surge scenarios. The ADCIRC model uses a flexible finite element mesh capable to resolve the complex coastline geometry and sophisticated model physics to compute storm surge and inundation. Hence more advantageous compared to the IIT-D storm surge model. Though the IIT-D model faired reasonably well in many case studies, it could be used only for storm surge computation unlike the ADCIRC which can estimate the net storm surge that also includes the sea level height due to astronomical tides and inundation at the coast. Bhaskaran et al. (2013), Murty et al. (2014, 2016), Gayathri et al. (2015), Poulose et al. (2017) coupled ADCIRC with SWANwave model, for the Indian coast. The most recent examples using coupled ADCIRC+SWAN are available in Bhaskaran et al., (2013) for Thane cyclone, Murty et al. (2014) for Phailin Cyclone, Gayathri et al. (2015) for Aila cyclone and Murty et al. (2016) for Hudhud cyclone and Pandey and Rao (2018) for all recent cyclones. The coupled model could provide the total water level at the coast during cyclone landfall episode. At present the coupled model is used by INCOIS (Indian National Centre for Ocean Information Services, Hyderabad) for operational forecast of storm surge and inundation in the North Indian Ocean basin.

Currently, the storm surge modelers use Jelesnianski (1973) and Holland (1980) wind schemes to generate wind distribution in the cyclone. The Jelesnianski wind scheme requires only two parameters of the cyclone - Radius of maximum winds and Pressure drop/maximum sustained winds. The cyclone wind distribution in this case is mostly symmetric, though the actual case is asymmetric. However, the Holland wind scheme provides asymmetric representation of cyclone with additional information in all quadrants of the cyclone like radius of maximum winds in each quadrant, pressure drop, closed isobar in the outer core of the cyclone, etc. The TC Vital information (Sharma and Mohapatra, 2017) obtained from the cyclone forecasts are then converted in the format required in the Holland wind scheme to force the storm surge model.

Further, in the numerical model the computation of coastal inundation is very tricky as it requires accurate data on nearshore bathymetry, topography of the coast and configuration of river systems. The land topography is provided by various data sets like CARTOSAT, SRTM, ALTM, etc. Among them, the ALTM data is most accurate. But the current availability of ALTM data is confined to ~ 2 km inland from shoreline. Since the storm surge can intrude further inland, ALTM data extending, at least, up to 10 m topography contour is necessary.

Whenever a cyclone passes over the riverine system, it is expected to cause more damages in terms of inundation as the storm tides propagate easily through the river system. In such case, storm surge model coupled with a hydraulic model to include precipitation and outflow from the river, is necessary to better simulate the scenario of coastal inundation. In addition, inclusion of information on land use-land cover (LULC) bottom and surface friction in the model are vital for accurate computation of inundation.

2.4 Gap areas

Though there has been tremendous progress in the field of storm surge forecasting in the north Indian Ocean region in recent years, there is scope for further improvement. Some of the areas that require immediate attention include:

(i) At present the tide gauge network comprises 36 tide gauges maintained by INCOIS. However, this network is inadequate to capture storm surges everywhere along the vast coastline of India (about 7500 km).

(ii) Currently, storm surge and coastal inundation are estimated based on post cyclone survey. Direct observation mechanisms are necessary for accurate measurement of storm surge and coastal inundation.

(iii) Accurate storm surge prediction critically depends on the quality of inputs like pressure drop at the center, wind filed, etc. Especially, the meteorological forcing and the parameterization of air-sea-land interactions, boundary conditions, bottom friction, bathymetry, land use-land cover pattern, etc. are important. Errors in any of them may further compound the errors in numerical computations of storm surge.

(iv) River discharge can significantly modify the surge, especially in the northern BoB, where large rivers carry lot of fresh water annually. Similarly, heavy precipitation associated with the tropical cyclone can also influence the total water level. Currently, these are not integrated in the storm surge model used for operational purpose.

(v) No serious efforts have been made for the quantification of uncertainties in storm surge forecasts arising due to the uncertainties in track, landfall and intensity forecast. The existing models provide deterministic storm surge forecast.

(vi) Existing ALTM DEM covers area up to 2 km. But the storm surge associated with very severe cyclonic storm, YAAS in 2021, intruded up to 10 km. The storm surge during the super cyclonic storm of 1999 extended up to 35 km inland.

(vii) Most of the available models for tropical cyclone forecasting are atmosphere only models except the Hurricane Weather Research Forecast (HWRF) Model which couples ocean and atmosphere models.

(viii) Currently, no maps of inter tidal zones are available.

(ix) No significant structural measures have been prescribed and implemented to reduce the damage due to storm surges which cause severe damages to life, erosion of beaches and embankments, etc.

(x) Cyclones also bring heavy rainfall adding to the water level. Improper drainage systems hamper quick drainage of excess water.

2.5 Scope

(i) The tide gauge network needs to be enhanced for objective determination of storm surges. Should have at least 75 tide gauges (1 tide gauge in 100 km) covering the coastline.

(ii) Instead of estimates by post cyclone survey team, automated monitoring instruments and suitable satellite/airborne (microwave Radar) techniques are to be adopted. This will help in objectively determining the height of storm surge and the landward extension of inundation.

(iii) Improvements are still required in the prediction system especially in the context to tropical cyclone induced flooding scenarios. The present operational system only considers the probable sea water flooding and run-up along the coastal regions during cyclone landfall. Various hydrological and hydrodynamical inputs including riverine flooding, information on present and past rainfall, etc also need to be integrated into the storm surge models to get accurate total water envelope.

(iv) Develop probabilistic storm surge model that will consider the uncertainties in track, landfall and intensity forecast.

(v) Improvements on existing DEM needs to be prioritized. This needs to be strengthened and will help the inundation models. Vulnerable sites along the Indian coast needs to be properly identified and the risk to be assessed for planning and developmental purpose. The ALTM data up to 10 m topography contour is required for precise inundation mapping.

(vi) A land, ocean and atmosphere coupled model that also includes heavy rainfall and river discharge information is necessary for further improving cyclone forecast and associated rainfall, wind and storm surge forecast and associated flooding. The forecasts are to be customized based on the existing infrastructure and land use-land cover (LULC) mapped on geospatial information system.

(vii) Mapping the inter-tidal zones and integration with the existing DEMs would enhance the accuracy of existing inundation models.

(viii) Planned infrastructure development in the coastal areas is a necessity to minimize the damages. Bureau of Indian Standards may evolve suitable engineering code for the construction of buildings and other infrastructure in the cyclone and storm surge prone areas to avoid damages to them during the events. Creation of natural barriers like plantation of mangroves and shrubs would help in minimizing the damages to life and property. Zonation of coastal areas based on historical cyclones and storm surges are to be considered while planning the development of coastal areas.

(ix) Construction of proper drainage system to channel the rainwater in cyclone prone areas based on the climatological data are necessary.

(x) Community preparedness with specific performance indicators for readiness and mitigation of the effects of cyclone like rainfall, wind and storm surge are required to minimize the damages to life and property.

2.6 Future projections

As per the 2019 Special Report on Ocean and Cryosphere in a Changing Climate (SROCC), the global mean sea level rose at 1.4 mm per year in the 20th century. However, the rate increased to 3.6 mm per year between 2006 and 2015. In fact, mean sea level is projected to rise beyond 2100 even if the greenhouse gas emissions are kept at current rates. The report released by Ministry of Earth Sciences (MoES) and the Indian Institute of Tropical Meteorology (IITM-MoES), Pune, in June 2020 suggests that India is following similar trends. Between 1874 and 2004, the mean sea level in the Northern Indian Ocean rose by 1.06 -1.75 mm per year – but at about 3.3 mm per year during 1993 and 2017. Studies have also shown that due to global warming the sea surface temperature and atmospheric temperature have increased.

The IPCC Special Report records that the number of category 5 cyclones have increased in recent decades. During the past 30 years, the intensity of landfall of extremely severe cyclones from BoB has increased at an average rate of 8% per decade (Singh et al, 2020). However, considering the data of 1965-2020, there is no significant change (Mohapatra et al,2021) The intensity of cyclones over the Arabian Sea is no exception to this trend in recent decades (Knutson et al 2019,2020). These trends point that the intensity of storm surges will also increase during the coming years accordingly under the joint impact of cyclone and sea level rise due to global warming.

2.7 Policy Intervention

Co-ordinated efforts with following agencies and research & development centres may be initiated to improve the storm surge forecasting, minimize the loss of life and damages:

- Ministry of Environment and Forests to improve shelter belt plantation in coastal areas.
- Research and development institutes in the field to develop probabilistic storm surge model and land, ocean & atmosphere coupled model that will also have the capabilities to forecast the extent of inundation at the coast.
- NDMA and NDRF to flag off the surge prone areas and to create mass awareness to mitigate the disastrous impacts of storm surges

Ministry of Jal Shakti and Water Resources management to build check dams to channelize and regulate excess water from rainfall and river outflows.

Section 3 Heavy rain and Floods

3.1 Introduction

In the backdrop of climate change and recently published IPCC AR6 report, likelihood of extreme events including heavy precipitation, riverine flooding and coastal flooding etc. will be more frequent. In the recent past, the weather patterns are already showing signatures of frequent extremes making public and society vulnerable. In view of this, the sub-committee deliberated and took a holistic approach of observation-modelling-dissemination-coordination by the respective stake holders. The details are mentioned below.

3.2 Gap areas

In the current forecasting system of heavy rain leading to natural disaster: flood (such as riverain flood, flash flood, urban flood, cloud burst, landslides, inundation of coastal region, coastal erosion etc), following points have been noted as possible "Gap Areas" in observation, modelling, application and managements.

3.2.1 Observation

- Need to enhance rainfall at higher spatial density (~5km) and temporal (hourly/3 hourly) over the region (hotspots of extreme rain) with use of various observational platforms.
- Currently there are significant gap in upper air sounding data and improved coverage of Dual polarized Doppler Weather RADAR.
- Non-availability of Digital Elevation Map (DEM) for all flood prone cities and flood plains.

3.2.2 Modelling

- Requirement to predict extreme weather events due to the occurrence of localized rainfall activity with very high intensity leading to urban flooding and flash floods, in view of increase in frequency of such events nowadays.
- Convective scale data assimilation is a need of the hour for predicting the extreme precipitation events with at least 2 days lead time.
- Downscaling of NWP model output at a high spatial resolution (~5km)

3.2.3 Application

- Customized, bias corrected rainfall forecast for early warning of River flooding, urban flooding with GIS compatibility.
- Impact based prediction of heavy rainfall and warning on inundation regions due to floods
- Development of stable National geodetic reference frame for capturing timely and high precision spatial data.

3.2.4 Management

- Lack of coordination between stakeholders need to be improved.
- Last mile connectivity needs to be improved.
- Policies to tackle Change in pattern of heavy rainfall due to Climate Change

3.3 Summary

- Sub-committee feels that on priority, the number of dual polarized Doppler RADAR needs to be enhanced for strengthening and enhancing the skill of nowcast of extreme events. However, the specific location, configurations and other details may be worked out either by MoES Institutes (e.g. IMD) or any other committee. Committee also felt an urgent need of high resolution spatio-temporal rainfall data at hourly or three hourly intervals at ~5km resolution over the vulnerable hotspot areas of India. The models (global and regional) also need to be scaled up to resolve the regional heterogeneity particularly the topography, with a target resolution of ~6km (global) and ~1km for the regional mesoscale model. Finally, the dissemination and coordination has to be scaled up utilizing all modern technology.
- Indigenous development of observational systems as mentioned above could help in ensuring self reliance, early maintenance/ trouble shooting, scalability and minimization of expenditure.
- High resolution geospatial data base along with socio economic data in digital format is essential for impact based forecasting on granular level.
- Land-Ocean-Atmosphere coupled needs to be developed/ implemented for realistic prediction of heavy rainfall and floods. Suitable improvement in hydrological and hydrodynamical modelling will also be required.
- Development of Decision Support System (DSS) is essential for each type of floods like riverine flood, flash floods and Urban floods.
- There is need for engineering solutions to drain out the water from heavy rainfall prone areas & cities/towns and harvesting of rainwater.

According to Krishnan et al (2020), the frequency of localized heavy rain occurrences over India has increased during 1951– 2015 (high confidence). With continued global warming and expected reductions of aerosol concentrations in the future, climate models project an increase in the annual and summer monsoon mean rainfall, as well as frequency of heavy rain occurrences over most parts of India during the twenty-first century (medium confidence). The interannual variability of summer monsoon rainfall is projected to increase through the twenty-first century (high confidence). Increased frequency of localized heavy rainfall on sub-daily and daily timescales has enhanced flood risk over India (high confidence). Increased frequency and impacts of floods are also on the rise in urban areas. In general, the increasing trend in the heavy rainfall events is found to be the major factor for the rising trend in flood occurrences in India. the observed increasing trend in heavy rainfall events combined with the intense land-use changes has resulted in more frequent and intense flash floods over urban areas, like Mumbai, Chennai, Bangalore, Kolkata, etc. (Guhathakurta et al. 2011). Though there is high confidence in the rising trend in extreme rainfall events and the associated flood risk over India, its attribution of climate change remains a challenging issue and an open problem for further scientific research.

Section 4 Cloud bursts

4.1 Introduction

Cloudbursts are intense precipitation events with rain rates greater than 100mm per hour for very short time-span of few hours over a relatively small geographical area. In most of the places it is associated with sudden convection; whereas in mountainous region it is convection plus orographic locking leading to its formation. The warm air currents of a thunderstorm tend to follow the upward slope of a mountain. The effects of heavy rain are especially evident in mountain region along the smaller rivulets because of the enormous water availability in shorter duration leading to sudden and destructive floods, landslides, debris flows and avalanches in downstream basins/habitat. Western Himalayas experience a routine occurrence of cloudbursts leading to associated disasters. Cloudbursts can also occur in deserts and interior regions of continental landmasses due to the warm air current rising above from the ground and leading to Cumulonimbus cloud (Cb) formation. Associated updrafts take away the falling raindrops/ available moisture to subsequently manifest in a steady shower. It causes excessive condensation in the clouds as new drops form and old drops are pushed back into it by the updraft. In the Indian Subcontinent, cloudbursts generally occur during monsoon seasons when cloud/moist warm current drifts northwards along the foothills of the Himalayas, either from the Bay of Bengal or the Arabian Sea.

Detection, forewarning and monitoring of cloudbursts are still in a very nascent stage and current status of the numerical weather prediction models are still not developed to capture such events in terms of exact location and timing. And hence this is a challenge for modeling and for the generation of localized specific warnings for these highly microscale and spontaneous events. Satellite imaging technology would be able to take sharper, focused and high-resolution pictures over a smaller area. But timely dissemination of alerts to the remote inaccessible locations is a big challenge for cloudbursts and related disasters. Short term and long-term plans are required for understanding, mitigating the after effects and technology preparations to alert the people living in the downstream regions and insurmountable locations for minimizing the human causalities and economic losses.

4.2 Possible impact of the disaster in the future

In the warming scenario due to global climate change, a warmer average global temperature will result in a higher rate of evaporation, causing the water cycle to speed up. Increase in water vapor in the atmosphere will lead to impact the precipitation/hydrological cycle. Global average precipitation increases by 1% to 3% for each degree of warming, which means rainier and snowier future. However, the changes in precipitation will not be evenly distributed everywhere and there will be less frequent but more intense rains at different regions leading to highly skewed distribution. The number of cloudbursts is likely to increase and their spatio-temporal patterns are as well likely to change. Earlier, cloudbursts were common during monsoon or post-monsoon season, but now are happening during pre-monsoon also. The decadal temperature rise in the Himalayan ranges is higher than the global rate of rising temperatures. Several climate change studies over the Himalayas reported a consistent warming in the present climate with rate of warming much higher than the global average of 0.4 degree Celsius. These findings thus corroborate with increased cloudbursts in the Himalayas.

4.3 Gap areas, knowledge gaps and recommended solutions

- Need to integrate the prediction using existing Numerical weather Prediction (NWP) models/methods and identify signals leading to the extremes. Satellite products and existing NWP products should be effectively utilized for the monitoring and early warning of the cloudbursts. Large scale environmental conditions favouring the cloudbursts should be identified and categorized using historical observations and NWP model analyses and diagnostic tools should be developed to detect the signals. Cloud Resolving Models can be used to study and forecast the cloudbursts. Hydro-meteorological and geological informations should be collected and integrated to look into the different aspects of the cloudbursts. Climatological records should be analysed to identify the pockets of valley locations as possible hot spots for the possibilities of regular cloudburst and flash flood occurrences.

- Studies show that convective instability and orographic forcing are must for cloudbursts to happen. We need to understand the underlying process of cloudbursts and flash floods which are still not properly understood. The western disturbances (WDs) and associated horizontal moisture flux play crucial roles. One of the best ways for monitoring is the satellite tracking of clouds and Cb towers. Geomorphological factors are also important in the evolution of high convective build-up, heavy rainfall and snowfall, flash floods, landslides, avalanches and debris flow which afflict wide causalities downstream.

- Pre-monsoon Forest fires can lead to drier atmosphere, supply lots of aerosol loading, create conditional instability and cause strong convective activity. Further any sudden moisture advection can trigger strong cloudburst activity. There are unproven hypotheses on how much is the role of dam and reservoirs as a catalyst for local supplement of moisture to trigger highly convective activities over the Himalayan region. Impact of climate change and global warming on the higher and higher frequency of extreme events and over the Himalayan ecosystem is also very evident in the recent decades.

- It is true that the some of the crucial factors contributing to cloudbursts are forest fires, reservoirs and strong wind gusts. Geomorphological factors such as unstable slopes also add to the high impact of the events. Geological mapping is done by IIRS Dehradun from where we can identify the favourable locations of cloudbursts and the digital version of the atlas will be very useful in hazard zonation mapping.

- Process understanding, hydro-meteorological and geological information gathering and mapping and linkages to possible glacial lake outbursts are some of the prerequisites. The observations of cloudbursts over the western Himalayas show that the WMO/IMD criteria of 10cm/hour may be unrealistic as the maximum rainfall recorded are of the order of 3-5cm only for the recent cases of cloudburst episodes. Also, pre-event conditions of continuous preceding rainy days, soil moisture accumulation and river breaches are important factors to be considered for the characterization of the entire deluge.

- High-resolution observation networks such as Doppler weather radars, automatic weather stations, wind profilers, radiometers that monitor and provide accurate data at short spatial and temporal intervals, are the most essential components of an extreme rainfall nowcasting system. It should be possible to construct the vertical structure of the wind, temperature, cloud and moisture variables and demark the regions with the existence of a mixed phase regime high up in the atmosphere. If the cloud base is higher and 2-3 km layer of fine aerosols exist much high in the atmosphere it can cause large number of cloud water residing above the freezing level, and can lead to the evolution of the cloudburst event. Radars should be complimented by satellite information to continuously monitor the fast reduction in cloud top temperature (CTT) to identify and predict possible locations of cloudbursts and heavy downpour. But many CTT-rainfall relationships exist and it is an active area of research requiring lot of work. Research on reflectivity-rainfall relationship over western Ghats region is underway.

- There are many indicators like consecutive rainy days and lightning observations which can hint at the possibilities of an increased threat from an impending cloudburst. Cross-linkages with other hazards should be incorporated and area of the routine cloudbursts also should come under scrutiny. Also need to classify and study the Cb clouds and Nimbostratus clouds on which of these can indicate more chances of a cloudburst over the hilly terrain. Need to collect information from the global literature on how to deal with the cloudbursts and on how other countries are faring in this regard.

- The definition of cloudburst of 10cm/hour may be true over Western Ghats and other regions of India, but not be very valid over Western Himalayas, where much less rainfall amounts can lead to flash floods and debris flow. So, it is highly dependent on local geography and geomorphology. Cloudburst also can happen over the pockets of 'free convective cells' forming along the fringes of intense circulations or along the demarcations of two distinct airmasses, which can be simulated by very high-resolution convective scale models with explicit convection.

- Cloudbursts itself are not very well recorded events in the history but their aftereffects only are visible most often. There is no technology which exists currently for the detection, monitoring and prediction of cloudbursts over vast stretches of distant Himalayas, except that the forecasts of heavy rainfall, wind gusts or lightning from mesoscale models can possibly indicate some hot spots of extreme convection over the hilly regions, though spatial and temporal accuracy may not yet be assessed due to the paucity of direct observations or records. Also, the genesis locations of actual events are difficult to obtain over the uninhabited and remote data sparse regions of Himalayas and the world comes to know about the event only when it impacts the downhill areas in the form of flash floods, debris flow, landslides or avalanches. Currently the cloudbursts and flash flood events happening over Uttarakhand may be having its origin over the uphill regions of the HP-Uttarakhand boundary region. The IMD radar network planned over the Himalayan region may give more hindsight on such events in future.

- Some measures suggested to mitigate the impact of cloudbursts are,

    (a) Regulation of construction activities along river banks with special consideration to water level during heavy rainfall

    (b) Adoption of eco-friendly policies and eco-sensitive tourism for development of the region

    (c) Strengthening of embankments, barrages and dams to constrain & regulate water flow

    (d) Localized planning taking into consideration the ecologically fragile nature of the region and involving the local communities

(e) Regulation of infrastructure projects and preserve the sanctity of eco-sensitive zones

(f) Identification of hot spots and high probability occurrence places and rehabilitation of the local population

(g) Better forecasting and incorporation of advanced technology to monitor and predict extreme weather events to enable early warning, evacuation and preparedness.

- Many other disasters are linked to cloudburst and there are overlapping themes and hence the technology solutions can be common for many of them. In view of the above fact, multiple strategies have to be evolved for possible future technologies and basic infrastructure developments (which should be further explored for its feasibility or technological efficacy) for the prediction and monitoring of cloudbursts and other related national disasters.

4.4 Future possible technologies and engineering solutions

(i) "AEWS- Airborne Early Warning System":- Specialized Aircraft fitted with Doppler Radar (4 Aircrafts stationed in 4 different corners of the country), available to deploy in a short notice to monitor any intense convective systems. Radar reflectivity and depolarization ratios from these AEWS can provide valuable information on the ice cloud formations that often lead to hailstorms and lightning. Proposal to use Indian Airforce's AWACS aircrafts in Doppler Mode (If Possible), by IMD scientists during peace time conditions, for tracking severe weather systems. (e.g., https://en.wikipedia.org/wiki/Boeing_E-3_Sentry).

(ii) Proposal for ISRO to develop satellites that will monitor "stable water Isotopologues" in the Atmosphere via making use of solar occultation technique, with special focus on intense convective cells. Refer: ACE -FTS instrument onboard SCISAT-1 satellite. (e.g., https://en.wikipedia.org/wiki/SCISAT-1).

(iii) Experimental use of Cloud Seeding silver iodide "Rockets", which can be easier to use and more widely tested in different parts of the country. (e.g., https://en.wikipedia.org/wiki/Cloud_seeding).

(iv) Possible use of High-power Microwave & Laser beams, in collaboration with DRDO, to induce initial triggering of precipitation (similar to cloud seeding).

(v) Special focus on "free convective cells" that form along the fringes of intense cyclones, that many a time is not captured well in the Global Models that use parametrized convection. Such systems are known to cause flash flooding. Regional models that use explicit convection can predict such free convective cells in a better fashion, which can cause flash floods, like the Hyderabad Floods (2020).

(vi) A "merged precipitation product" developed through a decision support system (DSS) by combining both global and regional model forecast could be more valuable product. It could be further augmented by relevant geo-spatial layers.

(vii) High altitude Balloons that provide internet coverage and severe weather monitoring. The movement of these balloons will be controlled based on the wind direction and intensity in the various atmospheric layers. Via changing the altitude of the balloons (between 850 and 500 hpa), the direction of the movement of the balloons can be controlled, guided by global model wind forecast. These balloons could also be employed for severe weather monitoring also. (e.g., https://en.wikipedia.org/wiki/Loon_LLC).

(viii) Setting up "moisture trapping nets" (extracting water from atmosphere) in the Indo-Gangetic plane to extract water from the atmosphere and use it for agriculture/household needs.

Section 5 Urban floods

5.1 Introduction

Urban Flooding results from the combination of overflow of rivers, high precipitation, sea level rise, tidal variability and coastal storm surges. Some of the major reasons for flooding in urban cities include urban sprawl, land use changes and poor drainage. The change in weather patterns and increased episodes of high intensity rainfall events occurring in shorter periods of time due to climate change exuberates the flooding. Encroachments along rivers and flood plains are also a major problem in many cities and towns. Consequently, the capacity of the natural drains has decreased, resulting in flooding thereby rendering large urban areas increasingly vulnerable to extreme rainfall and sea level rise.

Floods impacts both individuals and communities, and have social, economic, and environmental consequences. Flooding lead to impairment of goods, services, health and crops and often people get displaced and may have to evacuate to higher ground. The destruction of critical infrastructure adds to the human toll and prevents help from reaching devastated areas. The negative effects of floodwaters on coastal marine environments are mainly due to the introduction of excess sediment and nutrients, and pollutants such as chemicals, heavy metals and debris. These can degrade aquatic habitats, lower water quality, reduce coastal production, and contaminate coastal food resources.

5.1.1 Historical Perspective of Urban Floods

Floods are becoming a common occurrence in the urban areas across the rapidly developing cities of India. Mumbai floods 2005 & 2017, Chennai floods 2005 & 2015, and Hyderabad floods 2020 are only a few of many such instances of floods that are becoming an urban nightmare for planners and administrators across the world. Depending on the drainage and topography, the flooding can be relatively localized or spread across a large area from a few hours to several days. Due to their spatial and temporal scales, they could result in varying levels of infrastructure damage and impacts on the local population.

5.1.2 Causes and consequences of flooding in urban area, like climate change, population, land use changes, drainage network.

The lessons from these flooding repeatedly point to the following aspects where considerable technological interventions are possible:

i. Need for accurate flood forecasting and early warning system for every major city and river basin of the country.

ii. Flood ways / flood plains constricted due to encroachments reduces the carrying capacity and increases the risk of flooding

iii. Separation of sewage from stormwater and improper disposal and management of solid wastes leading to clogging of the stormwater drains and localized flooding / water logging

iv. Roads / highways without adequate cross drainage structures and improper relaying practices that lead to high formation levels of roads, raising above the plinth level of adjoining properties

v. Storm-water drains designed without accounting for future expansion

vi. Intensification of rainfall extremes due to urbanization and climate change

Recognizing the adverse impacts of the Urban Floods, NDMA has brought out detailed guidelines for management of urban floods that address many of the points listed above. The NITI Ayog report of 2021 clearly highlighted the need for continuous efforts towards modernization of hydrometeorological data and flood forecast dissemination and the need for scientific research in the development of models to forecasts flash flood with sufficient lead time.

5.1.3 Existing Central/ State, and NDMA guidelines to tackle Urban flooding

NDMA (https://ndma.gov.in/en/) is responsible for undertaking the actions for the development of a holistic and prompt response for floods or any other disaster. It lays down national policies and action plans for disaster management, provides guidelines and coordinates with states and other agencies to enforce the plans and takes necessary actions for disaster preparedness and capacity building. NDMA recognized the grave flood risk in this country and hence issued flood management guidelines. These guidelines aim at strengthening the existing flood preparedness capability and mitigation arrangements as well as improving post-flood response, relief, and rehabilitation practices. The guidelines highlight the need for providing early warning and maximizing the real-time hydro-meteorological network to cover all the urban canters in dealing with urban flooding.

5.1.4 Implications of Dam Break Analysis and Emergency Action Plans (EAP) developed under DRIP by the CWC in the context of Urban Flooding

Many of our cities are located downstream of the lakes and dams. Hence, management and operation of these storage structures, especially at times of flooding is extremely critical. CWC is implementing the Dam Rehabilitation and Improvement Program across the country (DRIP) to improve safety and operational performance of selected dams, along with institutional strengthening with system wide management approach. As a part of DRIP, Emergency Action Plans (EAP) is developed for many of the major dams across the country. The EAP is the document that must be used in case of an emergency. It identifies the roles and responsibility of the Dam's Owner and of the Authorities in charge to manage emergency situations (https://damsafety.in/). EAP consists of both structural and non-structural measures, including flood forecasting as a critical component. Hence, it is particularly important that any urban flooding studies in regions downstream of large storage structures dovetail with the flood forecasting and EAP of the structure.

5.1.5 Present system of flood forecasting at IMD and CWC

Flood forecasting is a joint operational responsibility of India Meteorological Department (IMD) and Central Water Commission (CWC). IMD provides sub basin wise Quantitative Precipitation Forecast (QPF) and other weather-related inputs in the form of QPF & Hydromet Bulletins generally during flood season through its Flood

Meteorological Offices (FMOs) and the same will be used by CWC to issue the flood forecast. Flood Meteorological Offices (FMOs) are established to provide meteorological support to concerned Flood Forecasting Divisions (FFDs) of Central Water Commission (CWC). This Hydro-meteorological service is operational from 14 IMD offices viz., Ahmedabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Jalpaiguri,

Lucknow, and New Delhi including Agra, Patna, Srinagar, Chennai, Bengaluru and DVC Kolkata (Fig.1). These functions under the technical control of office of Head (Hydromet), New Delhi, while their administrative control rests with Heads (RMCs). The technical aspects of FMOs should be referred to HQ office by FMOs directly. Regarding administrative aspects of FMOs, the recommendations of the concerned RMCs will be necessary to take further action on those aspects. Where MC and FMO co-exist, FMOs should work in close collaboration with MCs. RMCs concerned are to be seen that the technical work of FMOs should not suffer due to administrative reasons. As the basin areas may extend beyond the jurisdiction of a single RMC, the FMOs may correspond with such offices / centres as necessary for meeting their data requirements for the issue of 'Hydromet Bulletin'.

5.2 Possible Impacts

Urban floods have extensive effects especially as far as economic losses both direct and indirect. Flood risk is a component of exposure of the population and the economic activities alongside the vulnerability of social and economic components. The effect of such floods on the lives and livelihoods of individuals, a component of their vulnerability, should be comprehended. It results in inundation of storm water on railway tracks, roads, underground metro lines, and even runways at airports when the level of precipitation is low compared to the city's drainage capacity. This causes hindrances in the traffic movement of goods, services, and people. Educational services, industries, and the service industry get heavily disrupted when transportation gets affected. Urban floods are often associated with loss of life and physical injury either directly due to the effect of floods or indirectly due to infections by water-borne diseases spreading during the inundated period. Loss of shelter and relative creates emotional turmoil in the mental health of the stranded. These damages can be longlasting psychological trauma. The ecological losses include trees and plants being washed away during an extreme flood event. Sewage and solid waste being washed into houses and neighbourhood create a huge array of issues like disease outbreak, economic losses to the households.

5.3 Current Technology & Preparedness

5.3.1 Understanding of Flood inundation from precipitation, hydrology, hydraulics and hydrodynamics

Changing climate and increased precipitation had a huge role to play in the devastating floods that happened across central Indian states, including the 2006 and 2017 Mumbai floods. IMD's data reveal that - In the past century (1901-2015), there has been a rise in widespread extreme rainfall events across the Indian subcontinent by three-fold, especially in the states of – Chhattisgarh, Gujarat, Jharkhand, Maharashtra, Madhya Pradesh, Odisha, Telangana, Assam; and parts of Western Ghats – South Kerala, Goa, north Karnataka and. Tamil Nadu. The extreme rise in the number of rainfall events are directly linked with increased warming of the Arabian Sea and Bay of Bengal causing fluctuations of the monsoon winds. This results in the occasional high-intensity cyclones from the Arabian Sea to the western coast and Bay of Bengal to the eastern coast, resulting in heavy rains lasting for at least 2–3 days, which when spread over a large region causes flash floods.

An integrated hydraulic and 2D hydrodynamic model simulates the flow of runoff from precipitation over the study area, the flow of water that breaches river banks (river model), the effects of overflowing from drainages (1d hydraulic model), and the effect of the coastal boundary on inundation in the study area. The 2D hydrodynamic model incorporates sea bathymetry and considers water levels at the coast as the offshore boundary condition. This water level could be the astronomical tidal values. However, many extreme rainfall events are associated with cyclonic systems, coastal cities face an additional risk of flooding from the coast due to storm surges. Storm surges elevate water levels of the sea resulting from the atmospheric pressure gradient and strong winds induced by the cyclonic system. For a given atmospheric pressure gradient and path of a cyclone, the surge at coasts affected by the cyclone is modelled and given as input for the 2D hydrodynamic model. Many cities have a drainage network to drain out runoff and prevent inundation. However, during extreme events, it is highly likely that the drainage system could not handle such large volumes in a short time. Hence the drainage network is modelled as a 1D hydraulic model to map local inundation hotspots due to overflowing drainages.

5.3.2 Mesoscale Observations Network of AWS/Automatic Rain Gauges/Dual pole weather RADARs (x-band)

Monitoring rapidly developing floods in urban regions requires accurate measurement of rainfall (QPE) at high spatio-temporal resolution. Conventionally, rain gauge is considered as the most reliable instrument to measure rainfall intensity and its accumulation directly. Though rain gauges provide point observation, several rain gauges in a network can give rainfall information at high temporal and spatial resolution. Thus, the implementation of MESO-scale rain gauge Network (MESONET) is a vital rainfall data source for several hydro-meteorological applications. Applications of rain gauge such as the real-time monitoring of rainfall, input for flash flood forecasting, and ground truth for validating satellite estimates/model outputs stand them as a unique segment in observational systems (Sunil Kumar et al., 2016; Barton et al., 2020).

Numerous previous studies attempted to quantify extreme events and flash flood forecasting accessibility using mesoscale rain gauge network observations (Volkmann et al., 2010; Yoon et al., 2017). Based on results, monitoring the extreme rainfall events on a real-time basis and mitigation challenges are much concerned especially over highly populated urban regions since they cause severe catastrophes to wealth and lives (Paul et al., 2018). While other platforms such as satellite remote sensing provide the needful information with a latency period of ~3-4 hours, they often underestimate/overestimate the magnitude of extreme rainfall events. Moreover, a real-time application such as flash flood forecasting needs the input data at the earliest possible latency period.

With the availability of several interpolation techniques, high-resolution rain gauge data from MESONET can also evaluate interpolation methods' skills. Such studies assist in selecting a robust interpolation technique that is suitable to represent rainfall variability. Urban areas are much vulnerable to the consequences of extreme events for several physical, dynamical, and geographical reasons. For instance, floods in July 2005 in Mumbai and December 2015 in Chennai are positively associated with an unexpected deluge. The extreme precipitation event on 26th July 2005 in Mumbai shows the high spatial variability of the precipitation event over 24 hours in different areas (Lokanandham et al., 2012). Hence, such urban regions are suitable as testbeds for investigating the historical evolution and future projection of extreme events and associated floods. This investigation is feasible via various observational and regional scale model approaches. Several researchers attempted to address such challenges by combining measurements from radars and rain gauge networks (Chen et al., 2016; Yoon et al., 2017; Wijayarathne et al., 2020).

5.3.2.1 Urban small weather radar network

Radar observation at high temporal and spatial resolutions has shown great potential to drive flood forecasting by incorporating hydrological models. The radar resolution volume is continuously enlarged with increasing range. At long ranges, the earth's curvature and the blockage by the local terrain can often prevent accurate rainfall observations of interest. The temporal resolution depends jointly on the designed waveform and on the associated scan strategy. A network of short-range radars can mitigate these range constraints as well as lower beam height over the network coverage (Junyent et al 2010; Chandrasekar et al 2018).

Urban radar networks can provide an opportunity to study storm morphology, kinematics, microphysics, and rainfall estimation on time scales of several minutes with high-resolution data focused on the lowest levels of the atmosphere. The increased temporal resolution of such networks (5 to 15 min) also has a potential for relating radar-derived microphysics and dynamics to lightning and electrification.

The accuracy of radar QPE relies both on the radar system, such as beam width and side lobe, and on the environmental factors, such as clutter and storm variability. Radar beam can overshoot the lower part of the atmosphere due to blockages of the earth's curvature or local terrain. Radar observations can also be contaminated by hail, melting hydrometeor particles, and/or ground clutter. In addition, in urban environments, strong clutter is expected due to scattering from buildings in the neighbourhood which act as perfect reflectors when radar is steered down low.

5.3.3 Predictive capability-IMD/NCMRWF/IITM

Weather forecasts from days to season are becoming increasingly important for many applications such as: reducing loss of life and property from high impact weather systems; water resource management; sustainable agriculture; energy; public health; tourism and recreation; adventure sports; transportation; etc. The relentless increase in computing power over the last few decades has led to a corresponding increase in the resolution operational global NWP models, with resolutions of around 10 km feasible within the next few years. The better understanding of the physical processes coupled with better data coverage (specially coming from satellites) for initializing the models has contributed to a significant improvement in the forecast skill of NWP models. The benefits of the improved forecast skill have accrued to all sectors of Indian economy and society. In general, the NWP systems of leading global NWP centres are improving by 1 day of predictive skill per decade. These centres have been able to invest adequate resources, both in terms of computing power and manpower. The improvement is generally due to: 1) Better observations 2) Careful use of forecast and observations, allowing for their information content and errors-achieved by variational assimilation 3) Model improvements, 4) Better post-processing techniques.

5.3.3.1 National centre for Medium Range Weather Forecasting (NCMRWF)

The National Centre for Medium Range Weather Forecasting (NCMRWF) has been a lead centre in India for all weather and climate model related research and operations. NCMRWF currently carries out developmental work on NCMRWF Unified Model (NCUM). Unified modelling framework allows use of a single modelling system for different applications and at different grid resolution. Lists of various model configurations and applications are shown in Table 1.

Table 1 Model configurations and applications

Model	Application & Domain	Resolution	Forecasts
NCUM-G	Global NWP Forecasts	N1024L70 (12km horizontal resolution with 70 vertical levels)	00UTC: Day0 to Day10 12UTC: Day0 to Day 10
NCUM-R	Regional high resolution over Indian Region (5-40N and 65-100E)	4 km resolution Explicit convection	00UTC: Day0 to Day3 12UTC: Day0 to Day3
NEPS-G	Global Ensemble Prediction	N1024L70 (12 km horizontal resolution; Control+ 11 member)	00UTC: Day0 to Day10 12UTC: Day0 to Day10
NEPS-R	Regional high resolution over Indian Region (5-40N and 65-100E)	4 km resolution Explicit convection Control+11members	00UTC: Day0 to Day3
DM330m	Regional very high resolution domain over Delhi and NCR with Urban tiles	330m grid spacing, explicit convection and atmospheric chemistry	00UTC: Day-1 to day-2
DM1500m	Regional very high-resolution domain over North India, Urban tiles	1500m grid spacing, explicit convection and atmospheric chemistry	00UTC: Day-1 to day-2

5.3.3.2 India meteorological Department (IMD)

IMD runs a global model, viz., Global Forecasting System (GFS) model, a regional model, viz., weather research and forecasting (WRF; 3km grid) model and an ensemble forecasting system, viz., Global Ensemble Forecasting System (GEFS). In addition to these dynamical models, IMD also runs a cyclone prediction model, viz., Hurricane weather research and forecasting (HWRF) during Cyclone periods. The GFS and WRF models are run four times a day based on observation of 0000, 0600, 1200 and 1800 UTC respectively. The GEFS model is run two times a day based on 0000 and 1200 UTC observations. GFS is a spectral global model. In spectral models, the horizontal resolution is designated by a "T" number. The `T1534` indicates 1534 number of waves used by a spectral model. The T1534 mentioned in the GFS model indicates the horizontal resolution of GFS model. The approximate grid spacing can then be represented as $\Delta X=360°/(3T+1) = 12$ km in case of GFS model.

In addition, IMD runs high resolution rapid refresh (HRRR) model at a resolution of 2 Km with Doppler weather Radar data assimilation and updated every hour to provide rainfall forecast up to 12 hours.

5.3.4 Need for Flood plain maps (hazard maps and risk maps) for different return period flood for every city / district within the context of its larger river basin to develop action plans

Flood hazard maps for different return periods help the administrators in their flood mitigation and management operations. The traditional floods mapping and studies were based on conventional surveys and historical flood records. Geospatial technology can be used to develop an integrated methodology for flood mapping using combination of satellites images and Geographic Information Systems (GIS), and Hydrodynamic modelling and flood inundation maps can be generated using DEMs flood modelling was done using hydrodynamic models and comparison with the flood extent maps derived from satellite images. This can be used, in conjunction with the flooding data to adopt an evacuation strategy, rehabilitation planning and damage assessment in case of a critical flood situation.

The current state of art in flood studies with geospatial techniques are limited to mapping, monitoring and modelling of floods. The temporal SAR/cloud free optical images can give the rough estimates of duration of flooding and pre-flood terrain information form DEMs and flood extent maps can be utilize for the calculations of flood water depth and duration. This requires multi-satellite/ sensors/ altimeters/ ground-truth approach for flood studies.

5.3.5 Urban flood management methods in India

A scientific-based approach for preliminary and feasibility studies considering the strength and weaknesses of the proposed flood management plan is necessary for successful implementation. A secure connection between structural and non-structural measures will ensure considerable risk reduction for the present scenario and also assure a flood-proof strategy for future flood events. Integration of multiple measures is the key to building a robust system. The Government has set up various committees, task forces and working groups and formulated policies that have provided guiding recommendations for water resource management, including flood management. These strategies employed a normative approach by focusing on minimizing flood impacts by emphasizing various structural measures and emergency responses.

The flood management system has evolved over the years in the country. The seriousness of flood prevention and the need for an action plan to protect floodplain was acknowledged in 1954 after an unprecedented and devastating flood event in Bihar. Since then, substantial efforts towards flood protection began with controlling riverine flooding, with massive investments put into the construction of structural measures such as embankments, detention reservoirs, and at the same time improving the drainage situation in river basins.

Hence, the flood management institutional structure of India has twin hierarchies at:

(1) State government: The State Level Mechanism includes the Water Resources Departments, State Technical Advisory Committee and Flood Control Board. In some States, the Irrigation Departments and Public Works Departments look after flood matters.

(2) Central government levels: The Union Government has set up organizations and various expert committees to enable the State Governments in addressing flood problems in a comprehensive manner like CWC, National Disaster Management Authority (NDMA) Different measures have been adopted to reduce the flood losses and protect the flood plains. Depending upon the nature work, Flood protection and flood management measures may be broadly classified as under:

  (a) Engineering / Structural Measures

    (i) The engineering measures for flood control which bring relief to the flood prone areas by reducing flood flows and thereby the flood levels are –

    (ii) An artificially created reservoir behind a dam across a river

    (iii) a natural depression suitably improved and regulated, if necessary or

    (iv) by diversion of a part of the peak flow to another river or basin, where such diversion would not cause appreciable damage.

    (v) by constructing a parallel channel by passing a particular town/ reach of the river prone to flooding.

    (vi) The engineering methods of flood protection, which do not reduce the flood flow but reduce spilling, are:

    (vii) Embankments which artificially raise the effective river bank and thereby prevent spilling and,

    (viii) Channel and drainage improvement work, which artificially reduce the flood water level so as to keep the same, confined within the river banks and thus prevent spilling.

(b) Administrative / Non-Structural Measures: The administrative methods endeavour to mitigate the flood damages by

(i) Facilitating timely evacuation of the people and shifting of their movable property to safer grounds by having advance warning of incoming flood i.e. flood forecasting, flood warning in case of threatened inundation

(ii) Discouraging creation of valuable assets/settlement of the people in the areas subject to frequent flooding i.e. enforcing flood plain zoning regulation.

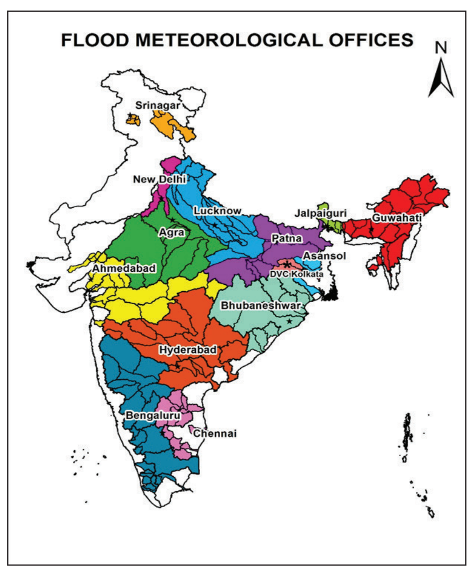
Providing absolute protection to all flood prone areas against all magnitude of floods is neither practically possible nor economically viable. Such an attempt would involve stupendously high cost for construction and for maintenance. Hence a pragmatic approach in flood management is to provide a reasonable degree of protection against flood damages at economic cost through a combination of structural and non-structural measures.

5.3.6 Urban flood management methods elsewhere across the globe

Some of the flooding warning and management systems in the world are discussed below:

1. London is protected from flooding by an immense mechanical barrier on the River Thames, which is lifted when the water level reaches a certain level. Venice has a similar arrangement, although it is already unable to handle the very high tides. The defences of London and Venice will be considered inadequate if the level of the sea continues to rise.

2. The largest and most elaborate flood defences can be found in The Netherlands, where they are referred to as Delta Works with the Oosterschelde dam as their greatest achievement. These works were built in response to the 1953 North Sea flood in the southwestern part of The Netherlands.



3. The St. Petersburg Flood Prevention Facilities Complex was built in Russia to protect St Petersburg from storms. It also has a main traffic function as it completes a circular road around St. Petersburg. Eleven dams stretch 25.4 kilometers and they are eight meters above water level.

4. Another elaborate system of flood defences can be found in the province of Manitoba, in Canada. The Red River flows to north from the United States, through the city of Winnipeg

(where it meets the Assiniboine River) towards Lake Winnipeg. As is the case with all rivers running north in the temperate zone of the Northern Hemisphere, thawing in the southern sections can cause river levels to rise before the northern sections have a chance to thaw completely. This can lead to devastating floods, as occurred in Winnipeg during the spring of 1950.

5. To protect the city from future floods, the Manitoba government undertook the construction of a huge levee system. The system kept Winnipeg safe during the 1997 flood which devastated many communities north of Winnipeg, including Grand Forks, North Dakota and Ste.Agathe,Manitoba.

5.3.7 Operational Systems like Flash Flood Guidance System and Integrated Flood Warning Systems

5.3.7.1 Flash Flood Guidance System

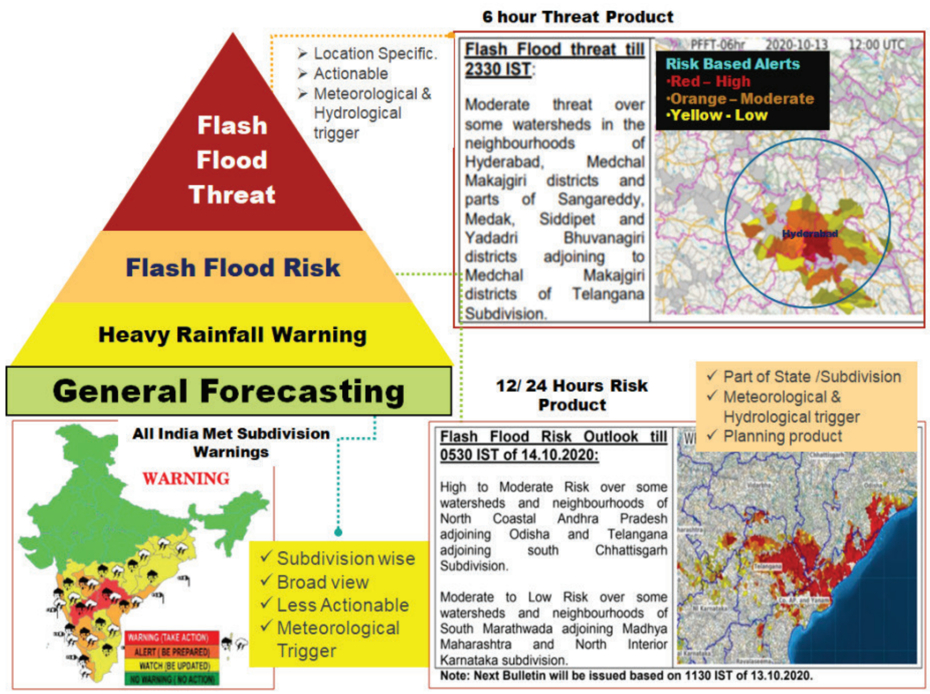


Figure 2 Impact based Analysis Event Diagram

Flash floods are typically associated with high-intensity rainstorms with short response time. They have the potential to severely impact and damage communities in different climatic settings especially in a densely populated region of South Asia. Recent years witnessed an increased effort to understand the dynamics of Flash floods with the availability of high resolution hydro-meteorological and topographical data. The FFGS provides global coverage to 3 billion people or 40% of the world's population. The countries using the FFGS have a combined land surface area of around 25 million square Kilometers, which is equivalent to 18% of the total land surface area of the world. Specifically, the South Asia Flash Flood Guidance System (SAsiaFFGS) provides coverage for nearly 51% of the world's population.

The aim and objective of the FFGS is to: (i) provide a diagnostic value (known as flash flood guidance) that estimates the amount of rainfall of a given duration within a watershed that is required to produce flooding at the outlet of the catchment. (ii) provide location specific flash flood guidance up to watershed level on pluvial flash floods in the form of Risks with 24 hour lead time based on numerical weather forecasts and Threats with 6 hour of lead time based on near real-time observations based on 00,06,12 and 18 UTC observations regularly (Figure 2).

5.3.7.2 Integrated Flood Warning Systems (iFLOWS)

- Integrated Flood Warning System for Chennai

  The 2015 Chennai floods which paralysed the city was due to three consecutive weather systems that brought in unprecedented rain to the city. Chennai came to a standstill, in spite of its extensive drainage connectivity, comprising three major rivers namely Kosasthalaiyar, Cooum, Adyar, the mammoth Buckingham canal, ennore creek, pallikaranai marsh and man-made drainage systems.

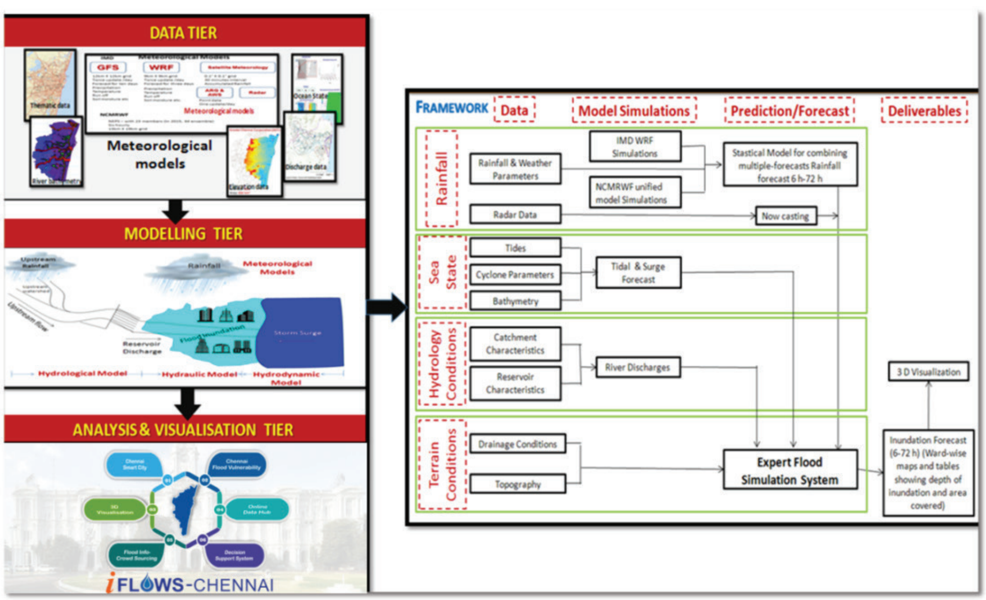


Figure 3 Schematic of the Chennai Flood Warning System

The Coastal Flood Warning system for Chennai, referred to as iFLOWS-Chennai, is developed as a Web GIS based decision support system, integrating data and outputs, derived from Weather forecast models, Hydrologic models, Hydraulic models and Hydrodynamic models (Fig. 3). The regional weather forecasting models from NCMRWF and IMD, form part of the operational iFLOWS-Chennai. The model datasets were validated, using field data, provided by IMD and the Tamil Nadu state government. Hydrologic models are used to transform rainfall into runoff and provide inflow inputs into the river systems namely Adyar, Coovum and Kosathalayar. Hydraulic models solve equations of fluid motion to replicate the movement of water to assess flooding in the study area.

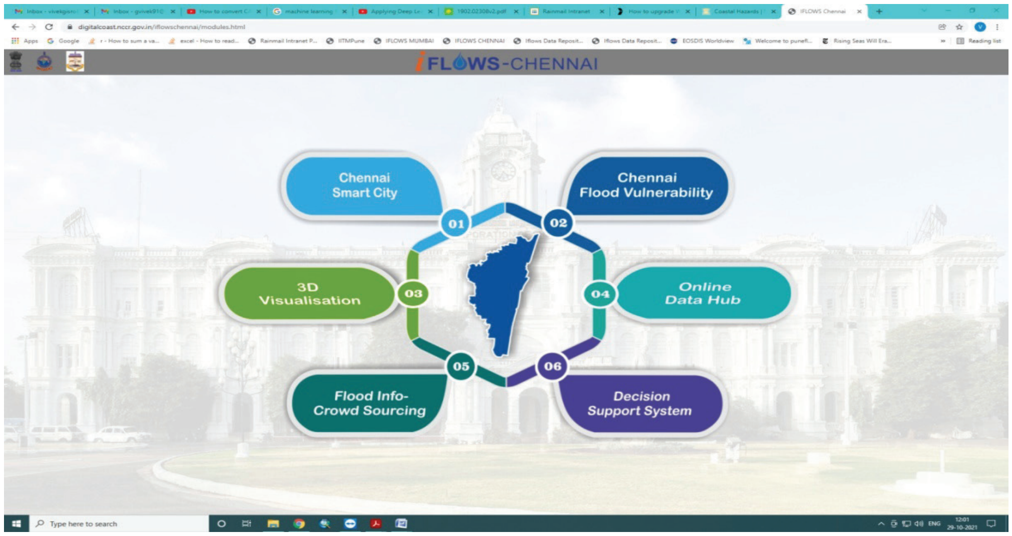


Figure 4 i-FLOWS-Chennai Dashboard

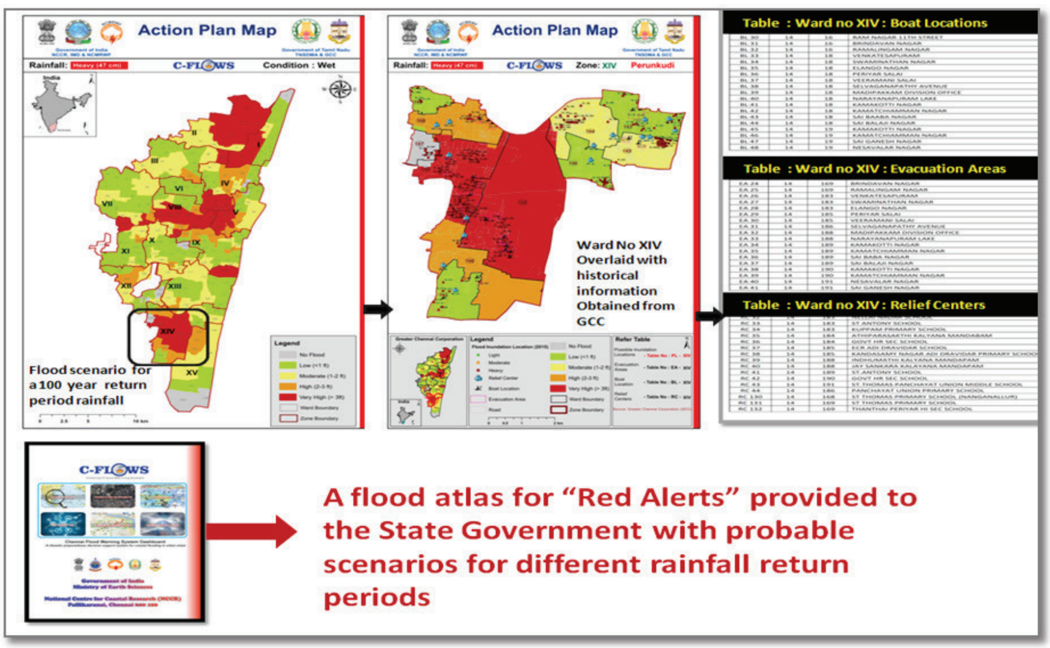


Figure 5 Flood Atlas for Red Alerts – for mitigation operations

The hydro dynamic models are used to calculate the tide and storm surge impacts into the model domain. Based on these models a flood library, comprising of about 796 Flood inundation scenarios, were developed corresponding to different rainfall return periods, tidal conditions, water discharge conditions etc. The WebGIS based decision support system comprising of six modules was build in-house by NCCR and they are Chennai smart city, Chennai flood Vulnerability, Online data hub, 3D Visualization, Flood info - crowd sourcing and Decision support system (DSS) (Fig. 4). A Red Atlas-Action Plan Map has been developed to serve as a ready reckoner for flood mitigation operations incorporating flood maps with field datasets on the streets, locations of relief centres, evacuation locations etc as provided by the state government (Fig. 5). iFLOWS-Chennai was launched by the in November 2019 and is in operation along with the Tamil Nadu State Government.

- Integrated Flood Warning system for Mumbai

The Mumbai flood during 26th July 2005, is probably etched in the memory of every Mumbai citizen, when the city received a rainfall of 94cm, a 100 year high in a span of 24 hours paralyzing the city completely. Anticipating floods before they occur facilitates precautions to be taken so as to protect property and save lives.

In a bid to aid in the mitigation activities of the flood prone city, Disaster Management Department, of MCGM, Govt. of Maharashtra approached the MoES to develop iFLOWS- Mumbai, as similar system was already developed by MoES and put into operation in Chennai. MoES initiated the development of flood warning system in July 2019 through National Centre for Coastal Research (NCCR), an attached office using the in-house expertise available within the Ministry (India Meteorological Department (IMD), National Centre for Medium Range Weather Forecasting (NCMRWF) and Indian Institute of Tropical Meteorology (IITM)), in close coordination with Disaster Management Department of MCGM. iFLOWS-Mumbai is a state of art webGIS based decision support system to enhance the resilience of Mumbai city by providing early warning for flooding specially during high rainfall events and cyclones (Fig. 6).

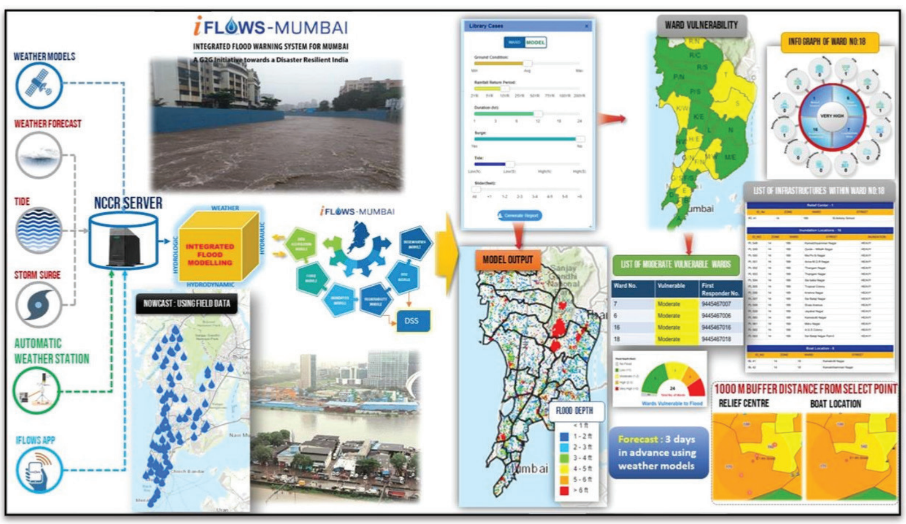


Figure 6 Workflow of i-FLOWS System

iFLOWS-Mumbai is a monitoring and flood warning system that will be able to relay alerts of possible flood-prone areas between six to 72 hours in advance. The system can provide all information regarding possible flood-prone areas, likely water depth, location-wise problem areas across all 24 wards and calculate the vulnerability and risk of elements exposed to flood. This data will be useful to the administration to plan evacuation from low lying areas at least 12 hours in advance. iFLOWS-Mumbai will address the flood inundation due to rainfall, river bank breach, storm surge, obstruction of flow due to roads, buildings, rail lines, high tides and sea level rise. The system will help make the city become more resilient, by providing early warning for flooding especially during high rainfall events and cyclones.

5.4 Gap Areas and recommendations

- There is a need for accurate, high-resolution rainfall measurements to validate model outputs for a growing number of regional scale weather model simulations. Such high-resolution rainfall observations are not available at regional-scale and consistent over a longer period.
- The potential application of rainfall measurements obtained with the MESONET is to examine diurnal variability and sub-grid scale spatial variability of rainfall. Such small-scale variability of rainfall often failed to represent by models, satellite and reanalysis datasets due to limited understanding of underlying physical processes responsible for such variability (Basu et al., 2007).
- While the location specific flash flood guidance up to watershed level is regularly provided in India through RMC's, MC's and FMO's up to sub district level., such system is not available for the urban locations. Hence there is need for development of flash flood guidance system for each & every urban location.
- There is need for geo referencing and impact-based forecast and risk based warning generation at granular manner for the cities utilizing a digital DSS. For this purpose, there is need for digital database on meteorological & hydrological data, socio economic indicators, geospatial data including drainage data as secondary & tertiary hazards and associated hazards like coastal flooding due to storm surge, astronomical tides, riverine flooding, landslides etc. The ultimate objective should be to develop high spatial & temporal resolution urban specific flood depth, its impact & risk assessment and real time communication to public & disaster managers for timely response actions.

Section 6 Thunderstorm / Lightning / Hailstorm

6.1 Introduction

The current technology level for prediction of damages associated with large scale natural phenomena such as tropical cyclones is improving every year for the Indian region, and accurate forecast of track and intensity of such phenomena are available with reasonable accuracy for up to five days in advance. This has resulted in substantial decrease in human mortality. However, on account of the population density and the increasing economic activity, the human and economic costs due to small scale convective weather phenomena such as thunderstorms are also increasing every year. On account of the small spatial scale of their occurrence, short lifetimes and relatively short prediction time, accurate forecast of these phenomena and timely dissemination of actionable warnings to the vulnerable people is still a developing field. The emerging technological advances are likely to have on huge impact on monitoring, numerical modelling, visualization of the various observations, forecasting, risk assessment and dissemination of final warnings of these localized severe weather phenomena.

Timely dissemination of alerts pertaining to impending Disasters to the population in local language has maximum reach to save lives and property. Presently, in India the dissemination of alerts is being done by the alert generating agencies by using various methods like fax, emails, SMS, mobile applications, telephones etc. The current system is less automated and driven without any central control and monitoring and is time consuming.

6.2 Possible impact of the disaster in the future

In the context of Global warming, the atmospheric moisture content is likely to increase with a corresponding increase in temperature. This implies that severe thunderstorms and extreme rainfall events are likely to be more frequent in a changing climate.

There are three thunderstorm maximum regions (a) northwest Indian Himalayas and adjoining Pakistan, (b) east & northeast India, and (c) extreme southern parts of peninsular India. Long period data indicates that on a monthly scale, the frequency of thunderstorm days has demonstrated a consistent spatially cohesive decreasing trend over east central and northeast India, collocated with the intra-annually shifting maximum of thunderstorm activity. The trend is more diffused for the thunderstorm maxima over north and south peninsular India. Further detailed analysis indicates that the frequency of thunderstorm days over these regions decreased during the latter half of the twentieth century followed by a gradually increasing trend. This corresponds to a global warming hiatus and matches similar findings around the world.

6.3 Analyse the gap areas

The Gap areas can be analysed as follows:

6.3.1. Monitoring of the phenomena

Active ground-based and satellite based remote sensing observations are a critical part of real time monitoring of severe weather.

The measurement of atmospheric variables is needed to accurately measure the heat transport, cloud genesis and its growth and decay, locating probable regions of wind discontinuities, regions with meso-scale convergence in the lower levels, regions with increasing or decreasing vertical wind shear, and other atmospheric events. Some of the fundamental atmospheric variables that can be retrieved and monitored by active sensors include vapor and liquid water content, wind vectors, cloud cover, rainfall rate, precipitation type, and ice cloud content.

Weather radars are used to remotely observe precipitation, locating probable regions of wind discontinuities, regions with meso-scale convergence in the lower levels, hail regions etc. Almost all modern weather radars have Doppler capability, allowing for an estimate of radial velocity in addition to the backscattered intensity. Furthermore, recent improvements to operational robustness have made dual-polarization weather radars more commonplace. **Cloud radar** may be used to observe non-precipitating clouds, which are made up of extremely small droplets. **Wind profiling radars** (also known as MST radars) and **microwave radiometers**, were conceived as a technology to provide wind, temperature and moisture profiles in the upper atmosphere with a much better temporal resolution than **radiosondes. Multifunction Phased Array** Radar is another new technology that may replace the band specific aging current radar infrastructure with phased-array radar technology. Significant advantages would be gained through such a concept, including rapid-update weather observations that are fundamentally important for mitigating severe weather. From an economic standpoint, an advanced radar network with a common design, replacing several systems with distinct parts, maintenance procedures, etc., would inherently have much lower maintenance and operation costs.

Radar remote sensing instruments operating from **Satellites (geostationary and polar orbiting**) are particularly effective in the observation of precipitation, clouds, and near-surface winds over the ocean, providing invaluable data of environmental parameters that are vital for a wide variety of scientific, commercial, and military applications and that enhance our ability to protect human life and property. Active sensors can provide measurements day or night, independent of solar illumination. Furthermore, because the microwave spectrum offers a wide range of penetration depths, the use of multiple-frequency observations can provide three-dimensional (3D) information about the microphysical properties of clouds and rain.

Dense network of **Automatic Weather stations** is another aspect that can help provide detailed ground observations of convection over a region.

Having a storm **Drone or Weather Aircraft** observations flying through different parts of the atmosphere gathering data will enable meteorologists to predict weather conditions for the coming days. This is very important especially in areas where frequent violent storms occur.

The Ministry of Earth Sciences and the Indian Space Research Organization are the nodal agencies of Government of India to monitor and record the observations.

6.3.2 Analysis of observations and Generation of Forecasts

A **suitable visualization platform** is necessary to combine all the above information to reach an informed decision about the weather. The platform should have the following:

Visualization of basic parameters (u,v,q,t) and derived 1D to 3D parameters:

(i) 2D depiction in the form of surface & upper-level maps, cross section charts, vertical profiles, meteorological symbols and diagrams.

(ii) Animation, meteograms and time-section charts, Hovmoeller diagram, Vertical cut, overlay of time steps, wind barbs, streamlines, trajectories/path lines.

(iii) Time evolution and uncertainty (spaghettis, probabilities) of convective storms

(iv) Comparison & fusion of heterogeneous data including Side-by-side depiction, overlay, regridding to common grid, differencePlots between model observation and radar and satellite plots, depiction of model data as observations e.g., synthetic satellite images

(v) Analysis of uncertainty in simulations including 2D depiction: stamp maps, spaghetti plots of contour lines and features, ensemble mean and standard deviation, ensemble probabilities, extreme forecast index, clustering, ensemble meteograms

(vi) Operational meteorological workstations support including interactive 2D visualization (e.g., pan, zoom, map styling), manual weather contour drawing, Contour filling, overlay of warning symbols and ASCII characters, computation of distance, area, eccentricity, orientation, major axis and minor axis length, highest parameter value in a chosen area.

(vii) Creation of 2-d "Decision tree" plots, parameter combination-based plots, threshold at multiple levels (Look Up Table) and plotting.

(viii) Overlay on Bhuvan map, Google map, physical geography map and IMD subdivision, state, district, block/village maps.

(ix) Map projection for display: Satellite, Transverse Mercator, Polar stereographic, Cartesian.

(x) Satellite multichannel combination display, radar, model and lightning data overlay on satellite data.

(xi) Skew-T and Tephigram

(xii) Total Precipitable Water, Reflectivity at -10 deg C level from NWP models.

(xiii) Macro creation facility, Autocreation and Autosaving facility for various products, GUI based interaction.

(xiv) Ensemble Forecasts: Boxplot, Barplot, Probabilities of exceeding warning thresholds, Probabilities of warning thresholds relative to climatology at a point value, exceedence probability 2D map, Risk factor 2-d map.

(xv) Overlay of multiple satellite, IPWV, lightning, Cloud Top Brightness Temperature, model and radar products and visualization in 2D and 3D format.

(xvi) Route Forecasts and Nowcasts: Roadways, Train routes, Power transmission lines, Pilgrim routes, Sports routes

(xvii) Area specific Decision tree creation facility for automatic generation of warnings for Hail, Squall line, Lightning, Heavy rain, and their automatic representation in 2-D map.

(xviii) Automatic generation of Warnings

6.3.3 Modelling of the phenomena

The availability of high speed data networks and high power capacity computers, recently NWP based, a High Resolution Rapid Refresh (HRRR) system are also being employed for preparing short range weather forecasts. The HRRR is a high resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized with 2km radar assimilation. Radar data is assimilated in the HRRR every 15 min over a 1-h period adding further detail to that provided by the hourly data assimilation from the 2km radar-enhanced Rapid Refresh. Its key features are:

- improved cloud representation for boundary-top clouds, especially for shallow cold-air layers with cold-air retention
- better cloud bands
- improved storm prediction for 1-12h

The outlooks are generally prepared by employing NWP models (Global or Meso-scale models). High-resolution models can provide unique and valuable information about severe thunderstorm forecasts. But they require to be fine-tuned to local conditions by studying sensitivity to microphysical schemes etc. Two meso-scale systems are now used routinely in India one is based on WRF (at IITM and IMD) and the other UM model (NCUM at NCMRWF). These systems are required to be modified to represent Indian conditions more realistically and that can be achieved by planning proper verification and validation.

Another technique being developed is the concept of "ensemble forecasting." Instead of using just one deterministic model, a good number of ensemble models are employed for forecasting. The Global Ensemble Forecast System with approximately 12.5km resolution (GEFS T1534) is run by IMD with 20 ensemble members and 1 control run. The model is run every day operationally with 00UTC initial conditions provided by NCMRWF and forecast of 10 days with 3hour interval is created. By utilizing the GEFS model output, following probability indices are developed for thunderstorm prediction over Indian Region at IITM. These probability methods are found to be very useful and forecasters need to be trained for using these probability forecasts.

To progress to finer resolution (cloud resolving scale) of weather forecasting, **computational resources and storage needs to be regularly augmented**. In this regard, **cloud-based computing and storage** needs to be integrated into the forecasting system.

6.3.4 Early warning of the phenomena

Evolutions of electrical, microphysical and dynamic characteristics in a thunder cloud occur almost simultaneously and influence each other. In the recent years many laboratory and field experiments have confirmed that a robust relationship exists between lightning flash characteristics and thunderstorm dynamics and microphysical parameters. Therefore, lightning information can be used in meteorological applications such as warning of severe weather.

The lightning detection network can be used effectively to monitor the evolution and movement of thunderstorm on real time, and lightning flash rate characteristics can be used for predication/warning of severe weather. Over India a lightning detection network with 83 sensors have been established. This network can monitor the movement of thunderstorm and can generate the lightning warning about 30 minutes in advance.

Many studies have demonstrated that the precipitation rate at mixed phase region of cloud plays important role in cloud electrification. The vertical extend of the convective cloud shows good correlation with lightning flash rate. It has been observed that the lightning flash rate increases dramatically with cloud top height which can be measured by radar. Therefore, Radar can be used to generate early warning about lightning and severe weather. IMD is generating early warning (nowcast) of severe weather and lightning for every 3 hours using radar, satellite and lightning network data.

6.3.5 Technology for disaster observation, Hazard analysis and mitigation

Seasonally, 57% of the lightning fatalities occurred in the monsoon season (June–September), followed by 31% in summer or pre-monsoon (March–May), whereas post-monsoon (October–November) and winter (December–February) accounted for relatively smaller number of fatalities. There is a discernible gender variation in lightning fatalities in India. (Far more males (89%) than females (5%) have been killed by lightning flashes in India). Remarkably, male and female fatality ratio indicates that males are killed 18 times more frequently than females. The high ratio of males to females reveals relatively higher work participation by males in traditional tasks, greater exposure to outdoor activities, labour-intensive practices such as agriculture (ploughing, cattle herding), construction work, and re-creation. For Hazard analysis, it is necessary for weather forecasters, disaster managers and town &country planners to have an accurate long term detailed report of occurrence of severe weather and the effects. Towards this end, a lot of efforts are already in place by various Government and private organizations. It is essential to coordinate these efforts and create a long term country wide unified database and maintenance of the same for severe weather and its effect at village level. For this purpose crowd sourcing of observations from the public also has to be integrated with all other information into the database. The Countrywide database developed from all this data will go a long way in developing and enhancing climate/weather models,aswell as Hazard modelling. These can then be used to evaluate risk management options and develop preparedness plans, thereby reducing the risks of disasters. By incorporating knowledge about projected climate changes, we can enhance our mitigation/adaptation/response and help make informed decisions to reduce vulnerability to extreme weather events.

6.3.6 Location specific risk-based warning generation and Dissemination

The current arrangement of dissemination of Alerts though effective is not efficient. In the absence of timely geo targeted alerts in regional vernacular languages, the lead time available to the likely vulnerable citizens and responders may be less. The present arrangement does not offer a common dashboard to disaster managers to peruse, amend, translate in regional, vernacular language, choose media of dissemination and finally approve the alert to be disseminated with minimum manual intervention.

Most of the advanced countries have adopted a Common Alert Protocol (CAP) based Alerting System. CAP defines a standard message format which contains all the relevant details like type of Hazard, its intensity, duration, area of impact, actions to be taken etc. In addition to implementing standardization and inter workability across the world, CAP messages also enable efficient routing, prioritization, geo targeting etc. CAP compliant systems and devices like the GSM network, Radio, Television, public PA systems, and highway Signage etc can plug and play with a CAP based alerting system. Non-compliant and vintage systems and devices can also be interfaced by a suitable interoperability converting device.

Actions taken to address these problems:

NDMA conceived a National Project to integrate the Alert Generating Agencies, Alert Disseminating Agencies and the Disaster Management Authorities on a CAP based platform. After a successful Pilot Project implemented in Tamil Nadu, Pan India implementation of Phase I of the CAP Project has been sanctioned by the Government. The Project will automate flow of Alerts between Stake Holders which are as under: -

- Alert Generating Agencies for all types of Thunderstorm and related Hazards is Ministry of Earth Sciences (India Meteorological Department (IMD) and Indian Institute of Tropical Meteorology).
- Alert Approving Agencies: Disaster Management authorities at the National level (MHA) and State Level (SDMA), as applicable to the alert will be the approving authorities for dissemination of alerts.
- Alert Disseminating Agencies.Geo targeted Alerts in vernacular will be disseminated by following means:-
    - (i) SMS and cell broadcast (CB) over mobile phones.
    - (ii) Broadcast media like Television, Cable TV, Satellite TV (DTH) and Radio Stations
    - (iii) Over Internet on social media, browser alerts and software applications.
    - (iv) Public address systems on railway stations.
    - (v) Coastal sirens and other legacy community warning systems.
    - (vi) GAGAN and NavI-C satellite channels

6.4 Analysis of Gap Areas

The Gap areas in Dissemination of Alerts have been largely covered by the initiative of NDMA. However, there are still some Gap Areas which need to be addressed: -

(A1) **Penetration of Terrestrial GSM/Telecom Network:** Penetration of GSM / Telecom networks is driven by commercial constraints. There are still a large number of sparsely populated regions which have poor/no GSM/Telecom network.

(B1) **Resilience of Telecom infrastructure to Natural Disasters:** Communication infrastructure is susceptible to damage by the natural disaster. This severely effects dissemination of subsidiary Alerts/instructions and relief and rescue activities.

(C1) Dissemination of Alerts over Satellite Media: Satellite communication offers most resilient means of dissemination of Alerts and DM communications. Prohibitive cost of Satellite terminals, satellite bandwidth and Licensing costs have restricted use of Satellite communication for dissemination of Alerts.

(D1) **Integration with social media**: social media which is widely subscribed by the masses can play a very important role in dissemination of Alerts. Platforms like Face Book, Twitter, WhatsApp, Instagram etc are owned by foreign companies which are reluctant to integrate with the CAP Alerting Platform being deployed by NDMA.

(E1) Compliance **by Telecom Service Providers (TSPs):** TSPs are bound to abide by the DM SOP of DOT. However, as experienced it has been found that they are reluctant to invoke certain functionality, namely ‘Cell Broadcast’ (CB) on the pretext that it would incur capital investment.

6.5. Summary

(i) Improvement of observation technology and increasing their density over the Indian region as highlighted in Section 10.3.1 above.

(ii) Improvement of Visualization platform as highlighted in Section 10.3.2 above.

(iii) Improvement of computational resources and storage as well as cloud-based computing and storage as highlighted in Section 10.3.3 above.

(iv) Creation of a Long term Countrywide Unified database for reports of severe weather and its impact information from various government and non-government agencies and general public as highlighted in Section 10.3.5 above.

(v) Lacunae in the current warning generation and dissemination procedure and recommendations for their improvement as highlighted in Section 10.3.6.

Section 7 Heat Wave and Cold Wave

7.1 Introduction

The heat waves, periods of sustained high temperature and high humidity, have long been recognized as a significant weather hazard. An abnormal heat resulting from the increase of temperature can impose severe physiological stress and can adversely affect the life, health and well-being of human society. If along with high temperatures, the humidity is also high then it compounds the effect of heat wave. The temperatures are dependent on the geographical region and time of the year. Heat wave generally occurs during summer months from March to July. As per India Meteorological Department (IMD), heat wave considered when actual maximum temperature ≥ 40°C for plains, ≥ 37°C for coastal stations and ≥ 30°C for Hilly regions. Heat wave and severe heat wave is considered a positive departure from normal i.e., 4.5°C to 6.4°C and more than 6.4°C respectively. The maximum temperature of ≥ 45°C and ≥ 47°C for plains is considered a heat wave and severe heat wave respectively. Warm night is also considered, when maximum temperature is 40.0°C or more, when is there is positive departure from normal of minimum temperature between 4.5°C to 6.4°C and if the positive departure is more than 6.4°C, then it is called severe warm night.

The duration of the heat wave is in general 5 to 6 days but sometimes it may go up to 10 days or more. However, severe heat wave generally does not last for more than a day or two outside Jharkhand, where it may persist for as much as 4 to 5 days. Maximum frequency of heat waves over most of the states is found to be in the month of May. However, the number of heat waves over Bihar, Rajasthan and Uttar Pradesh (UP) is more during the month of June compared to other months. The causalities due to heat waves are more over the regions where the normal maximum temperature itself is more than 40°C.

Similar to the heat wave during summer the country also suffers from severe winter & associated cold wave because of low minimum temperature. Cold wave is one of the extreme weather events that prominently occur during the winter season of India (November to February). It is a condition of air temperature which becomes fatal to human body when exposed. The precise criterion for a cold wave is determined by the rate at which the temperature falls. Like the humidity in the heat wave case, the dry wind speed in case of cold wave further compounds the effect of cold wave.

In general, cold wave is distinguished by a sharp fall of air temperature near the surface, leading to extremely low values, rise of pressure, and strengthening of wind speed, or associated with hazardous weather like frost and icing. Many parts of northern & central India generally experience cold wave conditions during winter months. It is distinguished by a marked cooling of the air, or with the invasion of very cold air, over a large area. The northern parts of India especially the hilly regions and the adjoining plains are influenced by passing Western disturbances in the mid-latitude westerlies.

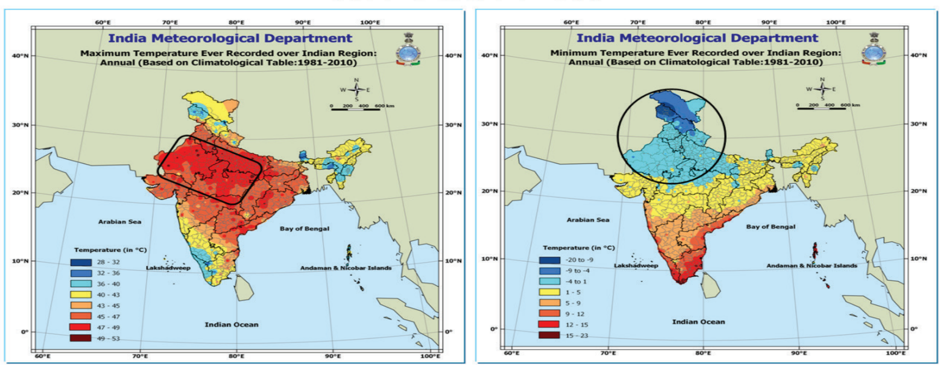
As per the definition of IMD, cold wave is considered, when the minimum temperature of a station is 10°C or less for plains and 0°C or less for Hilly regions. Cold wave and severe cold wave are considered when a negative departure from normal i.e. 4.5°C to 6.4°C and more than

6.4°C respectively. The minimum temperatures of ≤ 04°C and ≤ 02°C for plains is considered as cold wave and severe cold wave respectively.

IMD has a big network of surface observatories covering entire country to measure various metrological parameters like Temperature, Relative humidity, pressure, wind speed & direction etc. Based on daily maximum and minimum temperatures data, climatology of maximum and minimum temperature is prepared for the period 1981-2010 to find out normal maximum and minimum temperature of the day for particular station. Thereafter, IMD declared heat/cold wave or warm night/cold day over the region as per its definition.

In general, high temperature are observed over Rajasthan, south Haryana, Uttar Pradesh, Bihar, Madhya Pradesh and Vidharbha and low temperatures over northwest & adjoining central India as shown in the following figures.

Introduction



- The high temperature are observed over Rajasthan, south Haryana, Uttar Pradesh, Bihar, Madhya Pradesh and Vidharbha and low temperatures over northwest & adjoining central India .

7.2 Possible impact of the disaster in the future:

According to the climate change report published by MoES, the frequency & intensity of heat wave is likely to increase with different climate change projections.

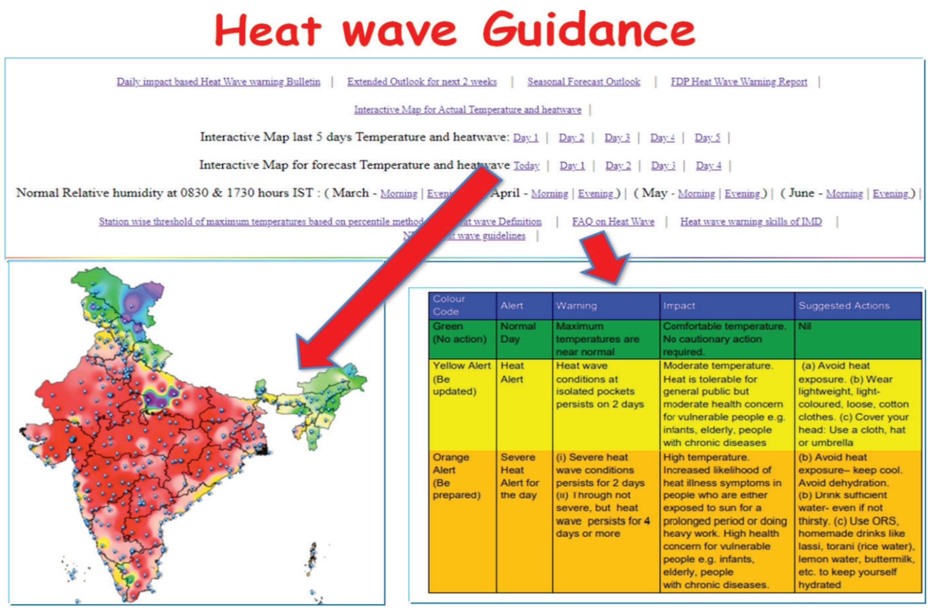
As per IPCC report, the cold-waves continue to be a problem in northern latitudes, where very low temperatures can be reached in a few hours and extend over long periods. The temperature may drop both during the day as well as night.

Sudden rise in temperature in summer can cause various health problems to the people who are exposed to direct sunlight. Heat wave may seriously impact the society with an increased strain on power, water and transport systems. Rise in temperatures may lead to water shortages and increased stress for plants, particularly in arid regions. This has the effect of reducing plant growth. Similarly, the severe winter also can cause health problem for elderly people, children going to school and various operations.

Thus, there is a need for the monitoring as well as forecasting of the same, which will be very beneficial for general public, children and also for other users. This has also got vast commercial applications to various sectors like Aviation, Power, Industries and Agriculture etc

7.3 Current status of heat wave and cold wave management

IMD prepares a detailed heat wave warnings bulletin during 1st March to 30th June which includes past Tmax, Tmin & their departures, observed heat wave, Temperature & Humidity & its 24 hours change and **impact based colour coded forecast & warning of heat wave for next 5 days along with suggested actions as per NDMA guidelines**. Another bulletin is issued at 0800 hours IST, which include heat wave warning for the same day. Extended range (upto two weeks) outlook for heat wave is also issued every Thursday. The Warnings are disseminated to different users like, MHA, NDMA, SDMA, CS of states, DC/DM of different districts of states, health department, Indian Railway, Road transport, Media etc. All the information is available in India Meteorological Department Website (https://mausam.imd.gov.in/).



Colour Code	Alert	Warning	Impact	Suggested Actions
Green (No action)	Normal Day	Maximum temperatures are near normal	Comfortable temperature. No cautionary action required.	Nil
Yellow Alert (Be updated)	Heat Alert	Heat wave conditions at isolated pockets persists on 2 days	Moderate temperature. Heat is tolerable for general public but moderate health concern for vulnerable people e.g. infants, elderly, people with chronic diseases	(a) Avoid heat exposure. (b) Wear lightweight, light-coloured, loose, cotton clothes. (c) Cover your head: Use a cloth, hat or umbrella
Orange Alert (Be prepared)	Severe Heat Alert for the day	(i) Severe heat wave conditions persists for 2 days (ii) Through not severe, but heat wave persists for 4 days or more	High temperature. Increased likelihood of heat illness symptoms in people who are either exposed to sun for a prolonged period or doing heavy work. High health concern for vulnerable people e.g. infants, elderly, people with chronic diseases.	(b) Avoid heat exposure– keep cool. Avoid dehydration. (b) Drink sufficient water- even if not thirsty. (c) Use ORS, homemade drinks like lassi, torani (rice water), lemon water, buttermilk, etc. to keep yourself hydrated

The IMD's multi-institutional initiative for cold wave / cold day monitoring and forecasting was introduced in 2016 in collaboration with NCMRWF, IITM, ISRO, and IAF. Presently IMD issues Seasonal Outlook: 1-3 months ahead for sub-divisional level; Extended Range Outlook: 15 days ahead for sub-divisional level; Watch: 5 days ahead for the district and Sub-Divisional level; Alert: 3 days ahead for sub-divisional and district level and Warning: 2 days ahead for the district, block and local level. Various numerical prediction models and techniques are used to arrive at these alerts like IMD GFS, WRF, NCMRWF NCUM, NCUM-R, GEFS, UMEPS, and various international models. The forecasting methods take into consideration various meteorological conditions like the past 24 hrs observed weather (RH, Tmin wind, and its tendency & departure from normal). Several causative weather systems including Troughs, Ridges, Cyclonic Circulation (CC) and anti-CC, Jet stream, low-pressure systems, and high pressure systems and dynamical parameters like divergence, convergence, and vorticity at different levels, lower & upper-level winds are taken into account before issuing forecast and warnings. Like heat wave, IMD issued an extended range forecast of Cold Wave every Thursday and valid for next 4 weeks. The extended range forecast is presently accurate with standardization over the last decade and can predict temperature changes up to 2 weeks with very good accuracy. The cold wave warnings are provided for various sectors including health, energy, water resource, disaster management and agriculture. The operational Agro-meteorological Services of IMD issues advisories under the Gramin Krishi Mausam Seva in collaboration with Ministry of Agriculture on cold waves/ frost to save cereal crops (eg. wheat), cash crops (eg. cotton), oilseeds (e.g. mustard), vegetables (e.g. potato, tomato), horticultural crops (grapes), livestock and poultry. Heat wave action plans are prepared by NDMA in collaboration with SDMAs, IMD and various stakeholders including city municipal corporation etc. Heat wave action plans are prepared for districts and cities. Similarly, cold wave action plans are being developed for districts and cities by NDMA.

7.4 Gap areas

Presently IMD gives heat wave/cold wave warnings based on departure from the normal and threshold based temperature as mentioned in introduction part. As heat wave have serious health impact particularly elderly and the people with pre-existing health problems and those who are economically challenged are most vulnerable and their vulnerability depends on the degree of exposure. Apart from vulnerable groups in cities & villages, the workers working outdoor (traffic police, street vendors etc.) and in closed environment (miners, industrial workers) face substantial risk to heat stress during extreme heat wave days. Specific action is needed for above mentioned vulnerable groups.

Impact of heat wave on human health is further exacerbated by increase in minimum temperature, humidity and wind speed. Hence it is very important to consider humidity and wind speed & direction to issue the impact based warning for heat wave. Also, whenever there is heat wave over region for continuous 4-5 days, the impact of the heat wave become more severe on human health as well as on agriculture.

Similarly, wind chill further exacerbated the impact of cold wave on human health due to its effect on the evaporation speed of the moisture from the skin. Higher the dry wind faster is the cooling of the skin which makes the surrounding air felt colder than it actually is. Hence there is need to consider the wind along with cold warning for issuing impact of the cold wave.

Heat wave impacts on the human health are more in the urban areas being more vulnerable due to the urban heat island (UHI) effect and population density. Many factors like pollution, changing climate, slump, lifestyle and city geography as well as geometry increase UHI intensity. It is caused by a combination of more heat absorbing surfaces like rooftops, buildings, the trapped hot air between buildings, limited tree cover etc. It can result in rise in temperatures in urban areas by about 1 to 3°C hotter as compared to surrounding areas.

Apart from impact on human health especially, the heat wave has also been found to profoundly affect agriculture production both in terms of quantity & quality. Agriculture production is dependent on temperatures and weather. Accumulated temperature directly influences the productivity of agricultural plants. Primarily, crop loss is encountered due to flower drop and higher mortality in new plantations. Kharif crops are more impacted than Rabi crops owing to variability in rainfall associated with Heat Wave.

As heat waves becoming more frequent & intense, there is threat on the dependability and effectiveness of the electricity systems. High temperatures have adverse effects on electricity generation, transmission, distribution and demand. The increased temperatures cause people to increase the use of their air-conditioning. This increased use, requires a greater amount of electricity and creates a strain on the transmission lines. Hence, it is important to consider the impact of heat wave in energy sector.

The cold waves affect health, agriculture and infrastructure in India. Some of the impacts of the cold waves include detrimental effects on the health of human beings. An unexpected cold wave can cause frostbites, hypothermia, or other serious medical ailments. A lot of damage is caused to agriculture, animal husbandry and wildlife. The damage to infrastructure is well evident e.g. damage when water pipelines freeze and burst. The impact on the energy sector is well marked with a rise in the demand for fuels and electricity.

7.5 Summary and recommendations

(i) To consider minimum temperature, humidity and wind speed & direction to issue the impact based warning for heat wave.

(ii) Need to consider UHI effect while issuing the impact based heat wave warnings.

(iii) There is need of issuing special impact of heat wave on agriculture, animal husbandry, wildlife and energy sector.

(iv) To consider the wind & humidity for issuing impact of the cold wave.

(v) To issue the impact based cold wave warnings for agriculture, animal husbandry, wildlife and energy sector.

Still, there are gaps in technology vis-à-vis capability. The scientific gaps in understanding meteorological phenomenon in Indian region especially due to lack of data in West Asia needs to be addressed through better international collaboration. The observational and modelling systems over the Himalayan Region have gaps, IMD should take every step to fine-tune models to improve in forecast skills. Similarly, Common Alert Protocol should be developed for warning dissemination to last mile in friendly and actionable manner.

Section 8 Global Warming and related impact on agriculture, health and diseases etc

8.1 Objectives

To identify scientific research and technology solutions related to global warming triggered impacts on agriculture, health and diseases, that need to be developed

8.2 Background

There is robust scientific evidence that human activities since pre-industrial times have altered the global climate, resulting in an increase of the global average temperature of the Earth by around 1°C since the mid-19th century (IPCC AR5, 2013, MoES, 2020). The human-caused global warming has affected different regions of the world and is projected to continue during the 21st century and beyond. The Indian subcontinent and the adjoining oceanic and mountain regions have also experienced the influence of global warming and climate change. A brief summary of global warming and regional climate change is presented below.

8.2.1 Global Warming and Climate Change

The global average temperature of the Earth has risen by around 1°C since pre-industrial times. There is unequivocal evidence that this magnitude and rate of warming cannot be explained by natural variations alone and must necessarily take into account changes due to human activities. Emissions of greenhouse gases (GHGs), aerosols and changes in land use and land cover (LULC) during the industrial period have substantially altered the atmospheric composition, and consequently the planetary energy balance, and are thus primarily responsible for the present-day climate change.

Warming since the 1950s has already contributed to a significant increase in weather and climate extremes globally (e.g., heat waves, droughts, heavy precipitation, and severe cyclones), changes in precipitation and wind patterns, global and regional monsoons, warming and acidification of the global oceans, melting of sea ice and glaciers, rising sea levels, and changes in marine and terrestrial ecosystems.

Climate models project that global warming will exceed 3°C by the end of the century. However, temperature rise will not be uniform across the planet; some parts of the world will experience greater warming than the global average. Such large changes in temperature will greatly accelerate other changes that are already underway in the climate system, such as the changing patterns of rainfall and increasing temperature extremes (IPCC AR5, 2013, MoES, 2020).

8.2.2 Climate Change over the Indian Region

Human-induced climate change has already manifested over the Indian region (MoES, 2020). The annual mean near-surface air temperature over India has warmed by around 0.7 °C during 1901–2018, with the post-1950 trends attributable largely to anthropogenic activities. The frequency of warm extremes over India has increased during 1951–2015, with accelerated warming trends during the recent 30 year period 1986–2015 (MoES, 2020).

Warming due to increasing GHGs and moisture content is generally expected to strengthen the Indian monsoon. Yet, observed data show a declining trend in summer monsoon precipitation since 1950, with particularly notable decreases in parts of the Indo-Gangetic plains and the Western Ghats. There is medium confidence that northern hemispheric (NH) anthropogenic aerosol forcing has offset the precipitation enhancing tendency of GHG warming in the past 6–7 decades. On the other hand, the frequency of localized heavy precipitation occurrences has risen significantly over Central India in the past 6–7 decades in response to global warming (MoES, 2020).

Additionally, the Indian region and adjoining oceanic areas have witnessed an increase in the intensity of severe cyclones and rising sea levels since the mid-20th century. There is compelling scientific evidence that human activities have influenced these changes in regional climate (MoES, 2020).

The 21st century projections of climate change over the Indian region indicate that the mean temperature rise over India is projected to be in the range of 2.4–4.4 °C by the end of the 21st century across different scenarios relative to the average temperature over 1976–2005. While noting that the RCP8.5 is an extreme scenario which projects a temperature rise of about 4.4 °C by the end of the 21st century, the projections under RCP4.5, which is a moderate emission scenario, indicate a temperature rise of about 2.4 °C by end of the 21st century (MoES, 2020).

There is high confidence that the frequency and intensity of warm days and warm nights are projected to increase over India in the next decades, while that of cold days and cold nights will decrease. There is high confidence that the pre-monsoon season heat wave frequency, duration, intensity and areal coverage over India are projected to substantially increase during the 21st century.

With continued global warming and anticipated reductions in NH aerosol emissions, the 21st century projections indicate intensification of mean and extreme precipitation, with increased interannual variability.

Human-induced climate change is expected to continue apace during the twenty-first century (MoES, 2020). The rapid changes in India's climate projected by climate models will place increasing stress on the country's natural ecosystems, agricultural output, and freshwater resources, while also causing escalating damage to infrastructure. These portend serious consequences for the country's biodiversity, food, water and energy security, and public health (MoES, 2020, Chapter 12).

This report provides a brief assessment of the impacts of global warming and climate change related disruptions on agriculture, health and diseasesover India and also highlights the role of technological preparedness and solutions to deal with the coastal impacts of global warming and related National disruptions.

8.3 Impacts of Weather and Climate Related Disruptions on Agriculture, Health and Diseases,

8.3.1 Agriculture

Globally, natural disasters caused a loss of about $96 billion between 2005 and 2015 due to damaged or lost crop and livestock production in developing countries and half of that damage occurred in Asia (Food and Agriculture Organization, 2018). Indian agriculture is particularly affected by the climatic stresses and the frequency and intensity of climatic risks are increasing putting farm income at risk. For instance, in 2018 unseasonal rains in February affected the crops in large areas. A powerful storm with damaging hailstorm over parts of central and southern India destroying more than 1.25 lakh hectares of crops apart from killing several people. This damaged crops in Buldhana, Amravati and Jalna and in nine districts of central and northern Madhya Pradesh, particularly in Sehore, Raisen, Bhopal and Dewas district. The unseasonal rains also affected Coffee in Karnataka. Similarly, in June 2019, the extreme high temperatures affected many parts of the country. In 2019, by the end of May 43% of India was experiencing drought. The country has seen widespread drought every year since 2015, with the exception of 2017.

India had suffered causalities of human as well as cattle due to extreme climate events. Heavy monsoon rains in 2018, 2019 and 2020, highest in 100 years in Kerala, and floods caused widespread devastation. Between 1953 and 2017, India suffered damages worth Rs 3,78,247.047 crore due to floods and heavy rains. Besides this, 1,07,535 people were killed, a total of 8,07,17,993 houses were destroyed and an area of 466.335 million hectares was affected. The overall damage to crops is estimated to be Rs 1,11,225.621 crore (nearly 30 per cent of the total damages) and 60,49,349 cattle dead. (Central Water Commission Report, 2017). Between 1953 and 1982, the loss suffered due to damaged crop was the biggest contributor to India's flood-related losses. But from the 1980s onwards, when the share of loss due to damaged crop was overtaken by the loss due to damages of public property. Between 1983 and 1992, India's loss due to damaged crop in floods was Rs 11,773.37 crore.

Such numerous examples exist not only for large areas but even for individual farmer's level, depending on the geographical position of his farm, availability of water, drainage facilities, crop and management practices. Hence every season, some portion of farmers get affected despite increase in production and productivity at macro-level, warranting more research to understand impacts, develop forewarning and adaptation technologies and strategies, and their deployment to minimize the climatic risks in farm sector.

These climatic risks in ensuing climate change scenarios is projected further increase in intensity and frequency. Without adaptation, climate change is projected to affect the productivity of wheat (~9%), irrigated rice (~12%), maize (~18%), potato (~13 %) and other major crops by 2040 under RCP 4.5 scenarios. Similarly, yield of horticultural crops is projected to be affected due to climatic risks. Climate change is projected to also affect the productivity of milk due to increased heat stress on livestock, poultry mortality due to heat waves. In addition, the frequency of pest outbreaks has been increasing. Though numerous examples exist, recently fall army worm affected several crops such as maize, paddy and sugarcane in Karnataka, western Maharashtra and Gujarat, and eastern states in 2018 and 2019.

All above indicate that the climatic risks to Indian agriculture have been ever increasing. A robust weather forecast led agricultural management is thus very important to minimize the climatic risk related losses to farmers.

8.3.2. Health

Weather and climate change are known to affect human and Animal health in several ways hence need to be handled under ONE HEALTH approach. Climate change is projected to have three main consequences viz. increase/decrease in temperature, erratic rainfall and sea level rise. The direct effect of temperature on human health is in terms of heat wave, hyperthermia, mortality, skin & eye diseases and disasters causing loss of life and public health infrastructure. In recent years unexpected floods have caused huge loss of life and infrastructure hampering public health interventions. Water borne diseases are likely to exacerbate due to floods. Owing to air pollution (increase in PM2.5 particles and allergens in air) respiratory diseases like Chronic Obstructive Pulmonary Disease and asthma etc. are likely to flare up. Similarly, unexpected floods also cause sudden outburst of a number of animal diseases already covered in NDMA policy documents.

The most adverse impacts of climate change have been studied on Vector Borne Diseases (VBD) which is transmitted by cold blooded arthropods or insects. Malaria has been projected to have new foci in some parts of Himalayan region, increase in intensity in northeastern parts while even reduction in some parts of Andhra Pradesh and Odisha (Dhiman et al 2011; Sarkar et al 2019). Since 2009, the outbreaks of dengue are being witnessed in Uttarakhand and Himachal Pradesh.In animal and birds, sero-evidence or emergence and reemergence of new diseases, some of which are of zoonotic importance includes Birdflu (Dubey et al 2009), Swine influenza (Dubey et al 2009), West Nile fever (Mishra et al 2012), Crimean-Congo Hemorrhagic Fever (CCHF), Nipah virus, (NIHSAD Annual report 2020) and Zika virus etc. Birdflu virus that affects mainly poultry but also causes high mortality in other birds mainly Crows (common scavenger) hence may lead to environmental imbalance (Nagarajan et al 2010; Kumar et al 2020).

In addition to risk due to climatic conditions, the knowledge of vulnerability of population/ communities is also vital. Some areas like Punjab and Kerala, in spite of having climate suitability for transmission of several VBDs, have very low burden of VBDs basically due to better socio-economic conditions and public health system. Therefore, the knowledge of adaptive capacity of communities and assessment of health systems is also necessary before planning intervention measures.

8.3.3. Diseases

Indian Council of Agriculture Research (ICAR) through Indian Veterinary Research Institute (IVRI) established a BSL 4 lab at Bhopal "High Security Animal Disease Laboratory" (nowNational Institute of High Security Animal Diseases (ICAR-NIHSAD) that was dedicated to nation in the year 2000. Since then the lab has been working 24X7. However, the 2006 Bird flu outbreak have given us an insight into our capacities and preparedness regarding management of the emerging and re-emerging exotic diseases of livestock most of which are of public health importance. ICMR new BSL 4 lab at National Institute of Virology (NIV) Pune (Pashan campus) was perhaps the outcome of the insight emerged after outburst of HPAI H5N1 in India. Contribution of both the institutions is well known

8.4 Technological preparedness and solutions (existing, gaps and future requirement) For Risk Management

Predictions of extreme precipitation events and associated floodingis a scientifically challenging issue and a key gap area. For example, Kerala witnessed a record 100-year flooding due to extremely heavy rainfall (50 - 480 mm per day) during 1-19 August 2018 (Vishwanadapalli et al. 2019). Likewise, the state again witnessed extremely heavy rains during August 2019, having standard deviations of at least 30-50 times of the climatological standard deviation (Mukhopadhyay et al. 2021). State-of-the-art weather prediction models, even at very high resolutions e.g., grid size ~ 10 km, have difficulties in predicting such extremely heavy monsoon rainfall (Mukhopadhyay et al., 2021).

While heavy precipitation occurrences are projected to become more frequent under global warming, robust predictions of these events at smaller spatial scales is a key gap area. In addition to very high-resolution (grid size < 5 km) weather and climate models and use of ensemble prediction approaches, use of data-driven innovative techniques like Artificial Intelligence and Machine Learning (AI-ML) will be important for advancing the predictions of extreme rainfall events.

8.4.1 Gap areas and Technological Preparedness (Agriculture)

Another major gap area is related to the impacts of land-use and land-cover change, irrigation practices, urbanization on the regional climate, water resources and crop production. Observational datasets need to be enhanced and climate models need to be substantially improved.

Currently many agencies including ICAR-IMD collaborative weather based agro-advisories as well as private companies such as TCS (m-krishi), TCS-IARI collaborative Pusa m-krishi, etc are providing the weather based agro-advisories claiming success at various degrees. However, a lot further needs to be done in significantly improving the weather-based agro-advisories. The locust monitoring Institute is monitoring its incidences.

8.4.2 Gap areas and Technological Preparedness and future requirement For Risk Management:

Existing knowledge and gaps: In India, there is greater awareness about the adverse impacts of climate change on human health which can be judged by the introduction of 'Health' as an additional mission by the government of India in 2014, the nodal agency of which is National Centre for Disease Control (DGHS) at Delhi. Subsequently an expert committee drafted National Action Plan on Climate Change and Human, which is available at the website of NCDC(2016). In 2019, a National Programme on Climate Change and Human Health (NPCCHH) was established to expand the activities at district level throughout the country.

In last decade, there has been remarkable technological development to address the issue of climate change and human health in India. Heat Action Plans have been prepared for Ahmedabad (NRDC, 2019) and some other cities of India, which provide alerts to public in the form of yellow, orange and red colours. Impact assessment has been done for VBDs particularly malaria and dengue (Dhiman et al (2011), Sarkar et al (2019). The impact of air pollution on human health and even on Covid-19 has also been assessed Pant et al (2020)

Tools for detecting the signals of early warning of outbreaks of malaria and dengue have been developed (Lingala etal. (2020); Laneri et al 2010; Nizamuddin et al (2013); Cash et al (2013). India being a vast country requires action plans for larger part. The heat action plans are still required for several vulnerable cities. The dissemination of knowledge about vulnerability, preventive measures and 'when to take action' is needed at ground level. The action plans for Vector Borne Diseases (VBDs) should be at district level in terms of when and what is to be done to avert the adverse impacts.

8.5 Future requirement

- In 2017, the Technology Information, Forecasting and Assessment Council (TIFAC) of DST after rigorous consultations had identified new technologies required for health sector in view of climate change right from newer diagnostic tools, use of mobile technology in communication, data collection, dissemination of information, telemedicine, training and modelling using artificial intelligence and early warning system etc.
- In 2020, the Govt. of India also organized a summit of Vaishvik Bhartiya Vaigyanik Summit (VAIBHAV) during October 2020 and identified several health issues related with climate change.
- In view of vulnerability due to heat wave, heat action plan for all vulnerable districts should be developed.
- Collaborative research between research institutes under ICMR, National Vector Borne Disease Control Programme, local state government, NCDC, IMD and NPCCHH for piloting of implementation of tools of early warning of outbreaks of malaria and dengue should be encouraged.
- The knowledge of link between disasters and VBDs is still required for planning VBD specific pre-emptive measures.

8.5.1 Gap areas and Technological Preparedness (Disease)

NDMA prepared guidelines, cover both endemic and exotic diseases of the animals and their management at the time of disaster. For example, Action Plan (AP) for diseases like HPAI/ Birdflu was developed by ICAR- HSADL (now NIHSAD) /DAHD and being implemented faithfully since 2006, the first outbreak in MH & MP (Dubey et al 2009). Since then, the AP has been religiously followed at all the levels and hence the disease is still limited to birds (mostly poultry, ducks, crows etc) only.-Though, HPAI is well known for its zoonotic nature but in comparison to other countries of the World very recently only a single human case has been confirmed by ICMR-NIV Pune. NDMA has covered the topic under "Management of the Biological Disasters" with all most all the details. However, Bio-engineering infrastructure requirement in form ofBSL2+BSL4 integrated laboratory facility, with most modern facilities, is essential for the early detection and control of animal disease and hence need to be given top priority.

8.6 Agriculture

8.6.1 Monitoring & Observing

In this the inputs are given in two dimensional, spatial and temporal

a. Monitoring advent of the climatic stress such as drought, flood, etc. In US drought monitor exists. Similar system of drought, flood and other climatic stress monitors are required.

b. The hailstorms are becoming more frequent and hence they need to be observed for identifying hotspots and forecast systems need to be established.

c. Placing radars and other sensors/ monitoring systems, etc to cover hotspots for forewarning of climatic risks with respect to agriculture is required.

8.6.2 Data analysis, Modelling, post processing

a. Making availability of real time weather data for use in data analysis and modeling

b. Use of models developed for Indian conditions. InfoCrop v2.1-developed the Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi which can simulate the growth and yield of 11 crops under various management, soil and climatic conditions may be used to develop an online platform DSS by linking the seamless inflow of weather forecast into the model for providing the automated advisory to farmers and for use by different stakeholders. For this the IARI and IMD can develop a join project.

8.6.3 Warning, Advisories, Information dissemination & feedback

Reliable high-resolution weather forecast, feed-back based correction methods and dissemination of advisory are the needs. Seasonal forecast is important for optimizing agricultural decisions. Currently these are a very coarse resolution and research needs to be strengthened to increase the efficiency of seasonal forecast at high resolution i.e village level. Currently science not yet progressed to this level but there is need for concerted effort in this direction. Seasonal forecasts in combination with simulation models such as InfoCrop V2.1, a indigenously developed crop simulation model that can simulate the growth and yield of 11 crops, can become important decision support tool for the farmers and other stakeholders.

8.7 Technology advancement required in the following various aspects of agriculture activities;

8.7.1 Water availability and its use efficiency

There is an urgent need to evolve improved methodologies for Weather forecast based water management and for the develop new technology for rain water harvesting

8.7.2 Energy use efficiency

Solar, renewable energy-based farm machinery and adopt precision agriculture

8.7.3 Nutrient use efficiency

Precision agriculture and slow release fertilizers, delivery systems

8.7.4 Seed use efficiency

Enhancing availability of improved variety seeds, storage and delivery facilities

8.7.5 Agro-chemical use efficiency

Precision agriculture technologies and fore-warning based preventive usage of chemicals.

8.7.6 Soil health

increasing soil organic carbon by residue management, vermicomposting, etc

8.7.7 Trees harvesting and protection

Agro-forestry management for wood/pulp requirement

8.7.8 Post harvesting & post processing

Storage, threshing facilities to minimize post-harvest losses caused by heavy rainfall events.

8.7.9 Technology for fisherman

Weather forewarning for fishermen. Ex m-krishi fisheries (developed jointly by CMFRI, IARI and TCS and INCOIS) has been very successful in providing the farmers information on weather forecast and location of potential fishing zones for marine fishermen. This helped them a lot in Raigad district of MS. This is having a large potential but some concerns related to security issues need to be addressed.

8.7.10 Technology for diary sector

Seasonal forecast will help a lot in managing water and fodder. Also, the disease forecast for livestock, poultry and fisheries etc are very important.

8.8 Diseases

The exclusive facility to work on Exotic animal diseases was established by ICAR at Bhopal, MP. Since, the year 2000 the lab has been working 24X7and have confirmed entry of a number of foreign animal diseases. However, the 2006 Birdflu outbreak have given us an insight into our capacities and preparedness regarding management of the emerging and re-emerging exotic diseases of livestock and also the diseases of public health importance. New BSL 4 lab by ICMR at NIV Pune (Pashan campus) was perhaps the outcome of the insight emerged after outburst of HPAI H5N1 in India. Contributions of both the institutions are well known.

Section 9 Global Warming and impact on coastal region submersing Introduction

There is robust scientific evidence that human activities since pre-industrial times have altered the global climate, resulting in an increase of the global average temperature of the Earth by around 1°C since the mid-19th century (IPCC AR5, 2013, MoES, 2020). The human-caused global warming has affected different regions of the world and is projected to continue during the 21st century and beyond.

Warming since the 1950s has already contributed to a significant increase in weather and climate extremes globally (e.g., heat waves, droughts, heavy precipitation, and severe cyclones), changes in precipitation and wind patterns, global and regional monsoons, warming and acidification of the global oceans, melting of sea ice and glaciers, rising sea levels, and changes in marine and terrestrial ecosystems (IPCC AR5, 2013, MoES, 2020).

The global mean sea level (GMSL) has risen at a rate of about 1.7 (1.5 to 1.9) mm per year since 1901 and the rate of rise has accelerated to 3.3 mm per year since 1993 (Swapna et al., 2020). Sea-level rise (SLR) in the Indian Ocean is non-uniform and the rate of SLR in the North Indian Ocean is 1.06–1.75 mm per year from 1874 to 2004 and about 3.3 mm per year in the recent decades (1993–2015), which is comparable to the current rate of GMSL rise. Relative to 1986–2005, the GMSL is very likely to rise by ~26 cm by 2050 and ~53 cm by 2100 for a mid-range, mitigation scenario (Swapna et al., 2020).

Human-caused climate change has also led to substantial increases in heavy precipitation and flooding events over the Indian region since 1950, which are projected to increase in the future (MoES, 2020). Additionally, the frequency of post-monsoon extremely severe cyclonic storms (ESCS) has significantly risen over the North Indian Ocean (NIO) especially over Arabian Sea, despite an overall reduction in the annual TC activity over the NIO. With continued global warming, the activity of ESCS over the NIO is projected to further increase during the 21st century (MoES, 2020, KnutSon et al 2019, 2020).

Global warming and sea level rise are expected to continue apace during the twenty-first century (MoES, 2020). The rapid changes over the Indian subcontinent and adjoining Indian Ocean and mountainous regions will place increasing stress on the country's coastal areas, natural ecosystems, agricultural output, fishery and freshwater resources, while also causing escalating damage to infrastructure. These portend serious consequences for the country's biodiversity, food, water and energy security, and public health (MoES, 2020, Chapter 12).

This report provides a brief assessment of the impacts of global warming and climate change over the coastal regions of India and also highlights the role of technological preparedness and solutions to deal with the coastal impacts of global warming and related National disruption

9.2 Present status of climate change projections – IPCC referenced projections –SLR along the Indian coastline

Oceans play a central role in regulating the Earth's climate by the uptake and redistribution of anthropogenic heat and carbon dioxide and also regulating the hydrological cycle. The IPCC AR5 assessed that ocean have absorbed more than 93% of the anthropogenic excess heat, with the remaining contributing to melting of the terrestrial and sea ice and warming the atmosphere and land (Church et al. 2011; Trenberth et al. 2014). One of the consequences of warming of the global ocean and the melting of ice and glaciers is the rise in mean sea level. The IPCC AR5 and Special Report on Ocean and Cryosphere in a Changing Climate (SROCC) assessed that the ocean warming is virtually certain, and there is high confidence that the rate of global mean sea level (GMSL) rise has increased. Human-caused climate change has made a substantial contribution to the sea level rise since 1900. The Earth's climate has warmed about 1°C (1.8°F) during the last 100 years. As the climate has warmed, the sea-level rise has risen at an average rate of 1.7 (1.5–1.9) mm year^{-1} between 1901 and 2010 (Church and White 2011). Recently, the rate of global sea-level rise has accelerated to 3.25±0.3 mm/yr (Cazenave et al. 2018) as estimated from satellite altimetry available since 1993. The acceleration is estimated to be 0.1 mmyr^{-2}. The global mean sea level is projected to rise by 0.71 m (0.51–0.92 m) for 2081–2100 and 0.84 m (0.61–1.10 m) in 2100 (IPCC AR5) due to increases in ocean warming and loss of mass from glaciers and ice sheets.

Assessing the potential impacts along the coastline, the change in regional sea level is critically important. Regional relative sea-level rise is influenced by multiple physical processes that vary both in space and time and can lead to large regional departures from the global mean. The regional variability in sea level trends is mainly due to large-scale changes in temperature and salinity-related density structure of the oceans (known as steric sea level), in response to forcing factors (e.g., heat and fresh water exchange at the sea-air interface and wind stress) and their interaction with the ocean circulation and with an isostatic adjustment of Earth's crust to past and on-going changes in polar ice masses and continental water storage (Stammer et al. 2013). The thermosteric component due to increasing ocean thermal expansion is the dominant contributor, especially in the tropical oceans including Indian Ocean.

Indian Ocean Sea level rise exhibit high spatial and temporal variability. Spatial pattern of sea level rise in the Indian Ocean exhibit a basin-wide pattern, with sea-level falling in the south-west tropical basin and rising elsewhere (Han et al.2010). Long-term sea-level trend estimates using tide gauge observations available along the coasts of India and the rim of the eastern Bay of Bengal show a rate of sea-level rise of about 1.06–1.75 mm year^{-1} in the Indian Ocean during 1874–2004 (Unnikrishnan et al. 2006; Unnikrishnan and Shankar 2007) and is has accelerated to 3.3 mm year^{-1} as evident from satellite data available since 1993. The uncertainty of the vertical land motion in India due to postglacial rebound is estimated to be about 0.1 mmyr^{-1} and the error by which the relative sea level rise can be estimated at the Indian tide gauges is mostly larger than 0.2 mm yr^{-1}(Boss et al. 2014).

Indian Ocean sea-level rise is dominated by the ocean thermal expansion (Swapna et al., 2017, Sreenivasu et al., 2016), halosteric contributions can, be important in certain regions, like the Bay of Bengal and south-east Indian Ocean (Nidheesh et al. 2013). While the addition of water mass from terrestrial ice-melting is the major contributor to the GMSL rise (IPCC AR5). The steric sea level in the Indian Ocean is projected to increase by about 20–30 cm by the end of the twenty-first century (Swapna et al., 2020). With the increase in the mean sea level, extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) at many locations by 2050 under all scenarios, especially in tropical regions (SROCC, IPCC). With the rise in regional sea level and increasing intensity of severe cyclonic storms in the Indian Ocean, extreme sea level is also projected to increase in the Indian Ocean.

9.3 Possible Impact of the disaster in the future

India with a coastline of about 7500 km has the 18th longest coastline and forms the second largest peninsula in the world. It traverses 9 coastal states and 4 union territories and is endowed with a wide range of habitats such as coral reefs, mangroves, sea grasses, sand dunes, estuaries, lagoons and is home to an estimated 170million people who live in the coastal areas. The coastal regions of India are now becoming highly vulnerable to natural hazards such as tropical cyclone, coastal flooding, erosion etc., due to impact of climate change.

Coastal erosion and flooding exacerbated by the rising sea levels and recurrent natural hazards displaces millions of people every year along the Indian coast. According to a report published by National Centre for Coastal Research (NCCR) about 33% of coastline is under varying degree of coastal erosion, 29% is of accreting nature condition and the remaining 38% is in stable state. Low lying areas are at much greater risk and it is understood that the climate change may intensify the current pattern of displacement along the coastal areas of India, such as the Sundarbans.

Climate change-induced changes on the coast could have serious repercussions on the coastal infrastructure, primarily ports. India has more than 200 ports and 95% of the country's trade by volume and 70% by value are done through them. Various studies indicate that SLR, storm surges and waves are likely to induce major impacts on coastal transport hubs and networks, including transient or permanent flooding of seaports and connecting coastal roads and rail lines.

Rising sea levels threaten popular coastal tourist destinations like Goa, Kerala, Andaman and Lakshadweep islands.

The east coast has historically been more vulnerable to cyclones than the west coast. According to the Indian Meteorological Department, the Bay of Bengal has had 520 cyclones between 1891 and 2018, compared with 126 in the Arabian Sea. In recent times, the Arabian Sea has also been experiencing cyclonic storms more frequently. The intensity and frequency of the tropical cyclones over Arabian Sea and extreme rainfall events over India seem to be increasing and is attributed to the changing climate. This makes the coastal areas even more vulnerable and underlines the importance of mitigation and management of coastal hazards to save life and property, which is a huge challenge to the coastal administrators.

9.4 Gap areas (Modelling, Downscaling, and Observations) – What is available and what is needed and the method to fill the gaps

Coastal areas are affected by climate change and global warming in a number of ways. In particular, the coastal regions are highly sensitive to various environmental drivers such as sea level rise, changes in intensity and frequency of extreme weather events like tropical cyclone induced storm surges, associated flooding and precipitation, and ocean acidification. Impacts from climate change can also worsen problems in coastal regions that is already being faced today. In addition, the additional stress imposed by climate change also affects the coastal ecosystems like shoreline erosion, flooding events and salinization of soils in the coastal regions. While few studies (Fang et al., 2016; Jayanthi et al., 2018; Malik and Abdalla, 2016; Mani Murali and Dinesh Kumar, 2015) have used arbitrary values for sea level rise in context to coastal inundation vulnerability, they do not truly reflect the local trends in the area and therefore can lead to over- or under-estimation that is vital for adaptation and mitigation strategies that are scientific and cost-effective. Recently, Jennath et al (2021) investigated the climate projections of sea level rise and coastal inundation for the Atoll Islands – a case study for Lakshadweep islands in the Arabian Sea. Their study evaluated the performance of CMIP5 GCMs to simulate sea level rise in the Arabian Sea using various statistical methods. The best performing GCMs were identified under varying RCP scenarios. Projections obtained from best-performing GCMs were then used to map the potential inundation using different RCP scenarios.

Regional sea level changes for the Indian Ocean region are quite different compared to global mean sea level, and an accelerated rate of rise is evident since 1993. More detailed study is required to address the underlying causes of regional sea level changes associated with dynamic variations in the general ocean circulation, variability in surface winds, and isostatic effects.

There is an urgent need to evolve improved methodologies for developing high resolution climate change scenarios of sea level rise and the associated impacts on coastal regions and islands. Scenarios should take into account the spatial and temporal resolution required by assessment models incorporating simulated changes in both the mean and variability of climate variables.

There are considerable opportunities for development and inter-comparison of the existing downscaling approaches. Considering the fact that the downscaling techniques and each approach has own advantages and limitations, there is no universal method that works fine for all situations. At present, all the downscaling methods are still in development stage and testing. Rigorous testing and comparison of best-performing models and statistical downscaling methods should be undertaken for the Indian Ocean region.

More observations from space borne technology are required to monitor sea level rise at sufficient spatial and temporal scales. Observational data will supplement and improve the skill levels of RCMs.

Keeping in view the gradual changes in Relative Sea Level, other environmental variables are superimposed such as tides, storm surges, and surface gravity waves and other high-frequency processes. These variables are important for understanding the localized impact of processes and therefore detailed knowledge of bathymetric variations, erosion and sedimentation, in addition to better description on temporal variability of wind fields generating waves and storm surges needs to be focused and addressed in the modelling system. Ocean acidification issues needs to be better understood using satellite data and ground based observations to monitor the health of Arabian Sea and Bay of Bengal waters, especially the coastal waters.

Many fragile ecosystems such as coral reefs, mangroves and lagoons will be highly vulnerable that in turn can impact the biological cycle and fisheries. It is very difficult to monitor ocean acidification, however, better methods need to be evolved utilizing satellite data such as SMOS mission of NASA Aquarius. Measurements are needed near coral reefs especially pCO2 to determine the bleaching characteristics.

Chemistry of seawater needs to be clearly understood such as the partial pressure of CO2, dissolved inorganic carbon, alkalinity, and pH. In addition, the physical properties such as temperature and salinity sampling can provide a better understanding on the carbon chemistry of the seawater. Observational framework should plan to equip with BGC sensors, identify suitable locations when and where to observe along with detailed data analysis plan.

The two important physical properties of seawater viz., temperature and salinity which affect the carbon cycle chemistry are directly linked to ocean acidification processes. Concentrated efforts such focus on long-term data of physical and chemical properties from satellite missions with thorough validation with ground truth data.

Lack of long-term sea-level observations in the Indian Ocean is a major caveat to obtain reliable basin-scale pattern of sea-level rise and multi-decadal variability in this basin. There are only two tide gauges in the Indian Ocean that go back to the nineteenth century: Mumbai (west coast of India) and Fremantle (west coast of Australia). More than 40 years of data is available only from 20 tide gauge stations in the Indian Ocean.

Except for a few gauge stations along the coastal India and west coast of Australia, no long-term gauge records are available in the interior ocean that spans over a minimum of 40 years. The potential for compounding effects, like storm surge and high sea level rise, are of particular concern for the small Islands as they can contribute significantly to flooding risks [SROCC, IPCC]. The sea level data for Island stations of Indian Ocean are available only since late 1980's.

Unavailability of long-term hydrographic profiles in the Indian Ocean limits our knowledge of long-term heat exchange and salinity variations in the basin and hence the steric sea level.

9.5 Summary

- Sea-level rise estimation along the coast should be carried out based on downscale models validated with tide gauge data. While validating local estimates, subsidence should be considered
- Coastal Topography and nearshore bathymetry should be mapped for analysing impact of sea-level rise on coast. Modern technologies like UAV etc., should be adopted for mapping
- Data policy should be evolved for sharing of information.
- The Bruun Rule can be used to model the beach stability process. Recession of shoreline can be estimated in terms of sea level rise. As a first approximation, the shoreline recession would be in the range of 50 to 200 times the rise in relative sea level. Volumetric estimates of eroded and deposited sediments can be estimated. Better practices can also be explored.
- Coastal protection methods involve defensive measures to protect regions against flooding due to extreme waves, tidal flooding, shoreline erosion, salinity intrusion etc. Hard defence measures include structures such as seawalls, dikes, revetments, armour units etc. Though hard solutions provide tangible protection in the hinterland, they are not proven to prevent physical process of erosion and other consequences. By adopting soft engineering or hybrid solutions, the negative effects of hard solutions can be avoided.
- Apart from all these above, green solutions can also be adopted for better sustainable management based on site conditions.
- Available ocean renewables especially offshore wind/ wave/tidal to be taken up on a large scale in India
- The most apt ocean renewable energy, Ocean Thermal Energy Conversion (OTEC) to be funded on a large scale through Industry – Institute participation and a plant established immediately.

Section 10 Drought on regional or national level

10.1 Introduction

India is among the top ten most-affected countries by various climate change related risks. According to the Climate Risk Index, 2018, India jumped nine places in climate vulnerability rankings and was ranked the fifth-most climate-vulnerable country in the world (German Watch, 2018). Amongst the climate risks, it is the drought that imposes highest socio-economic costs on the society. Looking at the developing scenarios of climate induced disasters in the country, a review has been made on the extent of disaster and its impact on the society; current level of preparedness and the agencies involved in these activities. It further emphasizes the need to study the information and knowledge gaps and identify the institutions to undertake research to fill those gaps; types of preparedness needed and the mechanisms which should be put in place.

Drought is a stochastic and creeping natural disaster, caused by significant and persistent deviation of precipitation relative to the statistical multi-year average for a region. Though precipitation is the dominant factor in triggering drought, but its occurrence is also associated with other factors such as timing of precipitation, distribution within the season, high temperature, and high wind speed. In general, arid and semi-arid areas are more drought-prone than humid areas.

Globally there are four basic approaches for categorizing drought: meteorological, hydrological, agricultural, and socioeconomic. The first two approaches treat drought as a physical phenomenon while agricultural drought involves both physical and biological processes. Social and economic impacts of droughts play crucial role to build the resilience of agro-ecosystems. In India meteorological drought is assumed to trigger if the rainfall deficit over a period is more than 25 % of average rainfall in an area; or more than 10 %, extending over more 20% of Indian planes. Agricultural drought is the situation when soil moisture and rainfall are inadequate to support healthy crop growth. It links various characteristics of meteorological (or hydrological) drought to agricultural impacts. Hydrological drought (resulting from prolonged meteorological drought) manifests in depletion of surface and sub-surface water resources. The socioeconomic drought associates the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural droughts. Its occurrence depends on the time and space processes of supply and demand.

10.1.1 Extent and frequency of droughts and impacts in India

In India, nearly 68 % of net sown area is vulnerable to drought. More than 100 districts, which receive less than 750 mm rainfall are officially "chronic drought-affected", while 35% of the area, falling in750-1,125 mm rainfall zone is classified as 'drought-prone. As mentioned in report on National Agricultural Drought Management Plan (NADMP), there were 48 districts in the country, which had 15 per cent incidence of severe meteorological drought (GoI- MoAFW,2020). About 302 districts, falling mostly in Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, Tamil Nadu, Maharashtra, Assam, Odisha, and Uttarakhand, may face an increase in drought incidence in future. On the other hand, incidence of drought is expected to go down in 144 districts in the country.

Based on 'All India Summer Monsoon Rainfall (AISMR)' data for the period from1871-2015 (134 years), India faced 25 major drought years. The rare droughts of severe intensity occurred once in 32 years. In recent times, the 1987 drought was one of the worst droughts of the century, with an overall rainfall deficiency of 19% and extending over about 60 % of the normal cropped area, followed by 2002 drought with similar rainfall deficiency causing a steep fall in 29 million tons in food production. The climate change is projected to increase the frequency and severity of these disruptions, and in the absence of adaptation measures agricultural productivity may fall by about 40 % by 2100 (GoI-MoAC&FW, 2018).

The intensity of adverse effects depends on a large number of factors including natural conditions, land use patterns, and socio-economic conditions. The extent of the affected area being large, droughts have significant impacts on the agricultural as well as non-agriculture sectors. Some figures of drought induced losses are reported after every drought (eg economic loss due to the 2002 drought was estimated at US$ 910.72millions (Gupta et al, 2011), but no comprehensive quantitative assessment of economic impacts is available. Most droughts have an unclear onset or ending, a large spatial coverage, and an extended duration; which all make the drought impact assessment a challenging task. Interdisciplinary research, involving economists, meteorologists, hydrologists, and engineers, is needed for the quantitative measurement of drought economic impacts.

10.1.2 Evolution of drought management framework

There are three important pillars of drought management: preparedness (identification of drought-prone area and prediction of drought and its intensity in that area), prevention (drought monitoring and early warning), and mitigation (reduce the chance of occurrence or intensity of impact by following preventive measures or by using preparedness plans (FAO, 2019). These three pillars depend on the support of cross-cutting policies. Historically, public response to drought throughout the world has been in the form of 'crisis management' involving post-drought relief, which increases vulnerability to future drought episodes by reducing self-reliance. The increasing frequency, severity, and duration of climatic disruptions under changing climate has spurred the global community to formulate more effective approaches in the form of Hyogo and Sendai Frameworks (Anonymous,2006; Anonymous,2016). Consequently, the concepts of drought management are undergoing change from reactive to proactive approaches to include, drought preparedness, prevention and mitigation; and more recently sustainable development. To promote and accelerate the adoption of Sendai Framework, the UN Office for Disaster Risk Reduction (UNDRR) has established the Global Science Technology Advisory Group and its regional sub-groups.

Drought management in India, which was in existence since pre-independence days, has till very recent past, largely been a relief-based approach using outdated famine codes. But a significant change in the government's approach to drought management is indicated in the 2009 Drought Manual (GoIMoA-2009), which advocates abandoning famine codes, emphasis on mitigation measures, adoption of new techniques and legal framework. These guidelines have been further refined and improved making use of the new developments in science and technology in 2016 Drought Manual (GoI-MoACFW, 2016).

10.1.3 Growing role of science and technology in drought management

Use of science and technology tools can help reduce or prevent the impact from disasters by way of assessment of the current state of data, scientific knowledge and technical availability on disaster risks and resilience (what is known, what is needed, what are the uncertainties, etc.)-synthesis of scientific evidence in a timely, accessible and policy-relevant manner; scientific advice to decision-makers; monitoring and review; capacity development; communication and engagement among policy-makers and stakeholders across sectors.

The Hyogo Framework for Action (HFA)2005–2015 assigned a strong role to science and technology in identifying, assessing, and monitoring disaster risks and enhancing early warning.It emphasizes on the increasing role of in- situ and space-based earth observations, space technologies, remote sensing, geographic information systems, hazard modelling and prediction, weather and climate modelling and forecasting, communication tools and studies of the costs and benefits of risk assessment and early warning. Further, technology is also required to communicate the information in appropriate format for improved reliability and longer lead times in seasonal climate forecasts.

10.1.4 Objectives of current exercise

India has made substantial progress in expanding irrigation infrastructure and its watershed management programmes, particularly in areas dominated by rainfed agriculture. Despite this progress, the country has been facing droughts frequently limiting our strategies to meet the sustainable development goals. This calls for a comprehensive assessment of the current level of technology preparedness in terms of technology utilization, identification of gaps in technology, infrastructure, enabling policies and institutions for increasing efficiency and reducing cost of drought disaster risk reduction activities.

10.1.5 Organization of this report

This report has five sections, and the subsequent sections include: possible impact of the drought in the future; analysis how the impacts have been addressed; analysis of gaps in respect of technology, infrastructure, institutions, policy; and recommendations.

10.2 Future Projections of Droughts and their Impacts

India is one of the most drought prone country in the world, and the recurrence of drought in India is largely due to the unique physical and climatic susceptibilities (GoI, 2016). These factors include : (i) large annual / seasonal/regional variations in spite of a high average annual rainfall of around 1,150 mm; (ii) a short window of less than 100 days during the South-West Monsoon season (June to September) when about 73% of the total annual rainfall is received; (iii) uneven distribution of rainfall over different parts of the country in that some parts bear an inordinately high risk of shortfalls, while others tend to receive excessive rainfall; (iv) low average annual rainfall of 750 mm over 33% of the cropped area in the country, which heightens the susceptibility to drought; (v) over-exploitation of ground water and sub-optimum conservation and storage capacity of surface water leading to inadequate water availability for irrigation, particularly in the years of rainfall deficiency; (vi) and limited irrigation coverage (net irrigated area in the country is less than 50%).

Historical observations suggest that the frequency of severe droughts has been increasing in the recent decades over India. The climate change, which is projected to make transformative changes in water demand and supply, together with anthropogenic changes induced by population explosion and its changing life style, is going to further complicate the occurrence of droughts in India. Based on a number of studies using models of varying in complexity (Aadhar and Mishra,2018; Krishnan et al, 2020; Suman and Maity, 2021) following are the future scenarios of drought in India.

10.2.1 Future drought scenarios

Under the warming climate, the temperature is projected to increase, affecting the atmospheric water demand (PET) and drought conditions. The future rate of global warming is determined at given representative concentration pathway (RCP), which is essentially a greenhouse gas concentration trajectory delivering global warming at defined rates in terms of watts /m2 across the planet. The RCP 8.5 pathway delivers a temperature increase of about 4.3˚C by 2100, relative to pre-industrial temperature and is considered the worst-case scenario. RCP4. 5 is a stabilization scenario and thus it assumes the imposition of emissions mitigation policies. Under the warming climate, there is an increase in the precipitation, and more than 2-degree rise in temperature leads to more atmospheric water demand and an increase in drought severity by the end of the 21st century. Overall, this study suggests that the severity of drought in India is projected to increase under wetter and warmer future climate. Under the RCP 8.5, the majority of the country shows high-frequency of severe drought events (more than three severe events per decades) towards the end of 21st century (Suman and Maity, 2021). More frequent severe drought events are projected by the end of the 21st century under both the RCP 4.5 and RCP 8.5(Aadhar and Mishra, 2018)

The research studies indicate geographically contrasting change in future agricultural drought, which would be more severe in north, north-east, and central India as compared with south India. The area under drought on mainland is also expected to increase by about 20% under moderate standard soil moisture index (SSMI ≤ −1) and 50% extreme (SSMI≤ −2) drought situations. Sub-basins in north and central India are expected to be vulnerable to frequent agricultural droughts, with the sub-basins in central India expected to be comparatively more vulnerable (Figure 1). However, the vulnerability of sub-basins in south India is found to be comparatively less.

Basin-wise Future Agricultural Drought Conditions

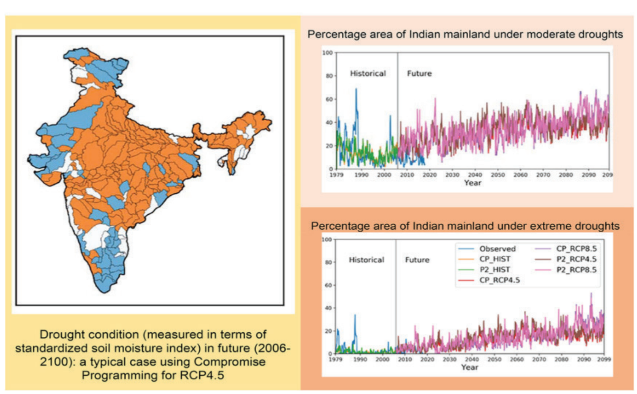


Figure 7 Basin-wise Future Agricultural Drought Conditions Source: Suman and Maity (2021)

In the future climate, significant variability and change in monsoon rainfall and temperature would further affect the future drought conditions. Historically, drought dynamics were more influenced by decrease in precipitation. But, in future the drought dynamics will be significantly influenced by increased evapotranspiration resulting from increase in temperature in spite of the likely increase in precipitation. The frequency of concurrent hot and dry extremes is projected to rise by about five-fold, causing approximately several-fold increase in flash droughts like 1979 by the end of the 21st century (Aadhar and Mishra,2018).

To summarize, the future drought scenario will see the following changes.

(1) Drought affected area would increase with climate change

(2) Droughts would be getting more severe and frequent with time.

(3) The central parts of India, including parts of Indo-Gangetic Plains would face an increase in drought severity

(4) The country may see more frequent flash drought by the end of 21st century.

(5) Evapotranspiration will have significant impact on droughts dynamics.

(6) Drought periodicities are not found to be changing due to climate change.

10.2.2 Projected Impacts

Drought produces wide-ranging impacts, categorized as economic, environmental, and social; which span across many sectors of the economy, affecting the overall economy at macro and micro economic levels, both directly and indirectly. The slow evolutionary nature of monsoon droughts and enhanced surface dryness will exert significant impacts on water availability, agriculture and socio-economic activities over India.

Direct impacts may include fall in agricultural production; depleted water levels; higher livestock and wildlife mortality; cattle and animal migration; damage to ecosystem from indiscriminate exploitation etc. The indirect impacts include fall in farm income and agribusinesses, food inflation, slump in consumption, default on agricultural loans, distress sale of agricultural land & livestock, rural unrest etc, which have huge negative multiplier effects in the economy and society.

(1) Fall in food production: A drought will have a negative effect on crop area, yield, and production, leading to a rise in prices and reduction in consumer demand. Rice and pearl millet are the most important crops that would be seriously affected by drought. As reported in Kumar etal (2014) a 10% increase in drought intensity would be responsible for a fall in production of rice and pearl millet by more than 10%. For cotton and sorghum, the corresponding fall in production would be 8.4% and 7.6% respectively. Production of maize, groundnut, and pigeon pea would fall by about 4% with a 10% deficit rainfall.

(2) Health and livelihoods: The effects of drought would be felt in people's nutrition, health, sanitation. Drought-affected communities are more vulnerable to famine and it would lead to increased migration from rural to urban areas in search of livelihood

(3) Impact on ecosystems: The climate change has exacerbated droughts, making them hotter, last longer, and extend over larger areas of land, which besides the human society will increase the vulnerability of ecosystems in a hotter and dryer environment. The dried-up natural water springs and streams will affect the flora and fauna in the affected area.

(4) Deterioration in water quality and availability: Potential impacts on water supply have received much attention, but relatively little is known about the concomitant changes in water quality. Projected changes in air temperature and rainfall would affect river flows and, hence, the mobility and dilution of contaminants. Meteorological drought that spreads through the hydrological cycle can reduce surface and ground water levels (triggering hydrological drought) and can lead not only to reduced water availability but also to a deterioration of water quality (Mishra and Singh 2010, Mosley 2015).

10.2.3 Data and analysis gaps

The future scenarios on droughts are based on certain assumptions and limited data. There is ample scope for further refinements in these projections. The following are the identified knowledge gaps.

(1) Lack of dense observational networks for essential climate variables like soil moisture, surface and sub-surface energy, water fluxes, stream flow, etc. limits our scientific understanding of the complex multiscale (spatial and temporal) interactions taking place in the climate system. To better understand the processes involved in the variations of intensity and duration of droughts over India in a warming climate, novel observational datasets are required.

(2) Attribution of anthropogenically induced climate change to the variability of drought in historical as well as future projections remains a challenging issue and an open problem for further scientific research.

(3) Model uncertainties in reproducing the observed variability of droughts, as well as the spread among the models, hamper confidence in assessing future changes. Efforts are therefore needed for reducing the model uncertainties.

(4) Assessing the impact of increasing urbanization, as well as agricultural intensification on the hydroclimatic extremes continues to be a challenge for the Indian monsoon region, and additional multiscale assessments are critically needed.

10.3 How the Drought has been addressed in therecent past

The drought management has in existence since pre-independence, and has been updated from time to time, focusing mainly providing relief in post disaster phase. A major departure was made when use of famine codes was abandoned with increased focus on mitigation and use of new technologies. The new bible on drought management is the Drought Manual 2016, which provides details guidelines on early warning, monitoring, assessment and declaration of droughts. In recent times, the drought management across the country is based on these guidelines, and administrative setup has been put in place. For drought, the Ministry of Agriculture Cooperation and Farmers Welfare (MoAC&WF) is the nodal agency with a designated Central Drought Relief Commissioner with a Crisis Management Group for monitoring and early warning of any drought like development in any part of the country on a regular basis. There is a similar setup at state level.The significant developments are discussed in brief.

10.3.1 National Agricultural Drought Assessment and Monitoring System (NADAMS)

After the phenomenal drought during 1987, which affected most parts of our country, the need for science based objective drought monitoring was recognized by all the stake holders. Consequently, satellite-based drought monitoring was initiated in India in 1989 through a project "National Agricultural Drought Assessment and Monitoring System (NADAMS)" developed by ISRO (NRSA). The operational services from NADAMS project commenced during kharif 1989, with the issue of biweekly drought bulletins from June to November, depicting the districts under different categories of drought intensity. NADAMS project has undergone many methodological improvements, from time to time keeping pace with developments in space technology and user requirements. A combination of different indices and bio-physical products are now being used for drought assessment at sub-district level (Table 1). Soil moisture data from hydrological modeling as well as satellite derived products are being used.

Realizing the importance of drought information and maturity and soundness of NADAMS project, Department of Agriculture, Co-operation and Farmers Welfare (DACFW) started implementing this project through its attached office - Mahalanobis National Crop Forecasting Centre (MNCFC), from 2012, with technology transfer and capacity building extended by NRSC. Thus, the end-use of drought information products has increased significantly from 2012 in the country.

Table 2 Satellite based indices for drought monitoring in India

S. No.	Indices	Spatial resolution (m)	Significance
1.	NDVI	10-1000	Crop vigour index
2.	LSWI	10-1000	Surface/crop moisture status
3.	SASI	10-500	Surface/crop moisture index
4.	RADAR Backscatter	10-20	Canopy volumetric scattering sensitive to biomass
5.	Surface soil moisture	10-25 km (satellites)	Soil moisture indices
6.	Root zone soil moisture	1-9 km Hydrological models/ satellites	Soil moisture indices

Recent developments in drought monitoring include the use of Synthetic aperture RADAR data, owing to its sensitivity for the dielectric properties of target, especially in case of unavailability of optical data due to cloud cover. Early-season drought detection using SAR data is being carried-out in Maharashtra state. As soil moisture increases (keeping the surface roughness same), SAR backscatter from target also increases; and as crop grows, backscatter also increases (due to increase in canopy moisture/ roughness) till onset of senescence stage. Dry soils respond with low backscatter intensity compared to wet soils. The large difference in electrical properties between water and air results in higher backscatter RADAR intensity over wet soils. Over flooded soils, the energy is specularly reflected off the water surface, resulting in low backscatter intensity. The flooded area appears dark in the SAR image. Backscatter profiles over crop lands exhibit phenological patterns. Early season drought caused by deficit rainfall leads to dry and un-ploughed crop fields and dried-up water bodies. Such an agriculture situation is characterized by low backscatter responses from SAR data. RADAR data of 20 m spatial resolution is currently available once in 12 days and this data in combination with optical indices provide unique opportunities for drought detection.

10.3.2 National Drought Manual

DAC&FW, developed the National Manual for Drought Management in 2009 through an Expert Committee. The purpose of this manual is to streamline drought assessment procedures and ensure uniformity among the states. The manual provided guidelines to the States for operational assessment of drought conditions in a more objective manner with a set of Indices. Use of satellite-based crop condition index, as drought indicator, was recommended in the manual. This manual has improved the drought assessment system in the country. The National Drought Manual was revised in 2016 to improve the assessment mechanism considering the technology developments in satellite data and weather data availability. More number of drought impact indicators were included to make the drought assessment more comprehensive and scientific. All the states are now following the guidelines for drought declaration and relief assessment. The drought manual is available at www.agricoop.gov.in.

Steps in assessment and declaration of drought

The drought manual lists the following steps are used for the determination of drought:

Step 1: Mandatory Indicators viz. rainfall (RF) deviation or SPI or Dry Spell will be considered as per matrix in Table 2.

Rf Dev/SPI	Dry Spell	Drought trigger
Deficit or scanty rf/SPI<-1	Yes	Yes
Deficit or scanty rf/SPI<-1	No	Yes, if rainfall is scanty or SP<-1.5, else No
Normal rf/SPI>-1	Yes	Yes
Normal rf/SPI>-1	No	No

Step 2: In the event that the first drought trigger is set off in Step 1, the Impact Indicators will be examined as per the matrix in Table 3

Mandatory Indicators		Impact Indicators				Category of drought
Rainfall Indices		Agriculture	Remote Sensing	Soil Moisture	Hydrology	
Rainfall Deviation (RF Dev) or SPI	Dry Spell	Crop Area Sown	NDVI / LSWI Deviation or VCI	PASM/ MAI	SFI/RSI/ SGWI	

The States may consider any three of the four types of the Impact Indicators (one from each) for assessment of drought, the intensity of the calamity and make a judgment.

The intensity of the drought will be contingent upon the values of at least three out of four Impact Indicators viz, Agriculture, Remote Sensing, Soil Moisture and Hydrology in the following manner:

(i) Severe drought: if all the selected 3 impact indicators are in Severe category

(ii) Moderate drought: if two of the selected 3 impact indicators are in 'Moderate' or 'Severe' class.

(iii) Normal: for all other cases.

(iv) Trigger 2 will be set off in the event of a finding of 'severe' or 'moderate' drought.

Step 3: In the event that trigger 2 is set off, States will conduct sample survey for ground truthing. The finding of field verification exercise will be the final basis for judging the intensity of drought as 'severe' or 'moderate'.

10.3.3 Drought monitoring systems by States – some successful examples

Karnataka is the first state in the country to develop a sound drought surveillance system. By establishing dense network of rain gauges and weather stations followed by data analysis platforms, Karnataka State Natural Disaster Monitoring Centre (KSNDMC) generates multiple drought indicators at Hobli (cluster of villages) and Village levels. Automated data analysis, visualization and alerts generation have been achieved. Tracking drought conditions at village level and integrating such information with farmer advisories have immensely strengthened the drought management in the State. Karnataka has become a model state in drought monitoring. More information about drought assessment in Karnataka is available at www.ksndmc.org.

Maharashtra state has developed Maha MADAT, a drought assessment system with Maharashtra State Remote Sensing Centre and Departments of Disaster Management, Relief & Rehabilitation and Agriculture, Government of Maharashtra. Maha MADAT is a web-based Geoportal hosting data from various sources for visualization, query, monitoring, and management for timely dissemination of the drought information. A systematic database of drought indicators prescribed in the National Drought Manual 2016 is maintained in the portal. Android based mobile app for ground truth data collection along with time stamped photographs/videos are also part of the portal. Maha MADAT permits objective assessment of drought conditions from time to time with customized visualization of the anomalies by different drought indices. The state has also initiated a digital Agriculture project called "Maha AGRITECH", a joint project of Department of Agriculture, Govt. of Maharashtra in collaboration with NRSC (ISRO) and Maharashtra State RS Centre. Under this project, a robust system of agriculture monitoring and assessment is being established using the data from multiple satellites. A variety of crop surveillance information products are being generated. Crop sowing intelligence and drought indicators are some of the deliverables in the project that directly benefits drought management in the State.

Andhra Pradesh and Telangana states are adopting satellite-based drought monitoring for many years. Moderate resolution satellite data are being used to assess agricultural drought situation at sub-district level. This assessment is integrated with other drought parameters to improve declaration procedures. Similarly, many other states have been focusing on strengthening their drought monitoring efforts in different ways. Infrastructure for collecting weather data is being increased in many regions in the country.

10.3.4 Mobile technology

Mobile Apps facilitate efficient field data collection covering large number of locations in less time. It provides objective evidence on the prevailing agricultural conditions. The mobile technology forms a very efficient tool to capture localized crop damages. Library of field information during crop growing period can be generated using Mobile Apps. Mobile based field data collection, analytics on such data and value addition have attained greater relevance in recent years for crop management in general and crop risk assessment for relief/compensation in particular. For drought enumeration exercises of state departments, Mobile Apps are gradually replacing the manual system of recording of drought impacts.

10.3.5 Crop Insurance

Relief and Compensation mechanisms play greater roles for managing the ever-increasing drought impacts on crops. Relief mechanism is strengthened by adopting objective drought assessment procedures and declaration protocols. Compensation mechanism is strengthened by adopting a robust system of crop insurance. At present Pradhan Mantri Fasal Bima Yojana (PMFBY) and Restructured Weather Based Insurance Schemes are being implemented all over the country from 2016.PMFBY, primarily an area-yield insurance contract, has many positive features to compensate for multiple risks during the entire life cycle of the crop season. Use of technologies viz. remote sensing, mobile and data analytics is strongly recommended for effective implementation of the schemes.

10.3.6 Agro-Advisory Services

IMD in collaboration with ICAR, SAUs and other institutes is implementing Gramin Krishi Mausam Seva (GKMS) scheme in India, wherein weather forecast and crop/livestock specific advisories on agricultural operations (land preparation, sowing, selection of crop/verities, scheduling irrigation etc) have been providing to farmers at district and block level on every Tuesday and Friday based on medium and extended range weather forecast. Currently, 700 districts and 3155 blocks have been covered under GKMS scheme. About, 43.7 Million farmers are receiving SMS advisory on their mobile phones through mKisan portal. Decision Support System, Mobile Apps, satellite-based agro-met products, ICT tools, surface instrumentation, strong field measurement network, advanced analysis tools etc have been strongly recommended for smooth implementation of the scheme.

10.4 ANALYSIS GAP AREAS

10.4.1 Drought monitoring, forecast, and early warning systems for different kinds of droughts

Monitoring and assessment of drought conditions at different scales and timely dissemination of information constitute the most vital part of drought management system. Inadequate system for monitoring the drought, unreliable data points, lack of standard procedures to calculate indices of drought prevalence and intensity could lead to inefficient management strategies. Therefore, the need is to have a sound, operationally feasible, objective and economically viable system for drought monitoring, drought impact assessment, design and development of drought management measures, field level implementation of different practices, monitoring and evaluation of impacts etc.

The gap areas for technology development in drought management domain include;

- Creation of geospatial data bases
- Development of new indices for drought assessment
- Advanced tools for geospatial data analysis
- Spatial Decision Support System
- Climatic models for simulation of drought events
- Drought early warning
- Quantitative assessment of drought impacts

Reliable data on drought parameters and powerful geospatial tools for analyzing such data are required to address these gap areas.

Technology driven drought management system addresses the ever-increasing challenges of drought risks in agriculture sector. Data and technology enabled decision support, governance of drought management prescriptions and policy making offers unprecedented opportunities to minimize drought impacts.

Data types are numerous in a drought management system – qualitative, quantitative, cross section, time series, physical data, biological data, socio-economic, primary and secondary, dynamic and static. It is multi-source and multi scale data generated from manual collection, instrumentation, satellites, mobile apps etc. and is related to weather, soils, water, crops, social and economic factors.

Many states are data deprived and rely on poor quality data. For successful implementation of drought management measures, a huge amount of real-time and high-quality data is the basic requirement.

The real challenge is development of a structured data base from the big pool of data from multiple institutions. It is the pre-requisite for all further steps. Data management includes processing the raw data, standardization, quality assurance, data exchange and making the data ready for use in real-time.

Remote sensing data of moderate resolutions around 10m is available free once in 5-10 days, thereby reducing the cost of surveillance over large areas. Similarly, mobile technology has tremendously improved the field data collection system by producing real time crop status and crop management data.

Large streams of data from multiple sources – satellites, weather stations, Mobile Apps etc are to be processed, combined to investigate the associations, establish relationships, perform predictions on crop health and risk occurrence. Digital crop area maps using satellite data during the season are vital inputs for crop management advisories and production estimations. Combination of Mobile based crop surveillance, satellite indices and weather-based indices enables comprehensive drought information products.

Analytics is key to the success of data application. Spatial analytics, data mining, data engineering, evidence-based tools etc. could only churn out useful information products in the data frame work.

Data sharing arrangements are very important because of misuse of data leads to financial implications and affects the stake holders. Connecting to the User community by sharing the data and information products in near real-time mode is to be given top priority.

Data quality and data usage also determine the soundness of the research methodologies.

More emphasis is now placed on the development of geo-physical products, large area coverage, adoption of process-based approaches and transfer of technology to the User departments. Investigations on new data sources and technologies are to be carried-out continuously.

10.4.2 Vulnerability, and impact assessment for different kinds of droughts

Drought preparedness activities include identifying drought prone area which generally refers to the area frequently affected by drought and to carry out the long-term drought mitigation activities that minimize the impact. Irrigation commission in 1972 suggested following criteria for determining drought proneness (i) low rainfall regions, (ii) areas that receive irrigation support less than 30 % of net sown area (iii) frequency of famine and scarcity. Later in 1976 National Commission on Agriculture suggested areas based on four rainfall categories (i) rainfall below 375 mm create conditions of extreme aridity, (ii) semi-arid zones have rainfall between 375 mm and 750 mm (iii) the dry sub humid areas receive rainfall between 750 mm and 1125 mm and (iv) certain areas which receive above 1125 mm but experience failure of crops. The task force on Drought prone area program and Desert Development Program evolved broad indicator comprising of rainfall and irrigation with relaxed irrigation yardstick to 40 per cent for areas having less than 750 mm rainfall and 30 per cent for areas having rainfall higher than 750 mm. However, the drought prone area identified based on limited data on rainfall and irrigation details of 1970's was not revised so far in spite of increase in the irrigated area and changes in the land use during recent years. The frequent change in the land use, irrigation development, cropping pattern and agricultural practices, it is necessary for frequent updating of drought prone area with enhanced understanding of drought impacts. However recently Venkateswarlu etal (2014) reclassified the DPAP and DDP districts in India based on the latest data on irrigation, land use and climate and there is a need to build consensus among states on this list so that development programmes can be better targeted to the most vulnerable districts.

Climate variability observed in recent years is changing the agricultural scenario in the country leading to changes in the vulnerability profiles of agricultural areas. These changes in weather, soil and crop factors and their interactions indicate the need for the development of new set of criteria for delineation of drought prone/vulnerable areas.

Proactive or mitigation/preparedness-oriented drought management needs the information on the hotspots of drought. Information on agricultural drought vulnerability levels of different areas is extremely useful for prescription, development and implementation of long term drought management measures. Different areas are differentially exposed to drought and have different levels of vulnerability mainly due to skewed development processes of environment, socio-economic, infrastructure etc. Assessment of drought vulnerability is important from multiple perspectives - drought management, crop insurance, climate change etc.

Information on hazard, vulnerability and risk is extremely useful for prescription, development and implementation of long-term drought management measures.

Hazard is a potentially harmful situation from natural or manmade events/climatology. It is a possible source of danger. Weather situation with low/no rainfall, high temperature etc. is hazardous to crop areas/agricultural activities. Soils with less water holding capacity are hazardous for crops.

Agricultural drought vulnerability is defined as exposure, sensitivity and adaptive capacity of an agricultural area to the situation of inadequate soil moisture availability during the season. Crop areas are exposed to hazardous weather –low rainfall, high temperature etc. The sensitivity and coping ability of the agricultural area, when exposed to drought situation or potentially harmful crop stress situations determines the vulnerability of the area. Exposure, sensitivity and adaptive capacity together determine the agricultural drought vulnerability which is a relative term and can be represented in a predefined scale.

Risk is a quantitative term derived from hazard and vulnerability. Based on hazard and vulnerability, risk assessment is carried-out. Risk provides the estimate of damage or crop loss due to agricultural drought, when an agricultural area having a certain level of vulnerability is exposed to hazardous weather.

Agricultural drought vulnerability status is a crucial input for developing long term drought management strategies. Agricultural drought vulnerability is determined by a number of factors related to climate, soil, water and crop. A composite index derived from multiple parameters provides a robust and scientific approach for mapping agricultural drought vulnerability. Further, all the components of vulnerability namely exposure, sensitivity and adaptive capacity need to be addressed to generate a robust vulnerability index (Murthy et al. 2016). Agricultural drought vulnerability framework is depicted in Figure 2.

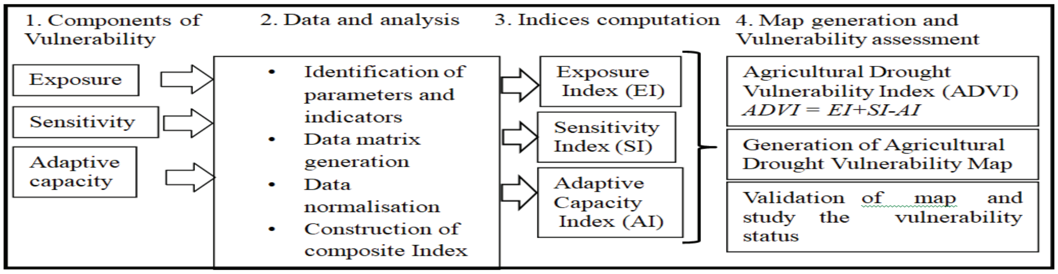


Figure 8 Drought vulnerability assessment framework

Exposure indicates the nature, extent, duration and frequency of drought conditions over a geographic area. Meteorological parameters play a vital role in determining drought exposure.

Sensitivity is the degree to which the water resources and crops are affected by drought conditions. Adaptive capacity is the ability of agricultural and hydrological system to cope-up with agricultural drought situation. It is generally determined by the static parameters of the system. The parameters and indicators of adaptive capacity are soil, irrigation and land holdings. Soil is an important link between weather and crops and strongly determines the occurrence of agricultural drought. Available Water Content (AWC) signifies water holding capacity of soils. Higher AWC means more amount of water can be accommodated in the soil column and higher adaptive capacity to drought conditions. Irrigation support is an important parameter and irrigation water is supplemented by rainfall to meet the overall crop water needs.

Drought preparedness, mitigation and response for different kinds of droughts

Dr. B.Venkateswarlu, Dr. K.V.Rao

Drought preparedness, mitigation and response for different kinds of droughts

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10.4.3 Crop Management; Current Technological Options and Gaps

Drought, a climatic anomaly, indicating the deficiency in available water in root zone or higher water demand than normal available resource has a significant effect on plant growth. Drought can happen in both high and low rainfall regions and even in irrigated areas largely depending on ground water. If crops / cropping systems in a given region are not matching to the available water, the problem of drought is further exacerbated.

Drought can happen at any point of time during the crop growing season. Occurrence of drought frequency at annual and monsoon season for the whole country is given in figure 9 below (NRAA Report, 2020). Arid and semi-arid areas of the country bear the brunt of frequent droughts.

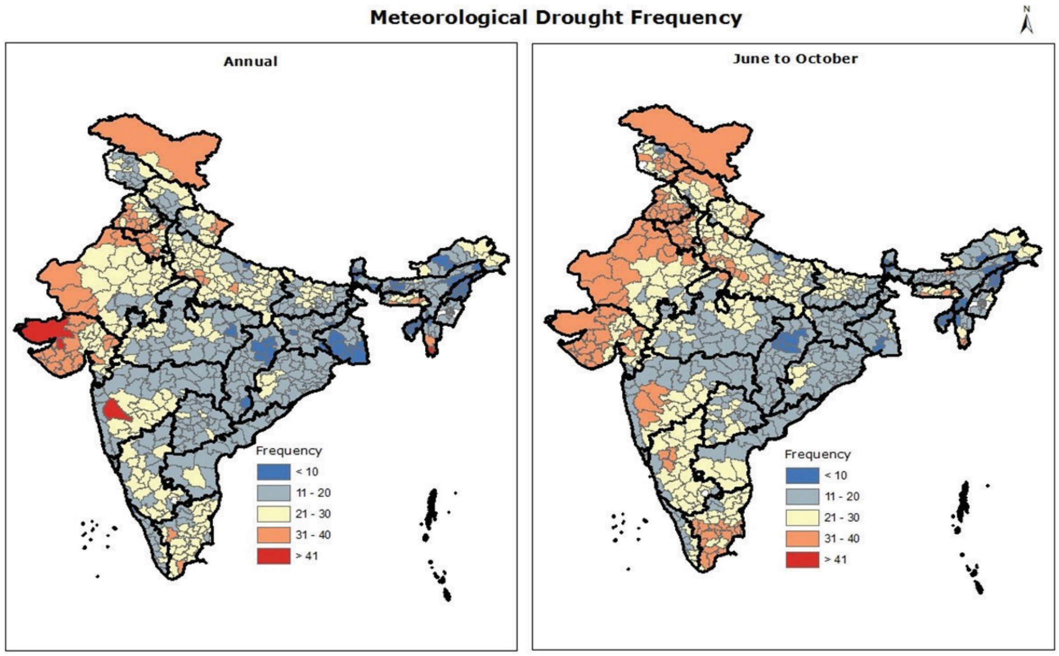


Figure 9 Meteorological Drought Frequency during the period of-1986-2015

10.4.3.1 Cropping patterns and cropping systems

Based on critical evaluation of important cropping systems covering soil type, rainfall pattern, length of growing season, temperature regimes etc. for efficient use of available farm resources, CRIDA (1997) identified potential rainfed cropping systems for varying range of rainfalls, soils and drought situations. However, later length of growing period (LGP) was found a better index than rainfall for crop planning (Velayutham, 1999). The LGP is the period when the moisture and temperature regimes are suitable for crop growth, and it is computed as the sum of the periods when moisture is more than 0.5 PET plus time taken to utilize stored soil moisture. For example, a LGP of 210 days in deep black soils of Vidarbha could suitably be used for growing a short duration soybean (kharif) followed by chickpea (rabi) instead of a single long duration crop. While, short duration drought tolerant pulses such as moth bean and cereals of 10-12 weeks duration such as pearl millet and minor millets could be cultivated in arid regions with low seasonal rainfall (<500 mm) and length of growing period (< 90 days).

Institutes of ICAR and SAUs developed drought resistant varieties for different crops including horticultural systems through All India coordinated projects and the National Initiative on Climate Resilient Agriculture (NICRA) project. Drought resistant varieties for different rainfed crops suited different states are described by Maheshwari et al (2015). In areas of frequent drought in these states, these drought resistant varieties are recommended so as to have sustainable yields.

Table 2 Potential cropping systems and agricultural drought vulnerability based on rainfall and soil types Source: Modified from CRIDA (1997)

Mean annual rainfall (mm)	Major soil order	Growing season (weeks)	Suitable cropping system	Agricultural drought (frequency)
350-650	Alfisols, shallow Vertisols, Aridisols and Entisols	15	Single rainy season	Severe drought (Once in <5 seasons)
350-650	Deep Aridisols and Inceptisols	20	Either rainy or post-rainy season crop	Moderate drought (Once in 5-10 seasons)
350-650	Deep Vertisols	20	Post-rainy season crop	Moderate drought (Once in 5-10 seasons)
650-800	Alfisols, Vertisols, Inceptisols	20-30	Intercropping	Less prone to drought (Once in 10-20 seasons)
800-1100	Deep Vertisols, Alfisols and Entisols	30	Double cropping	Less prone to drought (Once in 10-20 seasons)
>1100	Deep Alfisols, Oxisolsetc	30+	Double cropping	Nil to less prone to drought (once in >20 seasons)

Table 3 Cropping systems based on the length of growing seasons Source : Velayutham (1999)

Length of the growing period (LGP)	Crops and cropping system suggested
<75 days	Mono-cropping of short duration pulses, perennial vegetations
75-140 days	Mono-cropping with short duration pulses, pearl millet, sorghum, castor, sesame or mono-cropping during post-rainy season with safflower, chickpea etc.
140-180 days	Intercropping
>180 days	Double cropping with winter sorghum chickpea, safflower, barley, lentil, mustard

10.4.3.2 Watershed management

The erstwhile soil and water conservation programs started way back in 1970s, steered through Model Watershed Programs though ICAR (CRIDA and CSWCRTI) in early 1980s convinced the policy makers to choose Watershed Development Program as vehicle for development of Rainfed Areas in the countryfor drought proofing as it offers scope for production enhancement with resource conservation and efficient utilization. Watersheds not only provide the extended period of water availability for better crop stand; it also protects the environment by conserving natural resources efficiently. At the core of the watershed development program is the resource enhancement for conservation and demonstration of production systems improvement which accounts for 75% of total allocated budget. Meta-analysis of watershed programs in the country indicated modest benefit-cost ratio (2.14), a 22% of internal rate of return increased employment opportunities, irrigated area and cropping intensity and conserved soil and water resources. Watershed programs performed well in rainfall regions of 700-1100 and when the program ensured peoples participation especially low and medium-income groups. Though India has a long history of water harvesting at village level through a cascade of reservoirs, with the availability of electricity and pumping technology, private investment on tube wells has enormously increased and the community-based water harvesting systems (tank systems) were gradually ignored. The emphasis shifted from community-based structures which use surface water to individual investments which enhanced the exploitation of ground water. Broadly the water conservation measures can be classified into

1. In-situ conservation
2. Mechanical measures such as bunds (contour/graded)
3. Drainage line treatment
4. Water Harvesting and reuse
5. Groundwater recharge mechanism

Though all of them can be implemented in a landscape theoretically, the priority for each of them changes with rainfall pattern. In Arid regions with less than 500mm rainfall, in-situ conservation measures and drainage line treatment (based on topography) would be the priority interventions. The following Table 4. Summarizes the priority interventions for different rainfall zones.

Table 4 Prioritized water conservation measures in different rainfall regions

Agro Climatic Zone	Rainfall (mm)	Priority Order of components
Arid	100-500	1, 3
Dry Semi-arid	500-750	2, 1, 3, 5
Wet Semi-arid	750-1000	2, 3, 4, 5, 1
Sub-humid	1000-2500	3, 4, 2, 1, 5
Per-humid	>2500	3, 4, 2, 1

The suitability of any in-situ soil and water management practices depends greatly upon soil, topography, climate, cropping system and farmers resources. Based on past experiences several field-based soil and water conservation measures have been found promising for various rainfall zones in India (Table 5).

Table 5 Prioritized field-based soil and water conservation measures for various rainfall zones in India (Vittal et al. 2003).

Seasonal rainfall (mm)			
<500	**500-700**	**750-1000**	**>1000**
Contour cultivation with conservation furrows Ridging Sowing across slopes Mulching Scoops Tied ridges Off-season tillage Inter row water harvesting system Small basins Contour bunds Field bunds Khadin	Contour cultivation with conservation furrows Ridging Sowing across slopes Scoops Tide ridges Mulching Zingg terrace Off-season tillage BBF Inter row water harvesting system Small basins Modified contour bunds Field bunds Khadin	BBF (Vertisols) Conservation furrows Sowing across slopes Tillage Lock and spill drains Small basins Field bunds Vegetative bunds Graded bunds Nadi Zingg terrace	BBF (Vertisols) Field bunds Vegetative bunds Graded bunds Chos Level terraces

Some of the conservation practices listed above could be done by farmers themselves in every season before the onset of monsoon while others need a proper planning and execution on a hydrological unit.

10.4.3.3 On farm rain water management

Rainwater, a crucial natural resource, is the key input in Indian agriculture. It is the prime mover in agricultural development in general and in rainfed agriculture in particular. Storage of water in the soil and in natural or man-made structures and efficient utilization of given quantity of water are important aspects of water conservation. In situ water conservation is a more feasible and practical proposition under most situations. The strategy for in situ moisture conservation lies in soil management, which aims to maximizing the use of rainfall by increasing infiltration and storage. Soil cover management (mulching / Canopy), tillage and land configurations (ridge and furrow, Broad Bed and Furrow, conservation furrows etc.) are practices aimed at increasing infiltration and soil moisture storage. However, returns are more when surplus water is harvested in farm ponds and recycled for supplemental irrigation.

- Water harvesting and supplemental irrigation do not jeopardize the available flows in rivers even during drought years or cause significant downstream effects in the study areas.

Based on the resource availability, broad guidelines for water management in watershed programme are given below:

For regions with rainfall less than 500mm:

- In-situ conservation coupled with farm/field boundaries should be given emphasis.
- To be created as hubs for production of millets with assured MSP.
- Deep soils only should be encouraged for cultivation.
- Livestock based farming system should be encouraged.
- Fodder needs to be met by growing grasses in soils with low to medium soil depth.
- Limited water resources could be used to produce high yielding fodder varieties. Available location specific technologies form ICAR & SAUs could be utilized.
- Water harvesting and recycling can be promoted on a limited scale based on topographic considerations
- Extensive area coverage rather than intensive irrigation needs to be followed for achieving higher economic gains with harvested water
- Runoff harvesting can be possible only if watershed receives runoff from upstream areas.

Rainfall (500-700mm):

- Crops can be grown in medium to deep soils with high available water content.
- Runoff harvesting could be possible in few cases for critical/supplemental irrigation.
- Horticulture can be promoted to a larger scale.
- Land capability-based land use planning with emphasis on alternate land use need to be promoted.
- Nutritious cereals could also be promoted.
- Soybean to be promoted with industry support

Rainfall (700-1100mm):

- Runoff harvesting is possible on small farms also.
- In-situ conservation with water harvesting for supplemental irrigation can be planned with in watershed.

- In few cases, residual moisture with in fields or pre sowing irrigation for rabi crop is also possible and there is a need to explore the possibilities based on location specificity.
- Watershed based systems to be promoted
- Farming systems can be promoted.
- Medium to deep soils with medium to high available water Content can be promoted for cultivation.
- Cropping and livestock based systems can be promoted.

Rainfall of 1000-1100 mm:

- Large scale opportunity for intensive agriculture
- Double cropping possible
- Integrated Farming Systems with fish etc have ana opportunity
- Runoff harvesting is possible for every land parcel
- On stream water harvesting to be promoted on large scale
- Watershed development programme to be implemented with renewed emphasis
- Oilseeds promotion for cultivation during Rabi season

10.4.3.4 Contingency crop planning

The National Agricultural Research and Extension System lead by Indian Council of Agricultural Research (ICAR) through its institutes and state agricultural universities developed technologies to overcome the negative affects due to these weather aberrations and extreme climatic events. The Government of India initiated the process of documentation of available technologies for each district in the country, which is the primary administrative unit for intervention.The district based contingency plans were prepared for 600 districts in the country so far and hosted on ICAR / DAC websites (http://agricoop.nic.in, http://www.icar-crida.res.in/ and were made available to all state agriculture departments for implementation.

10.4.3.5 Technology and data gaps

- Lack of availability of suitable farm implements for promoting in-situ conservation measures for water conservation is one of the major problems. There is need to develop suitable equipment catering to various crops/ cropping systems/ intercrops for different agro ecologies
- Lack of suitable guidelines on water harvesting for various agro climatic regions leading to either excess capacity or insufficient capacity creation thus not realizing the optimum benefits

- Insufficient quantum of seed production of drought resistant varieties and contingent crops for popularization and distribution among farming communities

- Lack of mechanism for ground truth information collection on agriculture drought propagation in rainfed regions. The problem is more compounded in regions where multiple crops are grown.

- Lack of appropriate indices for agricultural drought for different crops. Different indices developed so far are dependent on rainfall based or earth observation based and are not specific to a particular crop.

- Indices used with earth observations compare the present crop condition to the crop conditions prevailing in different years and intensity of drought is quantified. However, this algorithm does not take into consideration of the changes in onset of monsoon, varying windows of crop sowings, change in crops sown form year to year.

- Lack of appropriate indicators for quantifying drought in inter cropping systems

- Non-availability of data on climate and earth observations in a timely manner

- Lack of trained man power for monitoring and issuing agro advisories

- In case of long-term measures envisaged in the watershed program, choosing appropriate solution to address with in season drought is an important event. It is very important to train the extension personnel as well as PIAs on the appropriate choices of interventions to be recommended based on soil, climate and topographic conditions. The present watershed programs which are implemented in large scale by government agencies lack this kind of trained manpower leading diversion of available funds to other interventions.

- Lack of awareness on agricultural contingency planning

10.4.3.6 Emerging technologies

The important emerging technologies, which would have wider application in future include

- Development of short drought resistant varieties with heat stress through new set of breeding tools to meet the challenges of rising temperature.

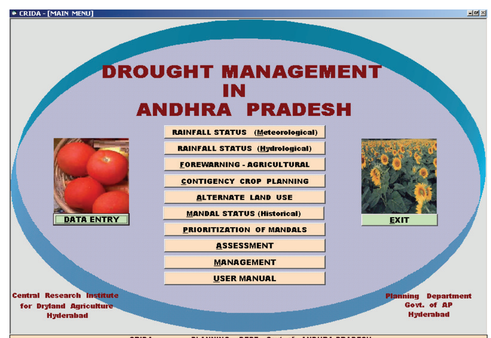
- Integration of climate and natural resources within GIS framework, which would help to build long term measures on ground for coping up with drought.

- Enhanced use of micro irrigation systems in various agro-ecologies to reduce the water demands.

- Availability of datasets at higher resolution through earth observation, and with advent of Google Earth Engine which facilitates computation and visualization in a cloud computer architecture, the necessity to host costly equipment is dispensed with. This offers a scope to deploy large personnel at state governments to deploy for monitoring which can be effectively translated to management of drought.

- The micro wave remote sensing data availability through some of the space agency offers scope to develop new tools for drought monitoring. The national and state space agencies in collaboration with agricultural research institutes and line departments can work together on large scale for drought monitoring. **DSS in drought management.**

A Decision Support System (DSS) is an integrated interactive computer-based system consisting of analytical tools and information management capabilities designed to aid decision makers. It typically consists of data bases, modeling tools and documentation of the decision-making process. CRIDA has developed drought management plan for 1200 mandals and 22 districts of United Andhra Pradesh (Venkateswarlu, 2010). The inputs include daily rainfall, maximum and minimum temperature for deriving PET, crop coefficient, available water content (AWC) for a given soil type, maximum yield of crop, duration of the crop and sowing date. Information on groundwater, surface water and livestock management are also included in the DSS. Drought preparedness is much more cost-effective than expenditure on relief measures.



To conclude, it can be said that present available mechanisms for monitoring still fall short of monitoring of drought for individual crops and in different years. New technologies or tools and datasets give hope for better monitoring in the coming years.Weather forecasting tools are also very important for drought management. Though significant improvements are made at block level weather forecast by IMD, reliability of the data is still an issue. Inventorisation of available water resources within blocks/ districts and making them available along with water application devices to line departments during long dry spells would help in quick rolling of interventions in farmer fields.

Recommendations

To enhance the dual polarized Doppler RADAR network covering the entire country, along with enhancing Automatic Weather Station (AWS) & Automatic Rain Gauges (ARGs) for hourly/3 hourly data (particularly to region of hotspots at mesoscale resolution ~5km

The objective is to improve Weather Observation using Automatic Weather stations (AWS) at village level.

- Aircraft observations for obtaining data from the TC field

- Ground based mobile observing platforms for improving the density of observations.
- IT based decision support system for devising effective disaster management strategy.
- All TC research groups to be brought under a single umbrella of National Centre for Tropical Cyclone Research.
- Advanced technological gadgets for communication, easy movement etc. for effective rescue and relief operations
- A multi-institutional approach involving all stake-holders would be effective in minimizing the disasters due to TCs.
- Development of Indigenous Technologies for the following observational equipment
  - Radio Sonde
  - Dual Polarized DWRs (S, C and X Band)
  - Wind Profilers
  - Lidars
- Improvements in Space based observations: Geo Stationary and Polar Orbiting
- Air borne Observations: Aircraft, UAVs & research drones: Real time Monitoring of the centre of the cyclone, intensity, winds and pressure and assimilation in Numerical Models.
- Improved Cyclone Prediction Models through coupled HWRF, Ensembles, Dynamical cone of Uncertainty.
- Improved Storm Surge predictions via improved set of inputs viz., current position and forecast of: Cyclone Centre, intensity, pressure gradient, RMW, wind speed in different quadrants for Storm Surge Predictions
- Impact based Multi Hazard Warning: Coastal inundation, inland flooding, Wind and Heavy Rainfall damage.
- Promote Cyclone related Citizen Science in Educational institutions in cyclone affected states.
- Upgradation of Doppler Radar network for good coverage over entire country will help to provide early warning of extreme weather events like heavy rainfall and Hail storms.
- Radar as well as other kinds of dense observation network should be established over hilly regions to construct the 3D vertical profiles of the atmosphere and should be complimented by satellite Cloud Top Temperatures (CTT) to study the mixed-phase microphysics and convection during cloudbursts.

- Expansion of existing network of tide-gauges (36 Nos.) with the addition of 40 tide gauges to record the sea level changes and storm surge on the Indian coast
- To enhance the upper air sounding to 100 stations with 2 times per day sounding across India.
- The Realtime data useful for monitoring the weather as well as bias correction of numerical weather prediction models should be carried out. Assimilation of these data will help to improve weather forecast at local scale.
- Seamless availability of LANDSAT and RADAR Sat data before and after the cyclone and extremely heavy rainfall events leading to floods from NRSA, Hyderabad for the validation of coastal inundation.
- Availability of ALTM data up to 10 m topography contour at 1 m or better spatial resolution. INCOIS has generated the ALTM data for the mainland coast over a 2 km width from the shoreline with the help of NRSC, Hyderabad. Survey of India also has generated the ALTM data over a wider width of the coast (exact width is not known). Both data sets may be examined before venturing to map the remaining area to obtain a uniform coverage up to 10 m contour.
- Development of land, ocean and atmosphere coupled model for cyclone, storm surge and other extreme weather forecasting. IMD, INCOIS, IIT-D and IIT-Kharagpur could be the implementing agencies with IMD or INCOIS acting as the lead agency.
- To quantify the uncertainties associated with extreme weather including heavy rainfall, cyclone intensity & storm surge forecasting, develop probabilistic forecast in addition to deterministic forecast (IMD and INCOIS).
- Conservation and Plantation of Mangroves in the coastal belt which would act as barriers for storm surge and waves.
- Planned infrastructure building with appropriate drainage systems based on historical data on storm surges and future projections to minimize or alleviate the damages to life and property.
- Construction of structures at an elevation higher than probable maximum storm surge. All buildings in coastal areas to follow the best practices set by BIS and Building codes of India. Other infrastructures like power and telephone lines could be laid through underground cabling to avoid the breakdown of services due to storm surge.
- Organisation of community awareness programmes in surge prone areas to create a disaster resilient society. NDMA may lead the efforts.
- There should be a formal coordination between the researchers who are engaged with cyclone & storm surge observations and modelling (IMD

or INCOIS acting as lead agency to coordinate between IMD, INCOIS, IIT-D and IIT-Kharagpur) or through the establishment of a Cyclone Warning Research Centre under Ministry of Earth Sciences to further improve the accuracy of cyclone & storm surge forecasts and associated inland inundation and to device better forecasting and dissemination modalities taking advantage of the changing information technology and communication means. Better collaborations with other operational cyclone & storm surge warning centres across the globe such as NOAA is also recommended to further enhance the existing forecasting system.

- Generation of high resolution (5km horizontal), hourly/3 hourly analysis of rainfall on real time basis from merged rain gauges, DWR and satellite derived rainfall.
- Generating the Digital Elevation Map to be used in Hydrological models for all the flood prone cities of India.
- Convective scale data assimilation and cloud resolving model-based prediction (~1km) is the need of the hour for meeting the current challenge of extremely heavy rain and location specific forecast.
- Probabilistic Quantitative precipitation forecast over river basin needs to have better accuracy with longer lead (~7 days)
- Improvement of the NWP models, its resolution and model diagnostics products are required. Downscaling (using AI/ML) of the NWP model products to meet the requirements of district, block, panchayat/village levels and location specific forecasts and warnings
- Incorporation of the reduction of the carrying capacity of river channels due to the phenomena viz. earthquakes and landslides leading to changes in river courses and obstructions to flow; synchronization of floods in the main and tributary rivers; retardation due to tidal effects; encroachment of floodplains; and haphazard and unplanned growth of urban areas in flood forecasting system.
- Better coordination with various agencies, State Governments and Disaster Management Authorities for the availability of data of exposure and vulnerability related to adverse weather events required for impact modelling and also to get support in prediction of possible impacts. Also, efforts to be made to get maximum observational data from the network maintained by such agencies.
- Tailor made location specific impact-based forecasts for easier and greater acceptance of forecasts by general public and disaster management personnel. IMD and INCOIS may implement.
- Introduction of nonconventional methods of observations through various platforms like IOT, crowd sourcing. Efforts to ensure better utilization of Crowd sourcing platform to get maximum information about the adverse weather scenario happening across the country.

- Refresher courses/Capacity building programmes to familiarize the forecasters with the latest developments and practices in weather monitoring and forecasting field for their better utilization.
- Climatology and geological information should be integrated for the analysis and finding out hot spots of cloud burst [Agency: IIRS/IITM].
- Satellite technology and geomorphological information should be maximum utilized to understand, simulate and monitor cloudbursts and the underlying processes [Agency: NRSA/IIRS]
- Influence of local factors like forest fires, aerosols, dams and reservoirs for occurrence of cloud burst should be incorporated in the studies with high resolution numerical models [Agency: IITM].
- Geological mapping by IIRS &GSI should be used for cloud burst related landslide & other hazard zonation mapping [Agency: IIRS, &GSI].
- Linkages to glacial lake outbursts and other pre-event signals like the number of days of preceding spells of continuous/heavy rainfall, soil moisture saturation and wilting point etc. should be established and routinely monitored [Agency: NCESS/NCPOR].
- Ongoing R & D on radar reflectivity-rainfall relationship over Western Ghats will be worth exploring [Agency: IITM].
- Cross linkages of cloud burst with other hazards like, lightning, wind gust, flash floods, landslides and debris flows should be utilized as early indicators [Agency: NCESS/NDMA].
- High resolution models should be implemented over Hilly regions and MCZ to study the explicit convection and turbulence under different synoptic conditions [Agency: NCMRWF/IITM].
- Short and medium term measures should be implemented on ground immediately to mitigate the impact of possible cloudburst over hot spots [Agency: NDMA/GSI].
- Feasibility studies for future technological innovations and engineering solutions should be sought out as long-term measures in connection with cloud burst [Agency: DRDO/IITM].
- Development of flood plain maps (hazard maps and risk maps) for different return period flood for every city / district within the context of its larger river basin to develop action plans
- Design and development of early warning systems- IT, communications, flood routing, dam controls, and innovative dissemination techniques like crowd sourcing and mobile apps.
- Development of libraries for different rainfall scenarios and city's thresholds. If possible real time rain/radar observations every 3 to 6 hourly ingestion into system and generating dynamic /animated graphics could be included in main texts.

- Developing Community resilience along with real time auto feedback system, use of technologies like drones for actual aerial survey of situation during floods

- Development of resilient infrastructure- structural and non-structural measures.. Best use of the existing available system for water discharge; like improvement in drainage network, planning or control on new developments in flood prone areas, pumping stations etc.

- Developing indigenous sensor systems, network & communication system, indigenous modelling platforms and operational guidance systems.

- **Disaster Resilient Communication Infrastructure**: Provisions for Disaster Resilient Telecom network have been clearly laid down in the DM SOP of DOT. These should be rigorously implemented and regularly rehearsed/checked.

- **Penetration of GSM/Terrestrial Network**: National Telecom policy should incentivize deployment of GSM network in sparsely populated remote regions to encourage TSPs.

- **Easing of Satellite Communication Regime**: There is a need for review spectrum charges, licensing policy and duties/taxes on satellite terminals to facilitate ease of business.

- **Integration with Social Media**: Regulations and Policies permitting social media platforms to operate in the country must incorporate provisions whereby they must facilitate the efforts of the Government to ensure safety of the citizens and mitigate loss of life and property.

- **Compliance by TSPs**.: Ministry of Communications through DOT must leverage TSPs to comply with the directions of Government.

- Heat wave impacts on the human health are more in the urban areas being more vulnerable due to the UHI effect and population density. Hence there is need to analyse UHI effect in all major cities for issuing the impact-based heat wave warnings.

- Heat action plan should be implemented for all districts, cities & towns. The impact-based heat wave warning to be developed to include special impact of heat wave on crops, electricity generation, transmission, distribution and demand (Energy Sector).

- In line with heat wave action plan, cold wave action plan should be prepared and implemented for all districts, cities and towns.

- Wind chill & humidity exacerbated the impact of cold wave on human health. Hence there is need to consider the wind & humidity for issuing impact of the cold wave.

- The cold waves also affect agriculture and infrastructure in India. Some of the impacts of the cold waves may damage to agriculture, animal husbandry and wildlife. The damage to infrastructure is well evident e.g. damage when water pipelines freeze and burst. The impact on the energy sector is well marked with a rise in the demand for fuels and electricity. Hence there is a need to consider the impact of cold wave over-all above-mentioned sectors while issuing the impact-based warning.

- Set up system for weather modification to suppress the development of Hail storm.
- A National Data Centre need to be setup for seamless inflow of data from various organizations and easy real-time access to expert Intuitions for value addition for providing impact based forecast advisory to stakeholders.
- High resolution (village level) weather forecast at various temporal scales (nowcast, short-medium range, monthly and seasonal). Seasonal forecast of rainfall & temperature needs to be given priority as leads in other temporal scales are encouraging.
- Integration of simulation models, weather forecast, remote sensing and expert systems is needed for improved management of agriculture.
- It is important to bring the intuitions with expertise and capabilities to bring together to develop such systems/platforms for the benefit of farmers, agriculture and Nation.
- An institution for hosting health data needs to be established.
- Inter institutional collaboration with advanced research and training should be developed to attract global talent to find solution of impact of global warming on agriculture, health and diseases etc and creating trained manpower.
- In order to identify animal pathogens and other vector borne diseases of zoonotic importance at ICAR-NIHSAD existing facility needs modernization of the structural / Bio engineering components. At present the old BSL4 lab can be graded as BSL3+hence, the facility has its own limitations to handle the high-risk zoonotic pathogens mainly vector borne diseases lurking at our borders. Considering emergence of certain exotic animal diseases like CCHF and Nipah, there is urgent need of establishing a new Bioengineering infrastructure in form of a BSL2+BSL4 integrated laboratory with most modern facilities. The estimated budget for such a facility may come to Rs 600crs (First phase Rs 350cr for Civil & Structural engineering components; Second phase Rs 250crs for lab equipment, personals and other biosafety requirements with additional 20% fund for emergency requirements.
- Considering the geographical area and risky sample transportation from all the part of the country to Bhopal, it is essential to have two additional BSL4 labs exclusively for animal diseases. One of these can be established in South and second one in NEH region. Including all the estimated cost for these labs may come to Rs 250 to 300 crores each.

- For the continuous and assured safety of the MME (man i.e. lab workers & surrounding residents, material & environment) BS & BC systems run on zero bioengineering mistakes without compromise in their day to day SOPs. It is needless to mention that in BS systems, if Bio engineering components fail or have substandard performance, MME stands at risk or may lead to escape of pathogens or a disaster. Besides infrastructure, it requires bio safety trained professionals (Biologists/Engineers). It's an open fact that a team of trained staff has been the backbone of successful performance of HSADL/NIHSAD over last two decades. In view of these facts INAE / IMD/ DBT in consultation with NABL, may constitute a panel of technical experts for pre and post evaluation, periodical validation and monitoring of the BS/BC (Biosafety/ Biocontainment) facilities throughout country.

- Based on the existing sea-level records, there is a need to have a detailed shoreline monitoring and in particular the changes in Island morphology in context to climate change.

- Different general circulation models (GCMs) under CMIP5 and CMIP6 family are designed at different spatial resolutions. There is a need to downscale the output from GCMs to finer-resolution on regional scale for the Indian Ocean region. Two of these methods such as the dynamic method and statistical methods are being widely used. Better methods and practices need to be developed using nested modelling approach for regional scale applications.

- The potential for compounding effects such as storm surge, extreme waves on sea level rise in a changing climate is a concern as they can contribute significantly to flooding risks and extreme events impacting coastal regions. There is a need to address this issue using hydrodynamic models.

- More research activities are required to improve the satellite algorithms especially for the coastal waters. Regions with mangrove vegetation should be prioritized.

- Monitoring activity should be made continuous for coral bleach health. Generation of alert maps along with capacity building.

- Numerical modelling efforts should investigate the pathways of CO2 in the Bay of Bengal and neighbouring North Indian Ocean region. Numerical models should be developed integrating heat and CO2 flux coupler to general ocean circulation models. Transfer of CO2 and its redistribution in the system should be better understood.

- Modelling activities should consider the emission scenarios from projections of CMIP5 and CMIP6 datasets to obtain estimates of ocean acidification scenarios.

- In order to understand the long-term changes in regional and extreme sea level along Indian Ocean coastline, continuous monitoring of sea level along the coastline is needed. Sea level rise will affect coastal populations in a variety of ways, including inundation, flood and storm damage, erosion, saltwater intrusion, rising water tables and impeded drainage wetland loss.

- High resolution climate modelling framework capable of resolving coastal processes, bathymetry and large-scale ocean dynamics needs to be established to understand the regional sea level rise. Reliable projections of regional sea level rise and extreme weather events are needed to address the projected changes in regional sea level rise as well as extreme sea level.
- Need continuous monitoring of sea level along Island stations of Indian Ocean, as compounding effects, like storm surge and high sea level rise, are of particular concern for the small Islands. A small increase in mean sea level can significantly augment the frequency and intensity of flooding in small Island regions, because sea level rise can elevate the platform for storm surges, tides, and waves.
- To effectively address the vertical land movements in sea level measurements, establish Global Navigation Satellite System (GNSS) stations co-located with tide gauge stations.
- Capacity building in climate modelling and training for the operation, data processing, and GNSS network of tide gauge stations needs to be established.
- Effects of Global warming and coastal erosion – Effects of global warming – SLR, enhancement of oceanogenic hazards due to SLR, and other effects like acidification, coral bleaching, effects on biodiversity, fishing etc. Loss of coasts and beaches – unscientific coastal development – Coastal vulnerability assessments –
- Coastal environments are subjected to changes as rivers, nearshore currents, and wave activity transport sediments inside, outside, and within the nearshore regions. Morphological evolution accelerates under extreme weather events which can also lead to irreversible changes. Relative sea level rise also contributes to coastal erosion in low-lying regions as well enhances the vulnerability from Oceano genic hazards. There has been considerable amount of anthropogenic CO2 emissions absorbed by the oceans from about 24% to 33% during the past five decades. Massive amount of CO2 in the oceans leads to abnormal changes in the chemistry of seawater affecting the carbonate cycle. Changes in the chemical properties of seawater lowers the pH leading to increased ocean acidification. Impacts of ocean acidification affects the marine biodiversity and coral reef bleaching is a matter of concern. There has been substantial decline in coral reefs. Though ocean acidification is a serious issue in global ocean basins, the Bay of Bengal in the North Indian Ocean is a region highly prone to serious issues of ocean acidification.
- Studies pertaining to ocean acidification in the Indian Ocean region have been carried out in the recent past. Utilizing remote sensing and field

data research studies attempted to correlate the carbon conditions in the Arabian Sea and Bay of Bengal. Studies pointed out there is a decreasing trend of particulate inorganic carbon in the last decade that is linked to decrease in phytoplankton abundance, microscopic organisms that forms the biological food chain the marine ecosystem. Studies have also analyzed parameters such as chlorophyll-a, SST, particulate organic carbon and photo-synthetically active radiation.

- Technological interventions – Ways and means of reducing global warming – renewable energy – reduced carbon foot print – IPCC numbers – globally and Indian efforts – sustainable coastal protection – Scientific Marine spatial planning – Climate change adaptation options –
- Technological intervention should consider strategies that addresses impact of climate change on coastal regions by selection of the best engineering solutions that can be put in practice. It should consider the best shoreline protection practices that are being adopted now and also take into account that these practices would prove successful in climate change projections. Sea level rise contributes to increased shoreline erosion rates, and has the capacity to exacerbate erosion through offshore sediment transport.
- A variety of different technologies are currently under development throughout the world to harness this energy in all its forms including waves. Deployment is currently limited but the sector has the potential to grow, fuelling economic growth, reduction of carbon footprint and creating jobs not only along the coasts but also inland along its supply chains. Given the long-term energy need through this abundant source, action needs to be taken now on R&D front in order to ensure that the ocean energy sector can play a meaningful part in achieving our objectives in coming decades. Most types of technologies are currently at demonstration stage or the initial stage of commercialization. Also, sensitivity of the performance of energy devices to ocean parameters and their variability and non-availability of specific data at desired locations leads to strong need for resource assessment with a prime focus on the energy extraction. The knowledge of resources available within the territorial waters will give good understanding and would lead to more efficient designs of energy devices suitable to the site-specific conditions. This can be done by carrying out detailed resource mapping along the Indian coasts with a focus on requirements of energy devices for Indian conditions.
- Commercial viability studies of offshore wind energy showed promising results for the states of Tamil Nadu and Gujarat and these studies can be extended to other parts of coast by measuring wind profile with LIDAR. The substructure that supports offshore wind turbine in ocean accounts almost of 40% of the project. Hence, to improve the economics of offshore wind projects, it is essential to develop reliable and innovative sub structure concept along with indigenize installation methodology. This can be achieved through continued R&D efforts modelling and demonstration.

- The demonstration projects aimed at analysis of behaviour of fixed/floating substructure concepts, which can lead to demonstration of these concepts in the field so that industry can take up these concepts for development of offshore wind project.
- India being a tropical country and being closer to the equator experience the warmer sea surface temperatures in the range of 28°C to 32°C. The temperatures at the presently exploitable depths around India are found to be in the order of 4°C to 6°C, thus providing the desired temperature difference. The energy generation from this ocean thermal gradient is called as Ocean Thermal Energy Conversion (OTEC). The sea water temperatures are observed to be stable and are prevailing continuously throughout the year. Ocean Thermal Gradient can also be utilized for desalinating seawater in the form of Low temperature Thermal Desalination (LTTD) as implemented by ESSO-NIOT in Lakshadweep Islands.
- Marine organisms like algae can be a potential bioenergy feedstock for the developing nation. The high growth rate and photosynthetic capacity of marine algae can produce much higher amount of bioenergy when compared to terrestrial plants and considered as better alternative than bioethanol from sugarcane. Generation of biodiesel from marine organisms is one of promising area of research.
- India has made substantial progress in understanding the causes and effects of drought. The use of science and technology has made considerable in roads in the processes of planning, implementing preventing and mitigation of droughts. But, as the overview of preceding sections reveals, there is considerable scope for intensifying use of the existing technologies, further refinement and innovations in technologies; and the supporting institutions and policies.
- Drought monitoring, impact assessment and management need to be strengthened with technology/science-based information products and services. The precision and accuracy of drought prediction need to be improved by combining the knowledge of physical mechanisms involved drought processes.
- Exploitation of emerging technologies for drought management: Richly available satellite data, increasing network of weather observatories, mobile based fast and efficient field data collection systems, expanding field instrumentation network, easily accessible advanced techniques of data analysis etc. are to be fully exploited to improve drought management system in the country(MNCFC,CRIDA,and NIH).
- Operational Drought Monitoring and Early Warning System: Operational drought monitoring and early warning system (EWS) using these new technologies, which may need more sophisticated analysis and modelling techniques, as well as improved scientific knowledge from the basic research, should be developed (IMD,MNCFC, NIH, CRIDA).

- Hybrid models and techniques for improving drought detection, mapping and impact assessments: The combination of Wavelet Transformation, Autoregressive Integrated Moving Average (ARIMA) and Artificial Neural Network (ANN) (hybrid models) have proved useful for accurately predicting the future droughts. The development and use such models should be promoted (, NRSC, IITs).

  - Interconnection between drought and large-scale atmospheric circulations: The teleconnection between drought, drought monitoring, forecasting, and future projection; and the large-scale atmospheric circulations in the South Asia is not adequately researched. Research efforts in this field need attention (IMD, IITs).

  - Region specific composite index of drought indicators: One size does not fit all. Use of region-specific impact assessment methodologies, appropriate drought index and meteorological parameters for declaring drought is warranted (CRIDA, IMD, and MNCFC).

- Integrated Drought Index (IDI): There are a large number of different types of indicators associated with meteorological, hydrological, and agricultural droughts, which create a challenge for monitoring and assessing their combined impact. (NRSC, CRIDA, NIH).

- Integration of multiple parameters related to weather, soil and crops based on parametric or non-parametric techniques should be done to synthesize a composite drought index specific to different crop growing environments or agro-ecosystems. Research reported on such composite indices reveals the scope for implementing such new methods in India also (ICAR-CRIDA, CAZRI, NRSC).

- Overcoming the non-stationary factor in meteorology dataseries due to climate change:The index-based approaches are useful tool to measure and monitor risks associated with natural hazards like drought and climate change. But the indices are static in nature and do not capture the complexities and dynamics of vulnerability and risk.This drawback can be overcome by system dynamics modelling and Bayesian approach, which are capable capturing complexity and generating information for decision making.(NIH, IITs).

- Establishing the time-lags between different type droughts: The time-lags of agricultural and hydrological droughts to meteorological vary across watershed. For planning effective management strategies, it is crucial to establish this lag in response time (NIH).

- Strengthening data base: Large historical data of meteorological and hydrological nature is required in order to study drought. Data mining, the technique which is used to find actionable patterns, profiles and trends using pattern recognition techniques such as neural networks, machine leaning and genetic algorithms, should promoted to extract information (MNCFC.NRSC,IITs,IMD).

- Development of suitable socio-economic drought index:Climatic and hydrologic factors are no doubt important, but not sufficient for correct assessment of vulnerability; and must include socio-economic factors. The occurrence of socioeconomic drought events is bound to increase in future due to continuous growth in population and climate change, causing multifold in water demand. It calls for a proper socioeconomic drought index (SEDI), for identifying and evaluating socioeconomic drought events on different severity level (ICAR-CRIDA, MNCFC).

- Heat and Drought resistant crops: It is now well established that intensity of heat and frequency of drought is going to increase due to changing climate. Application of crop engineering to tweak the genetics of crops to increase yield and better resistance to drought is recommended. (ICAR-IARI, CRIDA, SAUs).

- Groundwater Management: Groundwater is the most important drought reserve in several parts of India, which now stands depleted; and its value for drought management is getting reduced. It has therefore become incumbent to modify cropping pattern in harmony with the groundwater endowment for ensuring sustainability (All GoS).

- Propagation of soil and water conservation technologies: Quite a few good technologies (eg zero till, mulching and land surface modification etc) that mitigate risks from drought, and other climate-related hazards are available. Programmes for the widest possible dissemination of these tools and solutions are recommended (ICAR-CRIDA, CAZRI, NRAA).

- Conceptual perspective-shift from crisis management to managing risk: The drought policy based on the philosophy of risk reduction can alter approach to drought management by reducing the associated impacts (risk). It has been established that crisis management approach reduces self-reliance and increases dependence on government, as affected communities keep looking for doles; and this increases their vulnerability to future drought episodes. Therefore, there is an urgent need to change the paradigm for drought management from the one primarily focused on managing the disaster to one focused on managing risk. Safety net for most vulnerable is needed, but it should lead to drought risk reduction, which would involve investment in infrastructure (NITI AAYOG, MoAC&FW, GoS).

- Institutionalization of monitoring: Monitoring of planned risk management activities should be institutionalized. It would be beneficial to put in place a structured system of monitoring with larger use of technology and little of human interface. Additional human resources might however be required for establishing robust monitoring and hydrological modelling (CWC,CGWB,NRSC, IMD)

- Linking science-to policy: Science and technology tools play important role in the linking of the 'last mile. Therefore, the decision makers and the stakeholders should be familiarized with the importance of drought assessment and forecasting tools through frequent interactive sessions in the langue. This would help in arriving at investment decisions for strengthening research technology innovations and upgradations of infrastructure (MoA&FC, NRAA and ICAR).

- Education and training: The universities should initiate programs linked to DRR for producing trained practitioners and researchers. Further, new certificate and customized courses should be initiated for development of young professionals for undertaking disaster preparedness activities. Special attention be given to capacity building for utilization of space technology for its uses in understanding risks at the national level needs. (ICAR, NRSC,IMD,MNCFC,NRAA, SAUs, IITs).

- Intensification of monitoring stations: Weather monitoring at Panchayat level for estimating crop damages with spatial accuracy for insurance purpose; Stream flow gauging stations and groundwater levels for assessment of hydrologic droughts. Increasing used of remote sensing-based precipitation estimation and evaluation is recommended. (CWC, CGWB, IMD, NRSC).

- Research on DRR: India lags behind several countries in Asia in respect of investment in DRR related research as it had a normalized score of only 53 /100(Shaw et al,2016). Obviously, there is urgent need to increase investment. (MoA&FW, DST, ICAR, IMD, SAUs).

- Water positive activities: Groundwater recharge structures, surface water harvesting, micro-irrigation etc, should receive adequate funding to reduce drought risk (GoI,GoS).

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CHAPTER - 2

OCEAN RELATED DISASTERS

Contents

Marine Disruptions

1. Introduction

We live on a blue planet. With oceans covering more than 70 percent of the Earth's surface, our Ocean defines our planet and it is home to more than half of all the life on the Earth Today. The Ocean provides us with countless benefits. It sustains us by regulating the climate and providing every second breath of oxygen that we breathe, it feeds us and generates livelihood for millions of people who are dependent on it. From fisheries to Marine biotechnology, Minerals exploration to the global shipping industry, from renewable energy to tourism and coastal protection. We are interconnected with the oceans and depend on its health, in more ways than one. It is imperative that we understand our ocean for better management that will help us Conserve, Protect and Restore for future generations. However, Ocean also produces many disasters or hazards either due to natural or manmade to the mankind. In order to avert and equip to face such disasters, it is imperative to have forewarning and also preparedness for the same.

The following ocean related disasters / hazards need to be studied, and plan effective preparedness to avert or mitigate their impacts.

1) Coastal inundation and flooding due to Tsunami/Tropical Cyclones/Swell surge/ Extreme waves (Priority – 1)
2) Oil Spills (Priority – 2)
3) Harmful algal blooms / Hypoxia (Priority -2)
4) Sea level rise due to Climate Change (Priority-3)
5) Coral bleaching / Ocean acidification (priority-4)
6) Marine plastics / debris (Priority-4)
7) Marine heat waves (Priority -3)
8) Rip currents (Priority-4)

Out of the above oceanic disasters, Only Priority 1 and 2 are recommended since other priorities are not an immediate danger now.

2. Coastal inundation and flooding due to Tsunami/Tropical Cyclones/ Swell surge/Extreme waves

One of the biggest threats to coastal communities is severe inundation and its frequency associated with extreme water levels in the nearshore regions due to various environmental drivers affecting human population. Impact resulting from coastal inundation can significantly affect the shoreline configuration, cause damage to infrastructure, saltwater intrusion into groundwater, destruction of crops, and affect human population causing wide socio-economic consequences. This may be due to Tropical Cyclones or Tsunami or Extreme wave /swell evets, etc.

i) Tsunami

Tsunamis are considered as the most devastating marine hazard ever known, impacting large areas of coastal environment. In addition, to seismic activity, there are also other factors such as submarine landslides, under sea volcanic eruptions and meteoritic impacts that can generate tsunami affecting the coastlines. ESSO-INCOIS has 'state-of the art' tsunami early warning system for the Indian Ocean region that provides advanced information in the event of tsunami triggered due to underwater earthquakes, detected by land-based seismic stations and ocean bottom pressure transducers. Once the earthquake event occurs, it is possible to detect and model it to forecast the arrival of such large tsunami waves, coastal inundation, etc. The warning system is very effective, providing timely tsunami bulletins and alerts for countries surrounding the Indian Ocean rim. It is important to note that tsunamis can also be triggered by submarine landslides, under sea volcanic eruption and meteoritic impacts, that needs detailed work and action plan for implementation in the existing warning system.

ii) Tropical Cyclones and Strom Surges

Tropical cyclone is another natural oceanic disaster that occur both in Bay of Bengal and the Arabian sea. Tropical cyclones trigger storm surges that can inundate and impact large stretches of coastal areas. IMD has a state-of-the-art observational system for cyclone forecasting. Based on this, ESSO-INCOIS produces Storm Surge forecasts that are issued to public in the joint bulletins issued by IMD and INCOIS.

iii) Extreme waves

KallaKadal events are caused due to swells generated by storms in the Southern Ocean. This phenomenon mostly occurs during the pre-monsoon season and sometimes during the post-monsoon, and continues for a few days inundating the low-lying coastal regions. During high tide condition, the water levels can reach about 3-4 m above the maximum record. ESSO-INCOIS has documented the possible teleconnection between North Indian Ocean high swell events and the prevailing meteorological conditions in the Southern Ocean belt. Study has found the presence of severe low pressure system, also termed as 'Cut-Off-Low' quasi-stationary in nature in the Southern Ocean belt about 3-5 days prior to high swell events attacking the south-west coast of India.

2.1 Present Status

ESSO-INCOIS provides timely warnings and storm surge envelopes on real-time for cyclones approaching the landfall. The predictions made for storm surge characteristics and flooding is immensely useful for emergency preparedness and timely evacuation measures. Figure 1 shows the schematic diagram of current status of warning system established at ESSO-INCOIS. While risk assessments and warning systems are available for ocean related disasters such as Cyclones, Tsunami, Extreme Waves, etc., it is imperative to effectively disseminate the warning to various stakeholders with proper communication and dissemination systems. Once the warning is issued, there should be adequate preparedness at the disaster managements institutions and the public to respond it. All these disasters will eventually cause inundation along the coast which needs to be handled under an integrated multi-hazard framework.

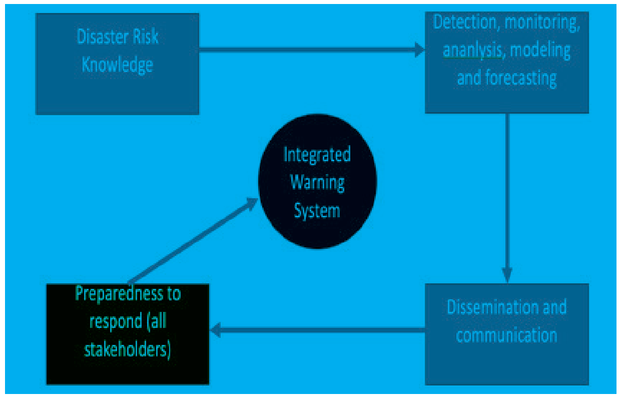


Figure 1: Blue box indicates the mechanism is in place, red indicates need to augment and Yellow indicates needs improvements.

2.2 Gap Areas

- The warning system for tsunami, cyclone triggered storm surges and extreme wave events are currently operationalised at ESSO-INCOIS.
- The existing tsunami warning system is only good for tsunamis generated from seismic events. However, about 10-15% of tsunamis are generated due to non-seismic such as submarine landslides, volcanic eruptions, and meteoritic impacts that are non-seismic in nature. Effective warning for such events demands implementation of additional ocean observing systems that can detect volcanic eruptions and massive landslides in the continental shelf and slope regions of the Indian coast.
- For exteme waves, there is a need to have a dedicated ocean observing system and remote sensing-based techniques to track 'Cut-Off-Low' events well in advance before the high waves affect the Indian coast.
- For cyclone induced storm surges, improvements are still required in the prediction system since the present operational system only considers probable seawater flooding and run-up along the coastal regions during cyclone landfall.
- The accuracy of the model forecast of such warning need improvement by incorporating various other data sets such as (i) Coastal bathymetry (100 m spatial resolution), (ii) Coastal topography (0.5 m contour interval), (iii) Inter-tidal DEM (cm level accuracy), and enhanced observing networks such as (i) GNSS in all tide gauge locations, (v) ocean bottom pressure measurements on submarine cables, etc. Further, it is imperative to have community preparedness for all coastal hazards, storm/tsunami ready communities, risk map, inundation map, evacuation/rescue map, etc. by state or NDMA.

2.3 Recommendations

Need to enhance the capabilities to include "Atypical sources" and develop SOPs to handle local tsunamis. Applications using space borne remote sensing techniques needs to be strengthened for coastal mapping. 181

Need Hazard Assessment of Tsunamis in the Indian Ocean, particularly along the coast of India (Submarine landslide, coastal landslide, meteorites, volcanos, etc.) and establish new procedure for detection and warning. (Geoscience Group may elaborate on this)

Improve monitoring networks by enhancing the existing sensors and integrating new platforms such as GNSS, Ocean Bottom Seismometers, submarine cables (SMART), infrasound, InSAR, altimeters etc.

Develop inter-agency SOPs for improving end-to-end warning chains, build effective and fail-safe last mile communication systems, and integrate them as part of multi-hazard framework.

Develop natural barriers (sand dunes, mangroves, coral reefs, grass beds and coastal forests etc.) and consider impact of past coastal hazards in coastal development plans. Also, to erect vertical evacuation shelters and warning towers with sirens along the coastline of vulnerable areas.

Mapping the inter-tidal zones, coastal topography and bathymetry with centimetre level accuracy needs to be done. This exercise will drastically improve the existing DEMs and also accuracy of existing inundation models.

Vulnerable sites along the Indian coast needs to be properly identified and also high-resolution vulnerability assessment in local and urban levels to be developed for planning purpose.

There is a need for larger community preparedness with specific performance indicators for readiness towards storm and tsunami events.

Need to develop a robust forecasting system by considering the 'Cut-Off-Low' events in the Southern Ocean belt and understand its teleconnection with swell surges in the southern Indian coast.

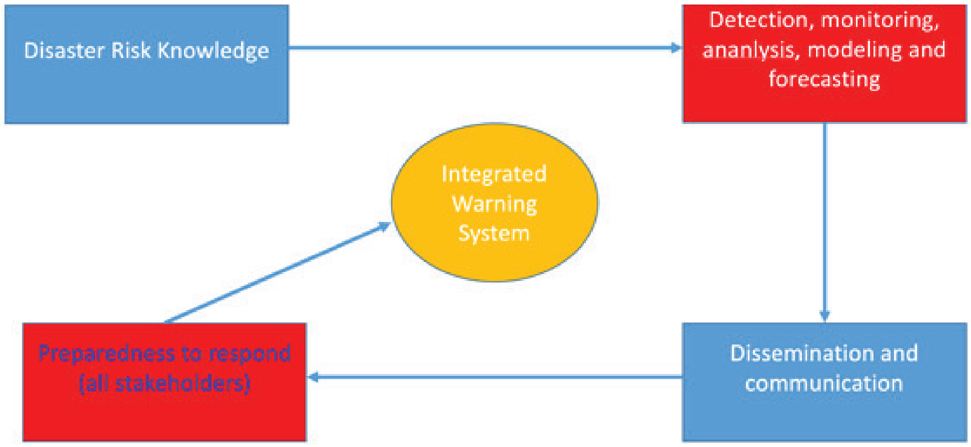
Develop capability of numerical storm surge and flooding modelling integrated with atmospheric model to evaluate the combined effects due to heavy rainfall and its contribution to the net flooding scenarios.

3. Oil Spills

3.1 Present Status

Marine slicks are a serious threat to the aquatic ecosystem and the wildlife relying on them. A report from International Tanker Owners Pollution Federation Ltd (ITOPF) reported about 5.73 million tons of oil released into the waters solely because of the accidents of tankers between 1970 and 2016.

The Indian Coast Guard is the nodal agency for oil spill contingency plan with tier1/tier-2/tier-3 plan. ESSO-INCOIS is involved in operational oil spill dispersion modelling, providing information on trajectories of oil spill particles and its movement based on predictive numerical models considering ocean circulation, wind and waves, and based on the prevailing environmental conditions. The figure below shows the current status of Oil spill warning system. As mentioned earlier, Blue indicates the infrasture or knowledge is available, red indicates not availability of robust system, and yellow indicates need improvement.



3.2 Gap Areas

- There is a need to develop predictive capabilities on oil chemistry that can lead to guide response activities on short-time period after the occurrence of an oil spill from hours to days.
- For decision making there are some potential information required such as: (i) how much of oil was spilled and its estimate, what type of oil, time and location of spill, is it a continuous release (ii) precise understanding on the movement based on environmental conditions, (iii) possible effects due to spillage, and the biota and ecosystems present in the near vicinity of the spill locations, (iv) possible harm that spill could cause for prioritizing the response activity, (v) action required to reduce the harm due to oil spill effect.
- Since the past couple of years, polarimetric SAR images have provided reliable results in monitoring oil spills. The detection of oil spills has become very feasible with growing techniques. However, the detection part is not the difficult phase, the difficulty lies in distinguishing between the oil slicks zones (potentially varying oil thickness areas).
- There should be a coordinated effort using space borne technologies such as SAR, optical imaging for monitoring the Indian coast. The following satellites/ sensor can be used for monitoring Oil spills
    - o COSMO-SkyMed Constellation (full constellation achieves a revisit time of a few hours on a global scale)
    - o RADARSAT Constellation Mission (4 days revisit)
    - o Sentinel-1 Constellation (6 days revisit)
    - o SAOCOM Constellation (8 days revisit)
    - o KOMPSAT-5 (28 days revisit)
    - o Proposed RISAT-1A/RISAT-1B (ISRO) to be launched in 2021/22 (8 days revisit by both the satellites, two passes daily)

- Involvement of multiple agencies, an end-to-end system with guidelines and SOPs needs to be framed, that involves training programs, drills, integrating SOPs for multiple disasters and information dissemination systems. At present, SOP and early warning chains is a big gap.

3.3 Recommendations

- Detection of oil spill is a major challenge. There is a need to have appropriate ocean observing systems with real-time oil spill detection and monitoring capabilities especially in regions of high marine traffic.
- A proper coordination mechanism needs to be worked out to leverage multiple satellite data in real-time mode for detection of oil spills. A monitoring dashboard need to set up by combining Indian and International satellite data set for detection.
- A decision support system needs to be prioritized for planning operations in spill response and mitigating damage to environment and economy.
- Contingency plans for mitigation measures after an oil spill needs to be incorporated in the decision making and forecasting system for the Indian seas.
- Standardisation of disaster warning signals such as sirens/pulses-long siren needs to be framed for the entire country.

4. Harmful algal blooms / Hypoxia

4.1 Present Status

Harmful Algal Blooms (HABs), occur when colonies of algae grow out of control and produce toxic or harmful effects on people, fish, marine mammals and birds. HABs have been documented both along the east and more predominantly in the west coasts of India, and are of growing concern worldwide as human activities lead to warmer, more nutrient-rich coastal waters. Algal blooms are created when there is an excess of nutrients which come from many sources causing eutrophication. This leads to oxygen deficient water or hypoxia condition which leads to degradation of coastal ecosystem. More than 101 cases of HABs have been reported in Indian waters and it is found that there is an increase in the number of bloom occurrences recently. Majority of blooms in the west coast are caused by dinoflagellates, and diatom blooms occur along the east coast. The common species are Noctiluca scintillans and Trichodesmium erythraeum. There has been reports on mass mortality of fishes in Indian waters associated with harmful algal blooms (HAB). It is important to monitor them because they are harmful to people, animals, ecosystems, and drinking water. We should know where they are and monitor them through the years to see if they are getting better or worse.

ESSO-INCOIS and ISRO are involved in the study of HABs. ESSO-INCOIS has established an operational service for detection of HABs for 4 highly probable sectors along the Indian coastline, and has also initiated modelling efforts for their eventual forecasting. It is also establishing moored coastal observatories for continuous monitoring of BGC parameters that influence coastal water quality. The following parameters, available from remote sensing observations, are commonly used to detect the presence of HABs.

- Chlorophyll-a Concentration (Chl-a)
- Sea Surface Temperature (SST)
- Optical Characteristics (absorption, backscattering)

The satellites/sensors used for monitoring of HABs include:

- Combination of Oceansat 2 and Oceansat 3/3A satellites (Daily observation)
- MODIS Terra and Aqua (1-2 times per day observation)
- SNPP VIIRS (1-2 times per day Observation)
- Sentinel 2A and 2B (5 days revisit)

4.2 Gap Areas

- There is a need to have better coastal observations, understand the reasons behind the rise in algal blooms and how they affect the water quality.
- More research is required to understand the physical processes such as seasonal upwelling, monsoon wind forcing and high riverine discharge that supply high nutrient rich waters favouring blooming of phytoplankton species.

4.3 Recommendations

- Due to sporadic and unpredictable nature of algal bloom outbreak, there is a need for regular monitoring of bloom prone areas through insitu and remote sensing platforms that can provide more insights into bloom dynamics leading to development of better tools for HAB monitoring.
- A comprehensive autonomous coastal ocean observing network should be established by ESSO-INCOIS to monitor BGC parameters along the Indian Coast.
- A monitoring dashboard needs to set up by combining Indian and International satellite data sets. High-resolution ocean colour data from a geostationary platform will be of immense help in monitoring HABs.
- Further research studies are required to improve algorithms for detection of blooms from satellite data, environmental conditions supporting the blooms and toxins associated with certain species.
- Need to strengthen regular service activity on both observation and modelling that is currently done by ESSO-INCOIS. Institutional collaborations with SAC, CMLRE, NRSC, NIO and Navy is required.

5. Sea level rise due to Climate Change

Sea level rise due to climate change is a slow process and almost irreversible causing significant flooding impacts along low-lying coasts and deltaic regions. Measurements have shown that the mean sea level has been rising rapidly in the recent decade as compared to the past, attributed to anthropogenic factors leading to global / ocean warming resulting in melting of ice sheets. As per the IPCC reports, while the global mean sea level rose at 1.4 mm per year in the past century, between the years 2006 to 2015 the rate increased to 3.6 mm per year. For the North Indian Ocean region, between 1874-2004 the mean sea level rose by 1.06-1.75 mm per year, however, an accelerated rise of about 3.3 mm per year was recorded for the period from 1993-2017.

5.1 Present Status

Sea level rise is monitored using tide gauge observations spread all over the Indian coast. The Survey of India maintains the tide gauges, and ESSO-INCOIS has the water level data for research purpose. However, there are inherent challenges in our understanding of sea level rise and impact on the Indian coast, which are being addressed as part of the development of Ocean Climate Change Advisory Services (OCCAS) by ESSO-INCOIS as part of the recently approved Deep Ocean Mission by the Government of India.

5.2 Gap Areas

- There is a need to develop multi-hazard vulnerability maps under different scenarios of sea level rise for the Indian coast.
- More detailed micro zonation of the impact of sea level rise on critical coastal installations such as naval, port, energy, etc. is required.
- Coastal land subsidence needs to be well understood, and so is the gradual build-up or removal of sediments by river deposits in deltaic environment such as Sundarbans. This is important as subsiding landmass can show rising sea levels over regions as recorded by tide gauge measurements. There are research reports that indicate that the deltaic region is sinking over time, however consistent monitoring system is not in place for a detailed understanding. Hence there is a need to have continuous monitoring for regions susceptible to land subsidence effects.
- Long-term measured data from tide gauges co-located with GNSS sensors is an essential pre-requisite to understand sea level rise due to climate change impacts and land subsidence. Rising sea levels coupled with increased storm intensity and wave activity makes the coast highly vulnerable to flooding impacts.
- Modelling studies are required that considers glacial isostatic adjustment of land attributed to melting of ice sheets.
- Research efforts are required to use satellite altimeter data depicting 10-days map of sea levels that is available for nearly three decades to understand the exact mechanism for the recent rapid rise in sea level for the period 1993-2012.

- Data from ARGO floats need detailed analysis on establishing the relationship between ocean warming and sea level rise.

5.3 Recommendations

- Though IPCC projections are good for understanding the acceleration of mean sea level at a global level, the regional projections for Indian Ocean region are not satisfactory.
- There is a need to strengthen Ocean observing networks such as tide gauges co-located with GNSS stations, Argo Floats including deep Argo floats, Gliders, Satellite Altimeters, etc. to study sea level rise and its impact on coastal areas.
- Ocean Climate Change Advisory Services being developed by ESSO-INCOIS under the Deep Ocean Mission includes dynamical ocean modelling, statistical downscaling and deep ocean observations to study the detailed impact ocean climate change indicators (sea level rise, cyclone induced storm surges, extreme waves, coastal erosion, etc.) on Indian coastal regions. This initiative is extremely important and needs to be pursued with inter-institutional collaboration.

6. Coral bleaching / Ocean acidification

There has been considerable amount of anthropogenic CO_2 emissions absorbed by the oceans from about 24% to 33% during the past five decades. Massive amount of CO_2 in the oceans leads to abnormal changes in the chemistry of seawater affecting the carbonate cycle. Changes in the chemical properties of seawater lowers the pH leading to increased ocean acidification. Impacts of ocean acidification affects the marine biodiversity and coral reef bleaching is a matter of concern. There has been substantial decline in coral reefs. Ocean acidification is a serious issue in global ocean basins including the North Indian Ocean that is a region highly prone to serious issues of ocean acidification.

6.1 Present Status

ESSO-INCOIS, SAC and NCCR have done mapping comprehensive mapping of Indian Coral Reefs using satellite data and in-situ observations. ESSO-INCOIS operationally provides coral bleaching alerts using satellite datasets. Studies pertaining to marine heat waves and ocean acidification in the Indian Ocean region has been carried out in the recent past. Utilizing remote sensing and field data research studies attempted to correlate the carbon conditions in the Arabian Sea and Bay of Bengal. Studies pointed out there is a decreasing trend of particulate inorganic carbon in the last decade that is linked to decrease in phytoplankton abundance, microscopic organisms that forms the base of the biological food chain in the marine ecosystem. Studies have also analysed parameters such as chlorophyll-a, SST, particulate organic carbon and photosynthetically active radiation.

6.2 Gap Areas

- There is a need to understand ocean acidification which is very difficult to observe and monitor. Many fragile ecosystems such as coral reefs, mangroves and lagoons will be highly vulnerable, that in turn can impact the biological cycle and fisheries.

- Chemistry of seawater needs to be clearly understood such as the partial pressure of CO2, dissolved inorganic carbon, alkalinity, and pH. In addition, two important physical properties of seawater such as temperature and salinity basically controls the carbon cycle chemistry that is directly linked to ocean acidification.
- A comprehensive observing system for long term measurements using satellite and insitu observations is necessary to monitor the health of Arabian Sea and Bay of Bengal waters, especially the coastal waters.

6.3 Recommendations

- Insitu observations should be enhanced with biogeochemical sensors at suitable locations including critical ecosystems such as coral reefs, with a detailed data analysis plan. In addition, concerted efforts should be made to develop long-term climate quality datasets of physical and chemical properties from satellite missions that are thoroughly validated with ground truth data.
- More research activities are required to improve the satellite algorithms for retrieval of geophysical parameters especially for the coastal waters. Studies om critical coastal ecosystems such as Coral Reef and Mangrove dominated regions should be prioritized.
- There is a need to have concerted numerical modelling efforts to investigate the pathways of CO2 in the Bay of Bengal and neighbouring North Indian Ocean region. Numerical models should be developed integrating heat and CO2 flux coupler to general ocean circulation models. Transfer of CO2 and its redistribution in the system should be better understood. Modelling activities should consider the emission scenarios from projections of CMIP5 and CMIP6 datasets to obtain estimates of ocean acidification scenarios.
- Coral bleaching alerts generated by ESSO-INCOIS should be enhanced with additional environmental parameters. Advisories should be developed on the impact of climate change on coastal ecosystems.

7. Marine plastics / debris

7.1 Present Status

Marine plastics is a matter of increasing concern due to their harmful effects on ocean and humans. Huge quantities of plastic debris occur on Indian coastline at sea surface and also at water depths. Effects of weathering fragments plastics into micro particles that are fed by marine organisms. Release of plastics into marine environment has pathways from riverine systems, shipping and fishing activities, and the main source attributed to land origin. There has been large number of field campaigns in national and regional levels to tackle marine plastic associated pollution problems, conventions, agreements, regulations and guidelines. The National Centre of Coastal Research (NCCR) under MoES has framed sampling protocols that are integrated with global standards.

7.2 Gap Areas

- Marine plastic pollutants need to be tackled adopting large number of instruments at international and regional levels. These instruments comprise of conventions, agreements, regulations, strategies, action plan, programs and guidelines. The United Nations Convention on the Law of the Sea (UNCLOS) is an important agreement related to the use of oceans, which specifically mentions on states to protect and preserve the marine environment in context to marine plastic and litter regulations.
- In Indian scenario, the production is about 25,940 metric tonnes of plastic waste per day. Major portion (about 94%) is thermoplastic such as Polyethylene terephthalate and poly- vinylchloride that is recyclable. The remaining categories of plastics such as fibre reinforced plastic, and multi-layer thermocol are non-recyclable.
- There is mis-management on land based litter that enters the sea through riverine systems and municipal drainage systems especially during monsoon with a large amount contributed by cities along the coast.

7.3 Recommendations

- Detailed methodology and plan need to be formulated on reporting mechanism and traces of heavy metals.
- There is not enough study and knowledge on the removal mechanism of plastics and cleaning up of waters in improving the water quality. Better methods and practices need to be evolved in this direction.
- An in-depth study is warranted to understand the pathways of plastic pollutants and its fate by eddies and coastal currents.

8. High waves along west coast of India and Makran swells

8.1 Present Status

In the mid-latitudinal belt of south Asia strong northerly low-level jets are influenced by presence of Makran mountain range and thereby the wind system blows predominantly in the west-northwest and northeast directions. These winds lead to the generation of a new wave system and propagate through the Arabian Seas as "Makran Swells". High wave activity associated with Makran events can influence the marine operations and coastal processes in the west coast of India. The phenomena of high-wave activity in the Arabian Sea associated with Makran events is documented and studied. These events are found to be prevalent during the months October-May. ESSO-INCOIS has operational wave forecasting system for the Indian seas that includes wave forecasts for the deep, coastal and nearshore waters.

8.2 Gap Areas

- There is a need for systematic study on wave spectral transformation and its role in influencing the local wind-wave climate associated with Makran events.

- Role of Makran swells in influencing the wind-wave climate for the west coast of India under changing climate scenario needs to be studied.

8.3 Recommendations

- Need to prioritize the wave forecasting system with a high-resolution for the west coast of India that accounts for the interaction between Makran swells and local wind-waves.
- Detailed study is required to understand the spectral characteristics of wave transformation and its effect on coastal process and marine operations.
- Comprehensive study is required on wind-wave characteristics in a changing climate scenario using CMIP5 and CMIP6 best-performing models.

9. Marine Heat Waves

The Special Report on the Ocean and Cryosphere (SROCC) of Intergovernmental Panel on Climate Change (IPCC) states that global ocean will continue to warm during the 21st century. By end-century the ocean warming in the upper 2000 m of water depth would be 5 to 7 times higher than the business-as-usual scenario relative to the temperature reported since the 1970s. Under the warming scenario, it is expected there would be rise in extreme temperature events in the oceans, as projected over land areas. In this context, the terminology 'Marine Heat Waves' (MHWs) is a new concept which is an outcome of the warming ocean. In a general sense, they are similar to heat waves over land, however, with differences in their identification and definition. Prior studies indicate it as a prolonged anomalous warm water event. Marine Heat Waves are reported worldwide, for example: in Mediterranean Sea, Western Australia, Tasman Sea etc. Effects from Marine heat waves can lead to habitat destruction and affect the ocean biological life, coral bleaching, destruction of seagrass, and fisheries sector.

9.1 Present Status

MHWs are characterized as anomalous warm water events that can last for at least five consecutive days. MHWs lasting for more than five days with a break of 1 to 2 days in warming cycle is referred as a continuous occurrence. There have been not many studies related to Marine Heat Waves (MHW) over the Indian Ocean region. In the southeast sector of Indian Ocean effects of MHW on coral bleaching was reported associated with ENSO and MJO oscillations riding over the global warming signal.

9.2 Gap Areas

- Understanding the effect of MHWs for North Indian Ocean region is very crucial to ensure food and water security, as it impacts marine primary productivity and also modulates the intra-seasonal and inter-annual variability of Indian summer monsoon.
- Effect of climate change and anthropogenic effects on the characteristics of MHWs and its implication on food cycle needs to be studied.

9.3 Recommendations

- Integrated Marine Observations through insitu and satellite platforms, as well as ocean models are key tools for monitoring, understanding and forecasting of MHWs. New observing platforms such as Deep Argo floats and Gliders should be deployed in deep waters especially over identified MHW regions in the Indian Ocean.
- An operational system needs to be established for forecasting of Marine Heat Waves.

10. Overarching Recommendations

The vast Indian coastal region not only provides unaccountable opportunities and benefits to the society but also presents challenges in the form of oceanic disasters. Some important disasters that impact Indian coasts include coastal inundation and flooding (due to tsunami, tropical cyclones, storm surges, swell surges, extreme waves), oil spills, harmful algal blooms / hypoxia, sea level rise due to climate change, coral bleaching / ocean acidification, marine plastics / debris, marine heat waves, etc. Present status, gaps and recommendations to effectively address these hazards are addressed in detail in the preceeding sections of this report. Important overarching recommendations that cut across all the disasters are the following:

- ESSO-INCOIS has operational capability for early warning of tsunamis, storm surges, high waves, swell surges, oil spills, coral bleaching and harmful algal blooms. ESSO-INCOIS is also developing Ocean Climate Change Advisory Services to assess the impact of sea level rise on Indian coastal areas. NCCR works on marine plastics / debris and IMD provides early warning of tropical cyclones. Considering the importance of early warning systems for ocean hazards on the safety of lives, livelihoods and economy of our country, these institutional mechanisms need further strengthening through enhancement of scientific manpower and budgetary resources.
- While upstream (technical) early warning capabilities for these individual hazards is state-of-the art and has improved over time, recent disasters have demonstrated the need to strengthen warning capabilities. For instance, while the current tsunami warning system is effective for more than 85% of tsunamis that are generated by undersea earthquakes, enhancements are needed for early warning of atypical tsunamis generated by submarine landslides, volcanic eruptions or meteoric impacts. New warning system needs to be set up for phenomena such as marine heat waves. Establishment of multi-hazard impact-based early warning covering all Oceano genic hazards in an integrated fashion is the need of the hour.
- Existing observing systems need to be strengthened, in addition to establishing new generation observing systems for detection and monitoring of ocean hazards. These comprise data from satellite as well as in-situ platforms including SMART Cables, Infrasound networks, GNSS sensors, deep argo floats, gliders, coastal autonomous observatories, etc. Most observing equipment are currently imported and it is extremely important to build capacities in the country to indigenise them.
- Efforts need to be mounted for enhancing scientific understanding, hazard assessment, modelling and forecasting of all ocean hazards. High-resolution coastal bathymetry and topography data needs to be acquired immediately for use in coastal inundation modelling and impact assessment.

- It is important to establish seamless multi-hazard Standard Operating Procedures (SOPs) among all agencies involved in the end to end warning chain including early warning centres, national / local disaster management agencies, media and coastal communities.
- To strengthen downstream component of the warning system and to enhance capacities of communities to respond appropriately to early warning of ocean hazards, it is important to undertake regular drills, establish effective last-mile communication methods and implement community recognition programmes such as weather ready / tsunami ready.

Contributors to the Report:

1. Dr. M. Ravichandran, Former Director, NCPOR & Secretary, MoES; Chairman
2. Dr. T. Srinivasa Kumar, Director, INCOIS; Member
3. Dr. M.V. Ramana Murty, Director, NCCR; Member
4. Dr. R. Venkatesan, Program Director, Ocean Observation Systems, NIOT; Member
5. Dr. Prasad Kumar Bhaskaran, Professor, IIT Kharagpur; Member
6. Dr. Prakash Chauhan, Director, IIRS; Member
7. Commodore A.A. Abhyankar, Director, DNOM, Member
8. Commandant Ashok K Bhama, Indian Coast Guard, Member

CHAPTER - 3

GEOLOGICAL RELATED DISASTERS

Executive Summary

India has made a clear beginning towards effective Disaster Management (DM). Enactment of the Disaster Management Act, 2005, articulation of the National Policy on DM, putting in place plans at the National, State and District Levels, release of Guidelines (thematic and cross – cutting), at the national, state and district levels, and raising of the National Disaster Response Force (NDRF) constitute major milestones in the journey towards safety. The basic legal framework is in place. With this the stage is set for implementing Earthquake Disaster Management (DM) in India…

But, the residual agenda is largely technical and glaring at us; it will humble the nation when strong earthquakes occur. This document presents the agenda that needs to be addressed urgently to make substantive progress by 2030. It includes three of the geological disasters, namely earthquake, tsunamis and landslides. In particular, the following actions are needed urgently:

(1) Earthquake Disaster Mitigation:

(a) **Education**: Building the needed technical human resources, who are trained in earthquake hazard & risk assessment, earthquake resistant design & construction, and earthquake safety assessment of existing structures;

(b) **Research & Development**: Solving difficult problems related to understanding earthquake process, quantifying them, considering them in the design of new structures & retrofit of existing structures, and formulating design and construction standards; and

(c) **Technology Development**: Creating infrastructure needed to deal with geological hazards, including: (a) earthquake ground motion measurement instruments (like accelerometers, velocity-meters, GPS displacement-meters), (b) satellite phones, (c) sensors and instruments for monitoring effects (ground shaking, geotechnical properties, and structural response), (d) research equipment for geotechnical and structural engineering studies, and (e) full-scale testing of structures with a view to qualifying, certifying and developing new technologies or existing technologies.

(2) Tsunamis Disaster Mitigation:

(a) Identification and assessment of tsunami sources in subduction zones, including areas prone to submarine landslides and volcanic eruptions; and

(b) Strengthening monitoring networks with state-of-art instrumentation, and integrating with platforms for faster numerical simulations.

(3) Landslide Disaster Mitigation:

(a) Establishment of Indian National Center for Landslide Mitigation, as a single national operational body (collaborating with all partner agencies) managing landslide hazard through an institutional mechanism, by following a systematic approach that includes both short-term and long-term planning after a study of the hazard, vulnerability and risk assessment.

It is prudent to make an imperfect start now than to wait for the ideal one…

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1. Introduction

The words Disaster Management (DM) have reached the desks of:

(1) All the ministries, departments and offices concerned of the government of India and state governments, and UT administrations;

(2) Almost all the educational institutions across the country, and

(3) Nearly all small, medium and large industries in the country.

The next step is to internalize it. One convincing way of doing this is by practicing it. But, for the effort of about 132 Crores of people in India to be effective**,** an organized, proactive and prioritized effort is required.

1.1 Disaster Management in India

A disaster refers to a catastrophe, mishap, calamity or grave occurrence from natural or man-made causes, which is beyond the coping capacity of the affected community. DM involves a continuous and integrated process of planning, organising, coordinating and implementing measures, which are necessary or expedient for:

(1) Prevention, where possible, of danger or threat of disaster, by appropriate forecast and warning,

(2) Mitigation, reduction of risk of disasters or their severity of consequences, by suitably designing and constructing the built environment,

(3) Capacity building, in people and organisations, including research and knowledge management,

(4) Preparedness of people to deal with disasters,

(5) Prompt Response to a threatening disaster situation or disaster,

(6) Assessing the severity or magnitude of the effects of disasters,

(7) Rescue, relief and evacuation, and

(8) Rehabilitation and reconstruction.

A typical DM continuum comprises six elements (**Figure 1**), namely:

(1) in the pre-disaster phase: Prevention, Mitigation and Preparedness, and

(2) in the post-disaster phase: Response, Rehabilitation and Reconstruction.

A legal and institutional framework binds all these elements together; these are described hereunder.

1.1.1 Disaster Management Act, 2005

On 23 December 2005, the Government of India (GoI) took a defining step by enacting the

Disaster Management (DM) Act, 2005, to spearhead and adopt a holistic and integrated approach to DM. The Act lays down institutional, legal, financial and coordination mechanisms at the national, state, district and local levels. These institutions are not parallel structures and will work in close harmony. This new institutional framework is expected to usher in a paradigm shift in DM, from relief-centric response to a proactive regime that lays greater emphasis on mitigation, preparedness and prevention initiatives, which conserve developmental gains and minimise loss of lives, livelihoods and properties.

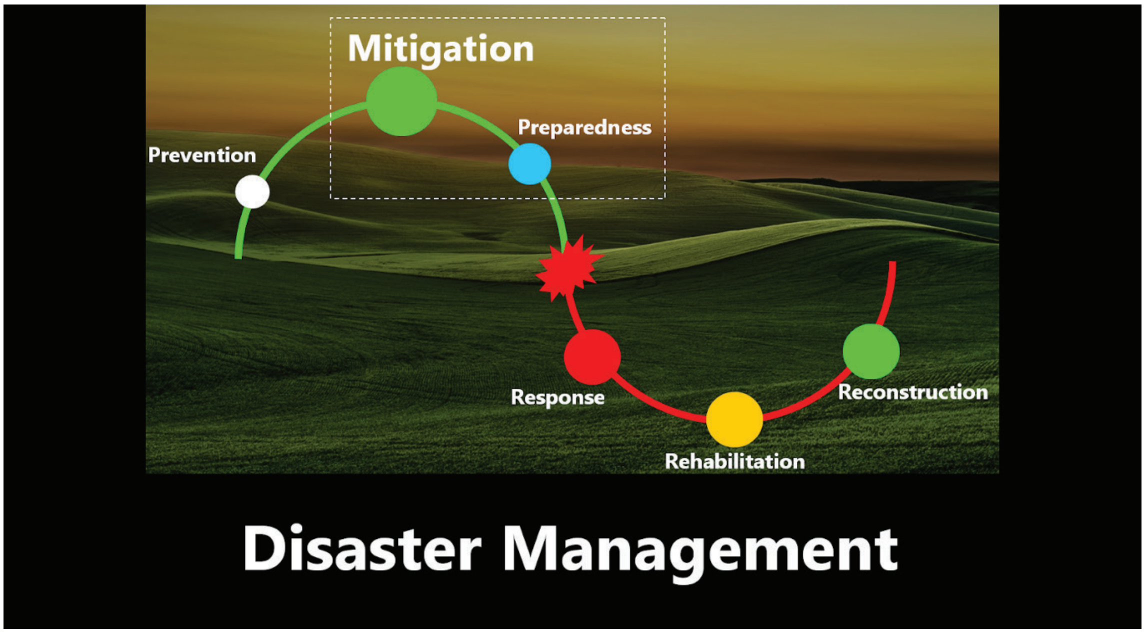

Figure 1: Six Pillar of the DM Cycle: Mitigation and Preparedness form the core of the pre-disaster initiatives

1.1.2 National Policy on Disaster Management, 2009

The National Policy on DM (NPDM) was released by the National Disaster Management Authority (NDMA) in 2009, to build a safe and disaster resilient India by developing a holistic, proactive, multi-disaster oriented and technology driven strategy through a culture of prevention, mitigation, preparedness and response.

It seeks to evolve a holistic and integrated approach towards DM with emphasis on building strategic partnerships at various levels. The themes underpinning the policy are:

(1) Community-based DM, including last mile integration of the policy, plans and execution,

(2) Capacity development in all spheres,

(3) Consolidation of past initiatives and good practices,

(4) Cooperation with agencies at national and international levels, and

(5) Multi-sectoral synergy.

The objectives of NPDM are:

(1) Promoting a culture of prevention, preparedness and resilience at all levels through knowledge, innovation and education;

(2) Encouraging mitigation measures based on technology, traditional wisdom and environmental sustainability;

(3) Mainstreaming DM into the developmental planning process;

(4) Establishing institutional and techno-legal frameworks to create an enabling regulatory environment and a compliance regime;

(5) Ensuring efficient mechanism for identification, assessment and monitoring of disaster risks;

(6) Developing contemporary forecasting and early warning systems backed by responsive and fail-safe communication with information technology support;

(7) Ensuring efficient response and relief with a caring approach towards the needs of the vulnerable sections of society;

(8) Undertaking reconstruction as an opportunity to build disaster resilient structures and habitat for ensuring safer living; and

(9) Promoting a productive and proactive partnership with the media for DM.

1.1.3 National Disaster Management Plan, 2019

The National Disaster Management Plan (NDMP) was released by the NDMA in 2019, towards making India disaster resilient across all sectors, achieve substantial and inclusive disaster risk reduction by building local capacities starting with the poor and decreasing significantly the loss of lives, livelihoods, and protecting assets of different forms (including economic, physical, social, cultural, and environmental), while enhancing the ability to cope with disasters at all levels.

NDMP provides a framework and direction to the government agencies for all phases of disaster management cycle. The NDMP is a "dynamic document" in the sense that it will be periodically improved keeping up with the emerging global best practices and knowledge base in DM. It is in accordance with the provisions of the DM Act 2005, the guidance given in NPDM, and the established national processes.

NDMP recognizes the need to minimize, if not eliminate, any ambiguity in the responsibility framework. Therefore, it specifies who is responsible for what at different stages of managing disasters. It is meant to be implemented in a flexible and scalable manner in all phases of DM, namely:

(1) Mitigation (prevention and risk reduction),

(2) Preparedness,

(3) Response, and

(d) Recovery (immediate restoration and build-back better).

While the names of ministries/departments of the center and state/UT having specific roles and responsibilities are mentioned in the Plan, in the spirit of the DM Act, 2005, and the exigencies of humanitarian response, every ministry/department and agency is expected to contribute to DM going beyond their normal rules of business.

1.1.4 National Disaster Management Guidelines, 2007–2019

The NDMA has prepared 30 National Disaster Management Guidelines (NDMGs) in keeping with the DM Act, 2005 (Table 1). Some of these are disaster-specific and the others are cross-cutting across all disasters. Each of these guidelines provides a detailed account of the major issues to be addressed towards preparing the states and UTs for mitigating the disasters related to each hazard and each cross-cutting theme. Also, each of these guidelines lists a number of actionable items in each chapter for implementation.

1.2 Earthquake Safety in India

Over the last 3 decades, over 10 damaging earthquakes have occurred in India and its seismic neighbourhood. Of these, two events caused major losses – in each of these events, over 13,000 lives were lost and over Rs.30,000 Crores were the direct economic setback. The total number of lives lost in these 10 events is over 50,000. Efforts are needed to mitigate such losses from recurring again in future events.

As on date, four critical national instruments are in place to enable earthquake safety in India, namely:

(1) Disaster Management Act, 2005;

(2) National Policy on Disaster Management, 2009;

(3) National Disaster Management Plan, 2019; and

(4) National Disaster Management Guidelines: Management of Earthquakes, 2007.

But, the country is far from being prepared to prevent another earthquake disaster. One important step that needs to be taken is to showcase scenarios of likely earthquake disasters in potential future events.

Table 1: List of National Disaster Management Guidelines released till October 2020

S. No.	Name of the Guideline	Release Date
1	Management of Glacial Lake Outburst Floods	October 2020
2	Task Force Report on NDM Guidelines on Management of Glacial Lake Outburst Floods	October 2020
3	Summary for Policy Makers on NDM Guidelines on Management of GLOFs	October 2020
4	Preparation of Action Plan - Prevention and Management of Heat Wave	October 2019

S. No.	Name of the Guideline	Release Date
5	Landslide Risk Management Strategy	September 2019
6	Disability Inclusive Disaster Risk Reduction	September 2019
7	Temporary Shelters for Disaster-Affected Families	September 2019
8	Prevention & Management of Thunderstorm, Lightning, Squall, Dust, Hailstorm and Strong Winds	March 2019
9	Boat Safety	September 2017
7	Cultural Heritage Sites and Precincts	September 2017
8	Museums	May 2017
9	Minimum Standards of Relief	February 2016
10	Hospital Safety	February 2016
11	School Safety Policy	February 2016
12	Seismic Retrofitting of Deficient Buildings and Structures	June 2014
13	Scaling, Type of Equipment and Training of Fire Services	April 2012
14	National DM Information and Communication System	February 2012
15	Management of Drought	September 2010
16	Management of Urban Flooding	September 2010
17	Management of Dead in the Aftermath of Disaster	August 2010
18	Management of Tsunamis	August 2010
19	Incident Response System	July 2010
20	Psycho-Social Support and Mental Health Services in Disasters	December 2009
21	Management of Landslides and Snow Avalanches	June 2009
22	Management of Nuclear and Radiological Emergencies	February 2009
23	Management of Biological Disasters	July 2008
24	Management of Cyclones	April 2008
25	Management of Floods	January 2008
26	Medical Preparedness and Mass Casualty Management	October 2007
27	Preparation of State Disaster Management Plans	July 2007
28	Preparation of State DM Plan	July 2007
29	Chemical Disasters	April 2007
30	Management of Earthquakes	April 2007

Some salient shortcomings include:

(1) Earthquake Disaster Mitigation:

(a) Earthquake safety of the built environment is not mandatory part of the Technical Education in India at the undergraduate level in civil engineering and architecture degree programs:

(b) Licensing of Civil Engineers is not in place for ensuring competence in the hands that design and construct the built environment;

(c) Building Bye-Laws of States and UTs of India are not revised to weed out unsafe typologies and ensure that mandatory earthquake resistant features are included in the design and construction of structures;

(d) Mandatory structural safety peer review of structural designs is not being done in any Urban Local Bodies and Panchayati Raj Institutions of new structures to be built, before providing consent to establish, except for Tall Buildings in a few cities in the country; and

(e) Prioritized Seismic Retrofit is yet to commence of critical and lifeline structures for ensuring governance continuity and for providing essential services to the people of India.

(2) Earthquake Disaster Preparedness:

(a) Policy makers and decision makers are not sensitized adequately on technology aspects so that they can take considered decisions. For instance, they need to appreciate:

(1) Minimum mandatory legal instruments needed to ensure earthquake safety in India;

(2) Importance of structural seismic retrofit; and

(3) Criticality of introducing Licensing of Civil Engineers in India towards ensuring structural safety of built environment in India.

1.3 This Proposal

This document is prepared at the behest of the Indian National Academy of Engineering seeking guidance to:

(a) Undertake the residual R&D agenda to overcome the high earthquake risk that the people of India are faced with,

(b) Launch implementation of Earthquake Disaster Mitigation initiatives, using earthquake risk assessment of built environment as a basis for prioritizing them,

(c) Meet additional technology needs to strengthen Tsunamis Disaster Mitigation actions, and

(d) Initiate formally Landslide Disaster Mitigation effort.

2. Technical Education

The use of modern technology and state-of-the-art equipment improve the accuracy and relevance of post-event studies. Quite obviously the format of the technical education should be so designed, as not merely to highlight the good practices that can be emulated and scaled up subsequently, but also focus on the failures from which it would be possible to learn what not to do in the future. The conclusions arising from post-earthquake field reconnaissance can serve the purpose only if they are widely disseminated to all the stakeholders including the community through the print and electronic media (especially the journals on the subject of Earthquake Disaster Mitigation) and through annual technical seminars and workshops on earthquake disaster mitigation.

2.1 Domains of Interest

Education and training of persons in the subjects of earthquake science and earthquake engineering should be focused to aid them to solve live problems faced in practice of the said subjects. The residual agenda needs persons with backgrounds in the following areas:

(1) Earthquake Science: Earthquake physics, strong motion instrumentation, and signal processing; and

(2) Earthquake Engineering: Structural safety of elements of the built environment (such as housing, critical structures, vital structures, bridges, water tanks, hospitals, schools, urban housing and infrastructure) and earthquake scenario development of Megapolis (such as Delhi and Bombay).

2.2 Master of Earthquake Science and Engineering

The seismic hazard in India is widespread; about 57% of land area with about 78%

residing on is under the threat of moderate to severe seismic hazard. High vulnerability of existing buildings and structures to earthquake shaking is evident from building and structural collapses during earthquakes in the last three and half decades in the country. The vulnerability is attributed to a number of factors, including the lack of sufficient scientific collaboration between seismologists and engineers. They are not exposed to a blend of basics of earthquake science and earthquake engineering. The vulnerability is attributed to lack of even basic education amongst teachers and the capacity building of teachers of earth science and civil engineering colleges in India is necessary to equip India towards ensuring improved earthquake safety – in both mitigation and reconstruction phases of earthquake disaster mitigation of the country.

It is suggested that a new academic program of **Master of Earthquake Science and Engineering be** launched, which is aimed to create a trained pool of Earth Scientists and Civil Engineers over the coming years with understanding in concepts related to evaluation of Seismic Hazard and Seismic Vulnerability **together**. The applicants to the proposed Master's degree program are from colleges of earth science, civil engineering and architecture across the country. The salient features of the program are:

(1) A two-year Master's Level education with a thesis requirement, administered under the academic requirements as laid down by the Institutes/Universities.

(2) The annual number of students admitted to the program shall be 20; 10 for students with earth science background and 10 for those with civil engineering and architecture background. Teachers of colleges of earth science, civil engineering and architecture shall be given preference.

(3) The first year of the program primarily has Course Work and the second the Thesis Work.

(4) The Thesis shall address national grand challenges being currently faced in India, and shall have suitable blend of elements of both earthquake science and earthquake engineering. At the end of each semester, the students shall defend their project work before a Jury of Examiners for assessment. The theses submitted at the end of the program shall be peer reviewed, modifications made as necessary and published by NGRI as treatises in the subject of earthquake science and engineering.

(5) After successful completion of the above requirements, the students shall be awarded Master of Earthquake Science and Engineering degree by the Institutes/Universities.

(6) The annual number of students admitted to the program.

2.2.1 Background

(a) Seismicity of India and Prevalent Seismic Hazard

Over 60% of India's land area and 78% of the 1.2 billion population of India's population are under the threat of moderate to severe seismic shaking, as per the Indian Seismic Code IS 1893 (Part 1), 2016. Clearly, knowing how to ensure seismic safety is a major expectation of every engineering degree holder that graduates. But, not knowing which graduate will be employed in these hazardous areas, it is prudent to include earthquake safety related education components in the curriculum of the undergraduate programs of architecture and civil engineering in India. There are over 250 colleges offering civil engineering undergraduate degree programs and about 250 architecture colleges including building safety in their undergraduate program. Together, they graduate about 20,000 students each year. Alongside, there are already a large number of practicing architects and civil engineers who have not been exposed to basic principles of earthquake behaviour, and earthquake-resistant design and construction. But, the number of faculty members with formal training in basic concepts of earthquake engineering is abysmally low, for the country to undertake a major capacity building activity of practicing architects and engineers, not to mentioned improving the existing undergraduate programs of architecture and civil engineering. The subject of earthquake engineering is still being viewed as a super specialization and not seen as integral part of structural safety for all civil engineers and architects to be conversant with.

(b) Seismic Vulnerability of Built Environment and Earthquake Engineering Education

On the other hand, the earthquakes that occurred in India in the last two and half decades have demonstrated the extreme vulnerability of the buildings and structures being constructed in India. Post-earthquake investigations revealed major shortcomings, like (a) earthquake resistant design and construction is not a mandatory part of the curriculum in architecture and civil engineering colleges in India, (b) there is no enforcement of techno-legal regime by the municipal bodies, (c) there are numerous lacunae in design standards employed in the country to design and construct structures intended to resist earthquake effects, and thereby in the designs being used to build structures, and (d) there is no formal guidance on construction materials, equipment and methods suitable for earthquake resistant construction.

India stands at the cross-roads of a serious crisis—the risk against potentially damaging earthquakes. Over 60% of India's land area is under threat of moderate to severe seismic hazard, and the current level of preparedness in the country is abysmally low as clearly demonstrated by the huge loss of life and property during and in the aftermath of nine (M>6) earthquake strikes that affected the country in the past 17 years. The earthquake problem of India is grave. The situation requires all the stakeholders to understand this problem and participate in the effort to reduce the risk against earthquakes. The performance of a community depends on three aspects, namely whether the (a) community is located in areas of prevalent earthquake hazard, (b) built environment (that the community occupies and is served by) is vulnerable to earthquakes, and (c) critical facilities and essential services required in the aftermath of an earthquake are functioning.

(c) Seismic Safety Strategy

India will continue to face earthquakes and each earthquake will offer another opportunity to become that much more prepared. A typical earthquake-cycle has six elements to it divided into two groups (**Figure.2**) — pre- and post- earthquake activities. The former includes prevention, mitigation and preparedness, while the latter consists of emergency rescue & relief, rehabilitation and reconstruction. These terms are defined below for clarity:

(i) **Prevention**: It involves undertaking measures towards avoidance of an earthquake disaster by effective utilisation of available information on seismic hazard. For already developed areas, effective land-use planning seems to be the only course of action but that would be applicable only in the case of newer developments;

(ii) **Mitigation**: It involves reducing vulnerability of the built environment by applying earthquake resistant design principles and detailing to the new structures and conducting seismic evaluation and necessary strengthening for existing structures;

(iv) **Preparedness**: It involves conducting advance activities (including developing plans and rehearsing through mock drills) with the communities and stake-holders to help them respond efficiently in the aftermath of an earthquake;

(v) **Emergency** Response and Relief: It involves the activities to be undertaken by the government and other stake-holders in the immediate aftermath of an earthquake, in the form of moving the affected persons to safer locations (especially women and children) and offering them food and medical attention, and conducting search and rescue for the missing;

(vi) **Rehabilitation**: It involves (i) providing temporary shelters to the affected, restoring "normalcy" through ensuring resumption of familiar daily living patterns (such as schooling for children, and involving men and women in activities they can identify with even while in temporary shelters), ensuring basic civic amenities, and offering livelihood opportunities to those who lost their livelihood, after the emergency response and relief phase is completed; and (ii) providing counseling for those suffering from trauma.

(vii) **Reconstruction**: It involves developing improved civic infrastructure, building permanent shelters and homes, and striving for higher technical standards for future compliance.

Prevention is not viable because of the nature of the earthquake problem; post-earthquake measures are mandatory and cannot be affected without efficient discharge of the mitigation and preparedness activities. Thus, the success of a community in negotiating the earthquake cycle critically rests on the effectiveness of the mitigation and preparedness initiatives it has taken. Until that happens, India will be plagued by reconstruction (and retrofit) activity also.

(d) Human Resource Development

To undertake any mitigation and preparedness activity in the country, a critical mass of technical persons is required to steer each of the initiatives of the country. Towards addressing this huge gap in the needs and capacities of the country to ensure earthquake safety, the National Program of Earthquake Engineering Education (NPEEE) was initiated by the Ministry of Human Resource Development in 2003; the program was run on a project mode with seven ("old") IITs and IISc as the resource institutes. Momentum was built through this program, but since the program was not continued beyond the three-year project period (2003-2006), the expected gains of capacity building in the nation could not be consolidated in the last 6 years.

India has witnessed at least 9 damaging and devastating earthquakes in the past two and half decades, which resulted in colossal loss of life and property across the country. The effects of especially three major events, namely, 2001 Bhuj earthquake, 2004 Sumatra earthquake and tsunami, and 2005 Kashmir earthquake, are testimony to the extreme vulnerability of Indian constructions. The lessons learnt from post-earthquake investigations of the 9 damaging earthquakes indicate a huge shortage of technical persons with formal professional training and background in the earthquake safety (covering aspects of earthquake hazard assessment, and earthquake disaster mitigation, and earthquake preparedness). Currently, there are only about 40-50 PhD degree holders (who are formally trained in the subject of earthquake engineering, conversant with the subject of earthquake resistant design, have aptitude for research and give priority for undertaking necessary R&D and technical support to prevent collapse of buildings and structures), that are effectively available to meet this great technological challenge of Earthquake Safety of India.

Formal technical knowledge needs to be imparted to large number of persons, who can ensure safety of buildings and structures in India. As a first step, capacity building should be started urgently through education and training to contribute towards earthquake disaster mitigation in India, and thereby prevent loss of life and property in future earthquakes.

Today, no government college in India, the subjects related to Earthquake-Resistant Design and Construction are included in the MANDATORY technical education related to the built environment. This is when about 57% of India's land area is under the threat of moderate to severe earthquake shaking, in which about 78% of India's population lives, approximately 100 Crores people. Many reasons are attributed to this. But, the fact remains is that each day new buildings and structures are being built in the country, especially in seismic zones III, IV and V, all of which may not be earthquake-resistant, as demonstrated by the ten damaging earthquakes in the last 23 years in the country – over 50,000 lives were lost and many lakhs injured, not to mention the collapse of lakhs of buildings and tens of lakhs of them damaged. This is not acceptable option for India, which now has a formal agenda for natural and man-made disaster mitigation. Hence, a need arises to take necessary action to formally include subjects related to earthquake safe construction in the mandatory part of undergraduate and post-graduate curricula in the technical universities/institutes/colleges of architecture and civil engineering in India. But, the number of qualified teachers available is small to undertake this gigantic effort.

(e) **Integrated Approach**

The integration of seismic hazard and vulnerability is a missing link in today's academia and R&D of the country. Standing on a common platform, earth scientists, engineers and architects will learn to appreciate the nuances in the allied subjects and also work towards solving the difficult of integration of knowledge in these streams. The salient advantages of integrated approach of bringing together earthquake science and engineering in the Indian context are:

(1) Seismic safety is a multi-disciplinary effort involving a continually evolving science of understanding earthquakes and earthquake behaviour of structures. The collaboration between scientists and engineers will help understand the role of geophysics, seismology, soil dynamics and structural behaviour.

(2) Seismic hazard assessment involves a number of parameters that are uncertain. Collaboration of scientists and engineers will assist the evolution of the next generation displacement-based seismic design codes with hazard assessment from standpoints of ground acceleration and ground displacements in a probabilistic framework.

(3) Modelling large seismic events in a 3D finite element framework is an interdisciplinary effort, which includes effects of source, path, site (including soil liquefaction and site amplification/de-amplification) and structure.

(4) Earthquake-induced landslide hazard zonation is possible only with the critical role of both scientists and engineers.

2.2.2 The Program

This program is aimed to formally train persons with background in earth science, civil engineering and architecture in earthquake engineering. The potential students of this program, who can benefit from the master's program (which has coursework, and training to address new situations through applied research in a practical problem) can be:

(1) Fresh graduates aspiring to be earth scientists with some background in earthquake engineering or to be faculty members in civil engineering with some background in earthquake science; and

(2) Practicing earth scientists (who wish to gather some background in earthquake engineering) and civil engineers (who wish to gather some background in earthquake science).

The program is aimed to enhance the technical preparedness of India for earthquake safety, through capacity building of teachers of civil engineering and architecture colleges across the country. This will have cascading effect, when the 'select group' of teachers will train students and teachers in their respective institutes/universities after their return from the successful completion of this program. Initially, these teachers will be able to introduce a new course on Earthquake Resistant Design and Construction in their respective colleges, and eventually internalize the components of earthquake resistant design and construction in all courses at appropriate levels of the undergraduate program. It is hoped that similar other programs will be initiated in the country in parallel to directly train practicing architects and engineers.

The proposal seeks to offer a two-year Master of Earthquake Science and Engineering Program. Of the two years, the students will spend the first year in course-work program, and the second year in thesis work. At the end of second year, students will present their thesis work. After the successful completion of above elements, the students shall be awarded Master of Earthquake Science and Engineering degree. The details of the courses and assessments are given in **Table 2**.

2.3 Faculty Development

The prevalent widespread seismic hazard in the country, and the demonstrated large seismic vulnerability of existing buildings and structures in India (though building and structural collapses during earthquakes in the last three and half decades in the country), there is an urgent need of capacity building of teachers of architecture and civil engineering colleges in India to equip the country towards ensuring improved earthquake safety – in both mitigation and reconstruction phases of earthquake disaster mitigation of the country. At least 4 teachers should be available in each college of architecture and civil engineering in India, to build a basic set of faculty members who can steer earthquake safety activities in the country. With about 500 active colleges of architecture and civil engineering in the country, this will mean immediate training of at least 2,000 Faculty Members.

Table 2: Course work requirements for Masters Program in Earthquake Science and Technology

Cat.	Title	H	C	Cat.	Title	H	C
C1	Physics of the Earth			C7	Tectonics of Earthquakes in India		
C2	Earthquake Wave Propagation			C8	Earthquake Hazard Assessment		
C3	Strong Ground Motions			C9	Siting of Engineering Projects		
C4	Earthquake Behaviour of Structures			C10	Compulsory Option 2		
C5	Compulsory Option 1			C11	Compulsory Option 3		

E1	Elective 1		E2	Elective 2	
	Compulsory Option 1 for Science Stream			Compulsory Options 2 and 3 for Science Stream	
C5	Measurements of Earthquakes		C10	Seismological Structure of the Earth	
			C11	Earthquake Geodesy	
	Compulsory Option 1 for Technology Stream			Compulsory Options 2 and 3 for Technology Stream	
C5	Earthquake Structural Dynamics		C10	Earthquake Resistant Design of Structures	
			C11	Assessment of Earthquake Safety of Existing Structures	
	Elective 1 for Science Stream			Elective 2 for Science Stream	
E1	Computational Geodynamics		E2	Computational Seismology	
E1	Earthquake Rupture Mechanics		E2	Space-Time Series Analysis	
	Elective 1 for Technology Stream			Elective 2 for Technology Stream	
E1	Numerical Methods in Earthquake Engineering		E2	Earthquake Protection of Non-Structural Elements	
E1	Earthquake Geotechnical Engineering		E2	Seismic Retrofit of Existing Structures	
C6	Field Camp	L	C12	Computational Laboratory	L
III Semester			IV Semester		
	Thesis			Thesis	

2.3.1 Ph.D. Program in Earthquake Engineering

The proposal seeks to offer a minimum three-year residency Doctor of Philosophy (Earthquake Engineering) degree program at select IITs and NITs that have competence in the subject of earthquake engineering. Each student will be required to undertake course work as per Table 3 and doctoral thesis research in the area of earthquake engineering. The other requirements for the award of Ph.D. degree shall be in line with the other Ph.D. programs in engineering disciplines at the host Institute, as laid down by the Academic Senate of the host Institute.

About 10 scholarships will be available per year for this PhD Program, of which at least 4 will be for teachers of colleges of engineering and architecture. Admissions will be open in both semesters, accommodation for admitted candidates will be arranged by the

Institute, either on campus (depending on availability) or in the neighbourhood on rental basis.

The progress of the research work will be periodically monitored through end-of-the-semester seminar presentations made by the research student. Students registered in the Ph.D. program must pass the Comprehensive Examination designed to test the overall comprehension of the student in the various subjects. A student can appear in the comprehensive examination only after she/he has completed the course requirements and satisfied the minimum specified CGPA requirement. All other rules of evaluation and thesis submission and examination shall be applicable, as approved by the Academic Senate of the host Institute.

2.3.2 Joint Research between select Institutes engaged in Earth Science and Earthquake Engineering

Human resources and high-end experimental research facilities are located unsymmetrically in the Institutes and organizations across the country. Where there is critical mass of people, the facilities are sub-optimal, and vice versa. A mechanism should be established to bring the two together, so that synergy can be developed between the people and the facilities.

Table 3: Course work requirements for Doctoral Program in Earthquake Science and Technology

Cat.	Title	H	C	Cat.	Title	H	C
I Semester				II Semester			
C1	Any two courses from Table 2 First Semester courses agreed upon by thesis supervisor and student			C3	Any one course from Table 2 Second Semester courses agreed upon by thesis supervisor and student		
C2					Thesis		
E1	Elective 1			E3	Elective 3		
E2	Elective 2						
	Electives 1 and 2 from courses below				Elective 3 from courses below		
	Ductile Seismic Design of Buildings				Displacement-based Seismic Design of Buildings		
	Probabilistic Seismic Analysis of Buildings				Deterministic Nonlinear Seismic Analysis of Buildings		
	Deterministic Seismic Hazard Assessment				Probabilistic Seismic Hazard Assessment, Macrozonation and Microzonation		
	Seismic Rehabilitation & Retrofitting of Structures				…		
III Semester				IV Semester			
	Thesis				Thesis		
V Semester				VI Semester			
	Thesis				Thesis		

3. Research

Significant progress has been made in so far as the accuracy of forecasting of Cyclones. But, the situation is not that bright in regard to other natural hazards. The accurate estimation of the earthquake ground shaking is found wanting equally, on account of the absence of a sufficient number of moderate earthquakes, a determined effort is required to:

(1) Arrive at a nationally agreed methodology for accurately assessing and forecasting different hazards;

(2) Revise temporally the assessment and forecast of hazards; and

(3) Project the risk prevalent from earthquake hazard, by convolve the earthquake **hazard** across the land mass of the country, the earthquake **vulnerability** of the built environment, and the **exposure** of people, property, businesses and governance in the built environment that is vulnerable to earthquake shaking.

Accomplishing these needs a mission mode approach for the nation to act swiftly towards implementing Earthquake Disaster Mitigation initiatives in a short time frame.

3.1 Gap Areas

The gap areas in the assessment of the earthquake safety of the built environment in India, include:

(a) Earthquake Hazard Assessment, especially Aggregate Hazard in populated areas, and Site-Specific Hazard in rural areas;

(b) Earthquake Exposure Assessment;

(c) Earthquake Vulnerability Assessment; and

(d) Earthquake Risk Assessment.

Development of simplified approaches to:

(1) Earthquake Hazard Assessment for sites across the Himalaya, with special emphasis on foreland basin of the Indo-Gangetic Plains; and

(2) Earthquake Risk Assessment of the various elements of the built environment in the states and UTs adjoining the Himalayas, are two scientific questions to be addressed urgently in the Indian context.

3.2 Earthquake Hazard Assessment

The simplified approach to earthquake hazard assessment should include methods to arrive at the displacement spectra in addition to the usual acceleration spectra. The study area across the Himalaya has foreland basin of the Indo-Gangetic Plains, which is characterized by sediments of large depths. The focus should be on:

(1) Image the fault planes to describe rupture of main frontal thrust leading to large earthquakes;

(2) Imaging and estimate the sediment depth across the Himalaya of the deep sediment depths in the foreland basin of Indo-Gangetic Plains;

(3) Scaling the spectra derived from ground motions recorded of low magnitude events to the spectra for high magnitude events;

(4) Estimating the hazard by employing two strategies, namely using:

    (a) Aggregate earthquake acceleration hazard for populated areas (cities and megapolis) and site-specific earthquake acceleration hazard for the remaining areas; and

    (b) Aggregate earthquake displacement hazard along the lengths of the lineal facilities that cross active faults, e.g., cross-country pipelines

    The following objectives are suggested:

    (1) Earthquake Processes:

        Improve the understanding of the mechanism of earthquakes at the inter-plate boundary by:

        (a) Densifying the deployment of instruments (co-locate accelerometers, velocity-meters and GPS instruments) in seismological networks adjoining the plate-boundary, and monitor the events online;

        (b) Undertaking a systematic study of strong ground motions recorded at inter-plate boundary and analyse the inter-plate earthquakes using the state-of-the-art earthquake location programs that characterize the inter-plate and intra-plate earthquakes;

(c) Integrating the above with the INSAR data to understand the seismogenesis; and

(d) Characterizing source, path and site effects by studying ground motions recorded in near-fault and far-fault regions.

This should be completed in about 2 years.

(2) Earthquake Hazard Assessment:

Improve the understanding of the assessment of earthquake hazard at the inter-plate boundary by:

(a) Ascertaining attenuation models (or GMPEs) using strong motion acceleration data for different seismically active regions. In absence of acceleration data, broadband may be used to develop GMPEs using already available data;

(b) Modelling ground motion using the newly delineated 1-D and 3-D velocity models and using broadband and strong-motion data;

(c) Deriving site-specific spectra for critical and vital installations; and

(d) Developing risk-based earthquake hazard for displacement-based seismic design of structures.

This should be completed in about 5 years.

3.3 Earthquake Risk Assessment

The simplified approach to earthquake risk assessment should include methods to arrive at the absolute and relative risk of the built environment to earthquake ground shaking across the Himalaya using the outcomes of the results of **Section 3.2**. An estimation of the earthquake risk at the inter-plate boundary requires earthquake ground shaking induced by inter-plate events along the Himalaya.

The following objectives are suggested:

(1) **Exposure** of the built environment (buildings and structures) and People:

(a) Adopt procedures used worldwide for documenting exposure of the built environment and of the people to earthquake shaking; and

(b) Update the data pertaining to the demographics and inventory of the built environment in the states and UTs adjoining the Himalaya.

(2) **Vulnerability** of the built environment (buildings and structures):

(a) Adopt procedures used worldwide for assessing vulnerability of typical buildings and structures to expected earthquake shaking; and

(b) Perform vulnerability assessment and develop vulnerability and fragility curves of the typical buildings and structures in the states and UTs adjoining the Himalaya.

(3) **Risk** of the built environment (buildings and structures):

(a) Review the procedures used worldwide for risk assessment of the built environment and of the people.

(b) Propose a 4-level telescopic method for assessing risk of the built environment and of the people in India, namely:

(1) Level 1: Simplified Qualitative Method;

(2) Level 2: Detailed Qualitative Method;

(3) Level 3: Simplified Quantitative Method; and

(4) Level 4: Detailed Quantitative Method.

(c) Undertake a pilot study to assess risk of built environment in a limited area and select typologies to establish the 4 levels of earthquake risk assessment procedures.

(d) Prepare a long-term plan for Earthquake Risk Assessment of the built environment and of the people.

This should be completed in about 5 years. It is will initiate a number of actions, namely:

(1) Awareness generation of the general public,

(2) Sensitisation of policy makers and administrators, and

(3) Prioritisation of retrofit of existing structures.

3.4 Formulating Earthquake Design & Construction Standards

In the recent times, the Bureau of Indian Standards (BIS) has launched a massive effort towards harmonizing and updating existing Earthquake Standards and formulating new design and construction standards. These standards largely address three major needs, namely:

(1) Criteria for Earthquake Resistant Design of Structures (as IS 1893);

(2) Earthquake Resistant Design and Detailing of Structures (as IS 13920); and

(3) Earthquake Safety Assessment and Retrofitting of Structures (as IS 15988).

The standards are expected to address all prominent structures, including:

(1) General Provisions for buildings (made of concrete, steel, masonry, adobe, and wood),

(2) Water Tanks,

(3) Bridges,

(4) Industrial Structures,

(5) Dams (including concrete gravity, concrete arch, earthen, and rock-filled earthen dams),

(6) Base Isolated Structures,

(7) Pipelines, and

(8) Tunnels.

These standards are being developed with deep studies on earthquake geotechnical engineering aspects and foundations. Further, a new standard is being developed on testing protocols for components, sub-assemblage and systems, including full-scale specimen and precast constructions.

Clearly, the development of standards has begun in a earnest and harmonized manner. In particular, the BIS has steered a comprehensive Probabilistic Seismic Hazard Assessment of India, with a view to scientifically project the likely earthquake ground shaking across the Indian landmass at a regional scale of 0.1° (~11km). This will not be sufficient to assess the earthquake hazard at a city level, which demands Probabilistic Seismic Hazard Assessment to be performed at a higher resolution 0.01° (~1km). Also, these two hazard assessments, namely the macro-hazard assessment at 0.1° and the micro-hazard assessment at 0.01° should reflect clearly the intents of their uses, and thereby arrive at appropriate methodologies, ensuring that the scientific procedures are consistent in the estimation of hazard. The BIS should be requested to undertake this effort on priority basis.

4. Technology Development

Earthquake Disaster Mitigation involves organizing and managing resources and responsibilities for dealing with all humanitarian aspects of earthquake emergencies before and after their negative fallout. This effort undertaken is expected to lessen the impact of disasters in five phases of the Disaster Management continuum, namely Mitigation, Preparedness, Response, Rehabilitation and Reconstruction. A few urgent steps needed are provided hereunder, which are towards implementing clear directions obtained from education and research.

4.1 Network of Earthquake Strong Motion Recording Instruments

Realistic seismic hazard assessment needs realistic inputs. Strong ground motions recorded during large magnitude events are mandatory primary inputs to site-specific earthquake hazard assessment. Currently, a limited number of instruments are operational along the Himalaya. Also, only in a few cases, the accelerometers and displacement meters (i.e., GPS devices) are co-located.

Considering the large investments underway and likely in the ensuring years of the decade on infrastructure development in the country, it is prudent to expand the number of strong motion instruments deployed along the Himalaya. Also, they should be networked and tele-metered to be viewed online.

4.1.1 Current Networks

Currently, the national strong motion program in India has 150 SMAs collocated with 150 broad-band seismometers as part of the National Seismological Network (NSN); it is operated by the National Centre for Seismology (NCS) (**Figure 2**). In addition, some national organizations are operating a limited number of strong motion accelerometers (SMA), the data from which is not integrated with the NCS database. For a nation of ~32 lakh km^2 land area, this is a small number, especially when 57% of its land area is prone to moderate to severe seismic ground shaking. In contrast, the approximate number of strong motion instruments deployed in countries with advanced seismic safety is:

(1) Japan : 2,600 in ~3.8 lakh km^2 land area

(2) USA : 2,600 in ~98.0 lakh km^2 land area

(3) Taiwan : 500 in ~0.36 lakh km^2 land area

(4) Italy : 550 in ~3.0 lakh km^2 land area

(5) Iran : 1,200 in ~16.5 lakh km^2 land area

These networks have grown gradually and have been operational for decades continuously and have provided valuable data sets, which have led to refined seismic hazard assessment. This has contributed to improved earthquake resistant design of structures.

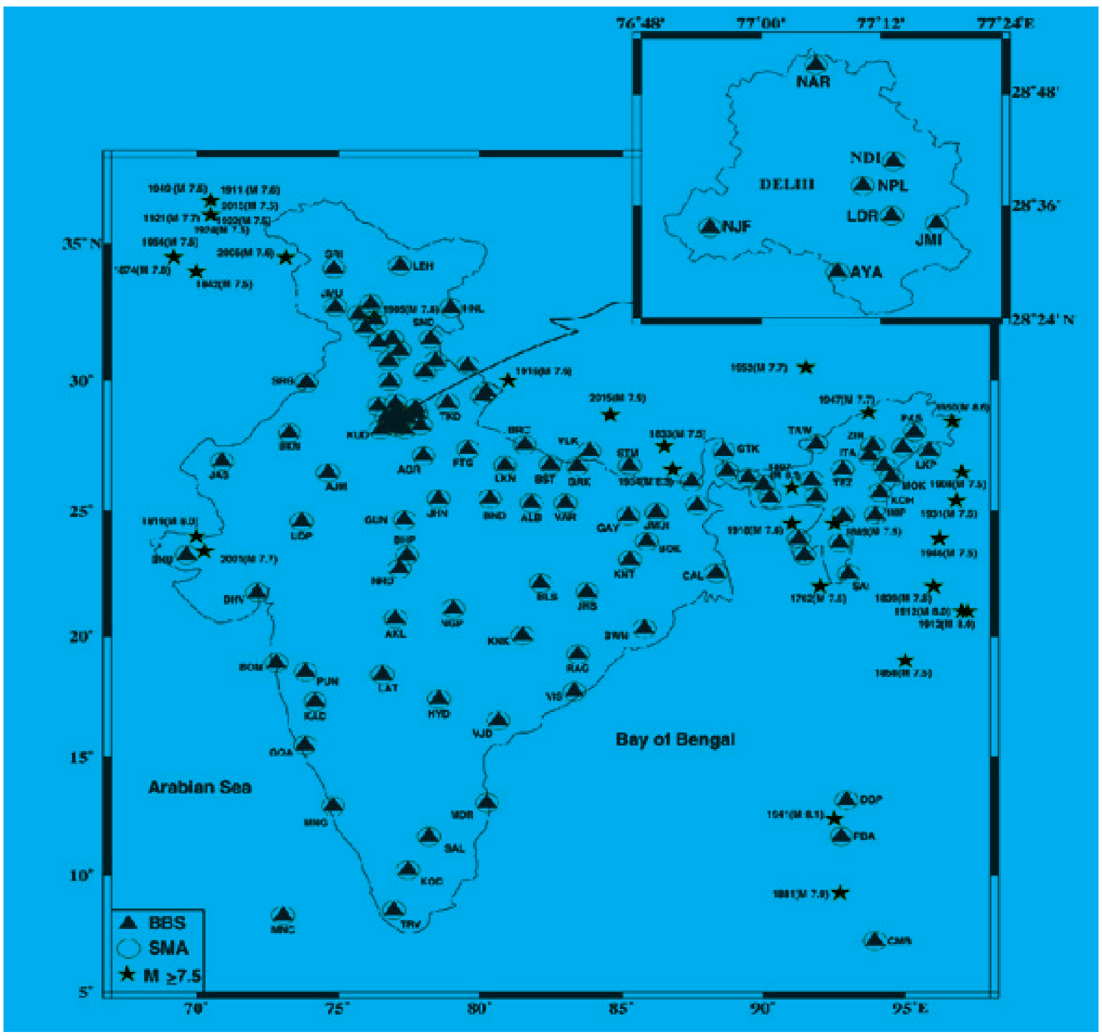

Figure 2: Distribution of the 150 observatories in the national seismological network of India (Source: B. K. Bansal, MoES)

4.1.2 The Need

Here are the technology development needs related to network of earthquake strong motion recording instruments:

(1) Strengthen Seismological and Geodetic Networks

This should include collocation of strong motion accelerometers, broad-band velocity meters and GPS sensors, with satellite-based telemetry to national clearinghouse. The first phase of development of the network should comprise at least 2,500 of each of the above instruments. In the long run, the number of instruments along the Himalayas and Andaman & Nicobar Islands should be on an average one set of these three instruments in every 100 km^2. In peninsular India, the effort should assure on an average one set of these three instruments in every 625 km^2.

(2) Manufacture and Develop Indigenous Instruments

With the large number of instruments needed to be deployed and upgraded in time to come, India should embark on a national mission to develop indigenous seismological & geodetic instruments. This will help the nation save a large amount of foreign exchange and thereby march towards Atmnirbhar Bhaarat.

(3) Create National Clearinghouse of Seismological and Geodetic Database

A state-of-the-art Seismological and Geodetic Database Center should be commissioned as per the standards set by the Indian Space Research Organization. Towards this end, a number of ancillary units need to be established for each of these instruments, including:

(a) DC Power devices and systems,

(b) Communication devices and systems, and

(c) Storage devices and systems.

As stated above, these devices and systems should be developed and manufactured within the country.

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(a) DC Power devices and systems,

(b) Communication devices and systems, and

(c) Storage devices and systems.

As stated above, these devices and systems should be developed and manufactured within the country.

4.2 Development of Indigenous Sensors and Instruments

In the coming decades in India, a large number of sensors need to be deployed, maintained and operated not only for recording ground shaking arising from earthquakes, landslides, snow avalanche and blast, but also for measuring geotechnical properties and response of the ground, and structural properties and response of structure under effects of various loads. Therefore, it is appropriate to design and manufacture these sensors within the country. This will not only save foreign exchange, but also permit regular & timely maintenance at a reasonable price.

4.3 Full Scale Testing

National Full-Scale Test Facilities are required across India, which can perform quasi-static cyclic and pseudo-dynamic loading of full-scale structures, especially of:

(1) Building systems up to 3 storeys;

(2) Sub-assemblages of buildings up to 10m in height;

(3) Bridge girders up to 15m span;

(4) Bridge piers up to 10m height; and

(5) Base isolation devices.

Three explicit outcomes of these tests at the National Full-Scale Test Facilities are:

(1) Technology Qualification – through Testing;

(2) Technology Certification – through Nonlinear Analysis and Testing; and

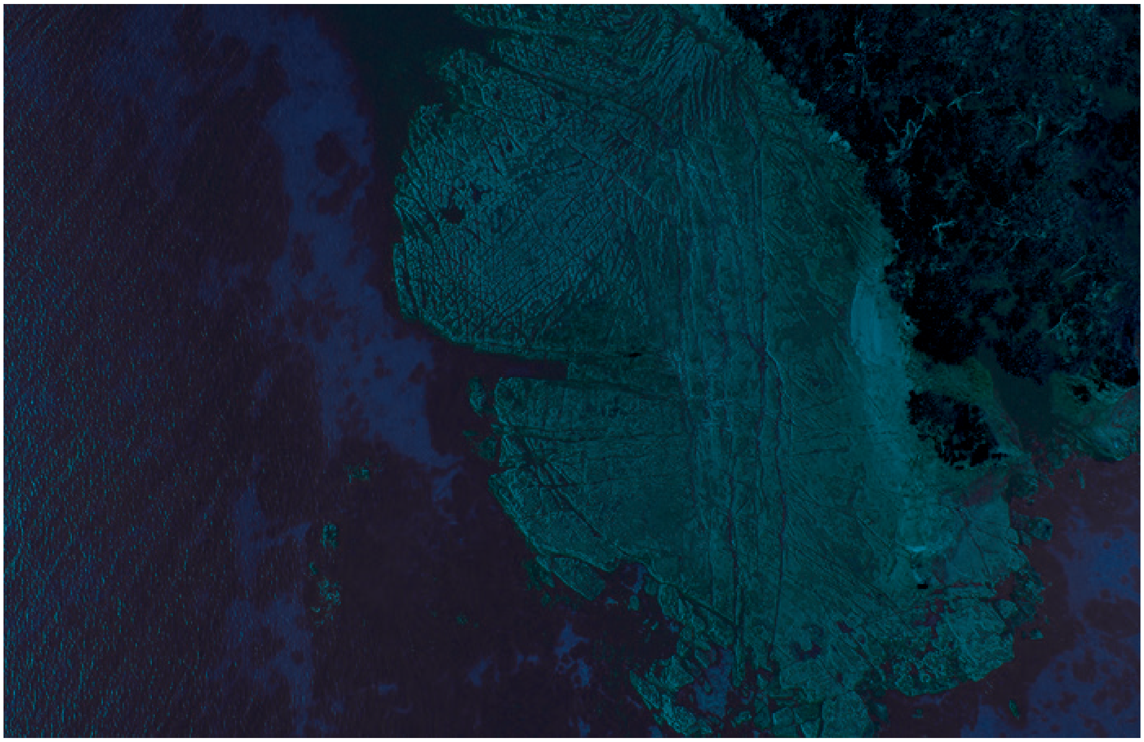
(3) Technology Development – through Design, Nonlinear Analysis and Testing.

The major equipment needed at such facilities include:

(1) Integrated Strong Floor-Wall System, and

(2) Actuators, Power Pack, Control System, Sensors and Data Acquisition Systems.

Thus, the outcomes of **Section 3.3** are vital.



5. Operational Aspects

People, process and performance need special attention in the matter of Earthquake Disaster Mitigation. In a country of 132 Crores population, the number of formally trained and competent hands available to serve the technical needs of the nation is abysmally small. So, it is imperative to make an imperfect start with the available hands, then to wait for the ideal situation of critical mass. This imperfect start notwithstanding, a formal program is needed to upscale the technical competence at all levels in the academia, governments and industry.

5.1 Lead Agency

The following lead agencies are suggested for Earthquake Disaster Mitigation:

(1) Earthquake Hazard Assessment	:	CSIR NGRI, Hyderabad and ISR, Gandhinagar
(2) Earthquake Risk Assessment	:	Consortium of select IITs
(3) Earthquake Risk Mitigation	:	Ministry of Housing and Urban Affairs, GoI, and Ministry of Rural Development, GoI

5.2 Mechanisms Needed for Dealing with Earthquake Disasters

The approach adopted so far in the last 7 decades towards mitigating earthquake disaster has resulted limited progress towards earthquake risk reduction. A focused and mission mode approach is needed to make substantial progress before more built environment is added at the current hectic pace.

(a) Technological Issues

There is a need for a single empowered technical body at the national level, which works towards ensuring earthquake safety of the people of India, especially to continually:

(1) Integrate the diverse works (science, engineering, architecture and social science) of various organizations related to earthquake hazard assessment, earthquake vulnerability of the built environment, and earthquake risk assessment of physical assets and people of India; and

(2) Propose practicable structural and non-structural changes to NDMA.

(b) Operational Issues

It is suggested that the following Operational Mechanism be created to effectively deal with the subject of Earthquake Disaster Mitigation:

"Hand-pick competent persons (who deliver), pose the national grand challenge to them, enable them to work on Mission Mode, and use the outputs and outcomes of their work towards improving life safety of the people of India."

5.3 Manpower

To bring fresh breath of air in the renewed approach to earthquake risk assessment, it is suggested to invite select competent Persons of Indian Origin. These persons should have specialist knowledge and skill in the allied subjects, and have the positive attitude and missionary zeal to serve and contribute in this national effort. A few persons who are acclaimed for this competence in the domains of earthquake hazard assessment and risk evaluation.

6. Tsunamis

6.1 Technological Preparedness

The 2004 Indian Ocean Tsunami came as a surprise to the coastal communities of India, since they were unaware of tsunami risk and vulnerability they were exposed to. Also, the absence of an effective early warning system compounded the disaster. The enactment of the Disaster Management Act 2005 and National Disaster Management Guidelines: Management of Tsunamis 2010 gave impetus to the establishment of the Indian Tsunami Early Warning System (ITEWS). This is being administered by the Indian National Centre for Ocean Information Services (INCOIS), in association with National Institute of Ocean Technology (NIOT), National Centre for Coastal Research (NCCR), National Centre for Seismology (NCS), Survey of India (SoI) and National Remote Sensing Centre (NRSC).

The real-time observational networks of seismological stations, tsunami buoys and tide-gauges together with numerical simulations have helped in forecasting the tsunamis accurately (within 10 minutes of the occurrence of earthquakes) and dissemination of the warning to all coastal stakeholders along the Indian Ocean. Towards preparing people to respond effectively in the event of a tsunami, INCOIS conducts outreach programs (like mock drills, communication tests and community awareness programs along the Indian coastline).

6.2 Recommendations

To strengthen the technological preparedness to face tsunamis, the following aspects need to be addressed:

(1) Generation of tsunamis arising from non-seismic sources; and

(4) Generation of high resolution topography and bathymetry data for real-time tsunami inundation modelling.

To address the above, the following technical recommendations are proposed:

(1) Preparing high resolution topography maps based on bathymetric data of potential areas;

(2) Identify and assess tsunami sources in subduction zones, including areas prone to submarine landslides and volcanic eruptions;

(3) Strengthening the monitoring networks with state-of-art instrumentation, and integrating with platforms for faster numerical simulations;

(4) Studying effect of natural and manmade barriers (sand dunes, mangroves, coral reefs, grass beds and coastal forests) to mitigate impact of tsunamis.

(5) Strengthening technical collaborations with regional and international agencies for sharing of critical data to improve warning services.

6.3 Lead Agencies

Lead Agency : INCOIS

Collaborating Agencies : NCCR, NCS, NIOT, SOI, NGRI, NRSC, NDMA, MHA, NGOs,

Ministry of Education

7. Landslides

7.1 Introduction

About 4.2 lakh km^2 (12.6% of land area) of India is prone to landslides (**Figure 3**). Of this, 1.8 lakh km^2 falls in the north-east, 1.4 lakh km^2 in north-west Himalaya, and 1.0 lakh km^2 along the eastern and western ghats in peninsular India. The Himalayas and Western Ghats are particularly vulnerable, accounting for ~65% of the landslides. On an average, the landslides cause movement ~2,500 tons of soil mass per km^2.

The Geological Survey of India (GSI) was identified as the nodal agency for Landslide Hazard Zonation (LHZ), while the Department of Science and Technology (DST) and the Ministry of Environment and Forests (MoEF) were identified as nodal agencies for Geotechnical Investigations and Land Use Zonation and Regulation, respectively. The DST launched the Coordinated National Program on Landslide Hazard Mitigation and published a document on the Status of Activities and Thrust Areas of Research in December 2003. Several projects have been sanctioned by the DST since then. There are many government departments and organisations which are engaged in landslide hazard studies and hazard management in the country. These include the GSI, Central Road Research Institute (CRRI), Central Building Research Institute (CBRI), Indian Institute of Technology, Roorkee (IIT-R), Wadia Institute of Himalayan Geology (WIHG), Department of Space (DoS), National Remote Sensing Centre (NRSC), Defence Terrain Research Laboratory (DTRL), Bureau of Indian Standards (BIS), some academic institutions, and individual experts. The Snow and Avalanche Study Establishment (SASE) under the Ministry of Defence (MoD) is the institution engaged in studying snow avalanches. In addition, the Border Roads Organisation (BRO) is the principal agency responsible for the construction and maintenance of roads in almost all the hilly and border regions of the country.

Clearly, there is no single national body (working with all partner agencies) managing landslide hazard through an institutional mechanism, by following a systematic approach that includes both short-term and long-term planning after a study of the hazard, vulnerability and risk assessment.

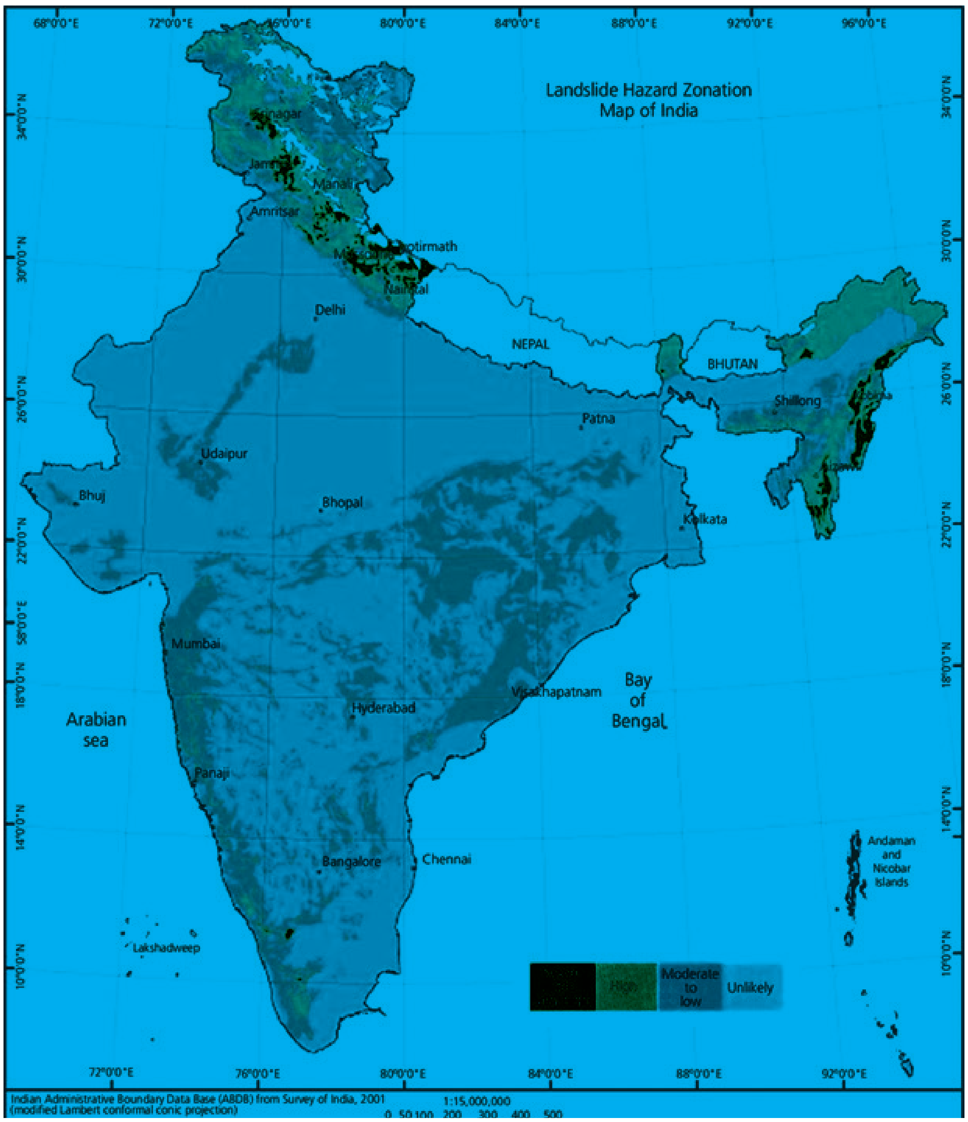


Figure 3: Landslide hazard zonation map of India (Source: www.bmtpc.org)

7.2 Recommendations

The following salient recommendations are made for landslide disaster mitigation:

(1) Digital Inventory of Spatial and Temporal Landslide Incidences,

(2) National Methodology for Landslide Hazard Assessment,

(3) Site-Specific Studies of Major Perennial Landslides for landslide hazard mitigation, including Instrumentation and Monitoring of Landslides, and remedial mitigation measures,

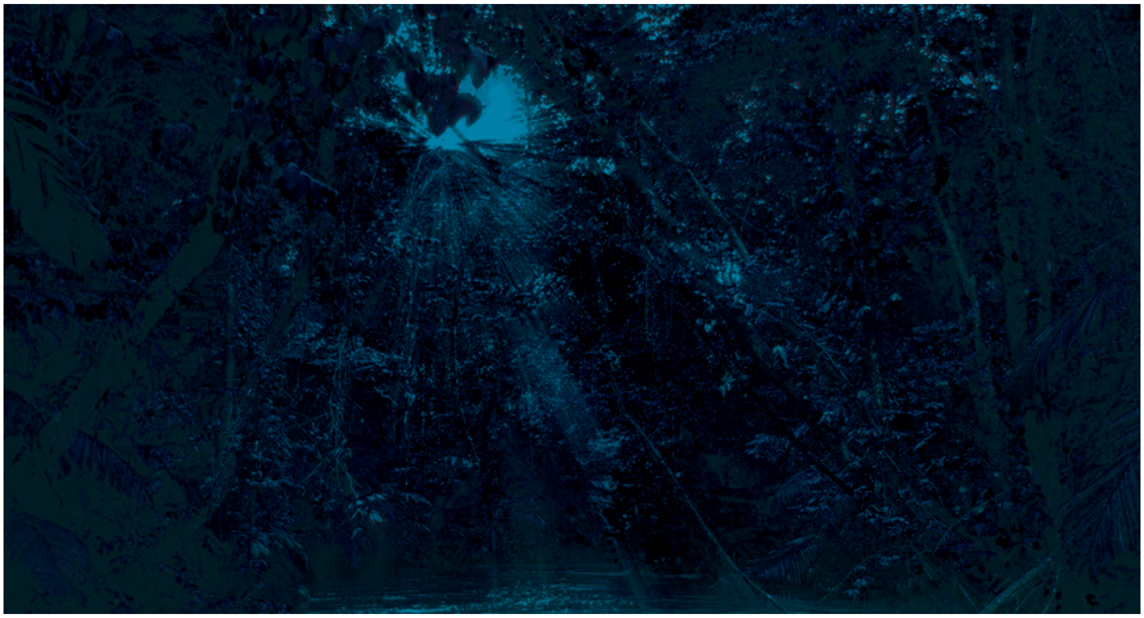
(4) Development of low-cost sensors for landslide monitoring,

(5) Capacity development of technical human resources in academia, R&D agencies, and government departments & ministries, and

(6) Establishment of Indian National Center for Landslide Mitigation, as a single national operational body (collaborating with all partner agencies) managing landslide hazard through an institutional mechanism, by following a systematic approach that includes both short-term and long-term planning after a study of the hazard, vulnerability and risk assessment.

7.3 LEAD AGENCIES

Lead Agency	:	Indian National Center for Landslide Mitigation
Collaborating Agencies	:	GSI, NRSC, RSACs, SASE, DTRL CSIR-NGRI, CSIR-CBRI, CSIR-CRRI, CSIR-CSIO, CMRS, NIRM, BRO, NGF, WIHG



8. Closing Comments

The extra attention and effort to mitigate the effects of the ongoing Corona Virus pandemic notwithstanding, Disaster Mitigation (DM) of Geological Hazards remains a major need of the nation, and should be acted upon.

8.1 The Gigantic Task

Developing a culture of safety and prevention across the people of India needs to be the focus. While the task may sound too daunting, an imperfect start is the perfect start! So, the work should begin simultaneously at all the levels, and the work completed within a targeted time. The key initiatives needed are described in this document, which will help the nation manage earthquake disasters in an effective manner.

Given the bewildering complexity of the unfolding canvas, and the rapidity with which change is occurring, it is absolutely imperative that the DM should be pursued in a real-time mode. All effort and activities spanning the DM continuum should remain driven by the imperatives of human and environmental sensitivity. The need to protect preserve, protect and defend the benefits of growth and development, which have resulted from long years of imaginative planning and in maculate implementation heads to remain upper must in the psyche of planners and administrators. Needless to say, all effort should be undertaken in an inclusive and participatory manner, apart from being transparent and accountable. Finally, especially in the area of reconstruction, the challenge presented by the occurrence of an earthquake is really, in the long run, an opportunity to build back better!

8.2 Technological Readiness of India

The salient needs to further geological hazard mitigation are:

(1) Earthquake Disaster Mitigation:

(a) Introducing earthquake safety of the built environment as mandatory part of the Technical Education in India at the undergraduate level in civil engineering and architecture degree programs:

(b) Licensing of Civil Engineers for ensuring competence in the hands that design and construct the built environment;

(c) Revise Building Bye-Laws of all States and UTs of India to weed out unsafe typologies and ensure that mandatory earthquake resistant features are included in the design and construction of structures;

(d) Start the mandatory structural safety peer review of structural designs in all Urban Local Bodies and Panchayati Raj Institutions of all new structures to be built, before providing consent to establish; and

(e) Prioritized Seismic Retrofit of critical and lifeline structures for ensuring governance continuity and for providing essential services to the people of India.

(f) Sensitize policy makers and decision makers on:

(1) At least the minimum mandatory legal instruments needed to ensure earthquake safety in India;

(2) Importance of structural seismic retrofit; and

1. Criticality of introducing Licensing of Civil Engineers in India towards ensuring structural safety of built environment in India.

(2) Tsunamis Disaster Mitigation:

(a) Identification and assessment of tsunami sources in subduction zones, including areas prone to submarine landslides and volcanic eruptions; and

(b) Strengthening monitoring networks with state-of-art instrumentation, and integrating with platforms for faster numerical simulations.

(3) Landslide Disaster Mitigation:

(a) Establishment of Indian National Center for Landslide Mitigation, as a single national operational body (collaborating with all partner agencies) managing landslide hazard through an institutional mechanism, by following a systematic approach that includes both short-term and long-term planning after a study of the hazard, vulnerability and risk assessment.

Contributors

Dr. V M Tiwari, Director NGRI	Chairman
Dr. D. Srinagesh, Retired Chief Scientist, NGRI	Member
Professor C.V.R. Murty, IIT Madras	Member
Dr. T Srinivasa Kumar, Director INCOIS	Member
Professor Surya Prakash, NIDM	Member
Dr. Sumer Chopra, Director ISR, Gandhinagar	Member
Dr. I. D. Gupta, Former Director, CWPRS	Member
Dr. Amit Kumar Verma, Associate Professor, IIT BHU	Member

CHAPTER - 4

MEDICAL AND HEALTH RELATED DISASTERS

Introduction

India has been listed as one of the top 10 countries with most natural disasters. The geographical features render it vulnerable to a number of natural hazards such as earthquake, floods, fire, cyclone, landslide, avalanches etc. These disasters have huge socio-economic impact on the country (Figure 1). Preparedness for dealing with disaster and recovery is critical for saving lives and minimizing damage and disruption in the aftermath.

India, rather whole world has seen a terrible disaster in the form of Covid 19 (Corona as it is generally called) for past two years and it is not the first time. The plague in the early nineteenth century wiped out a large percentage of the population and many other incidents have happened. Certain human races have vanished because of virus. Covid 19 once again has highlighted the importance of preparing the country against health-related disasters.

We have learnt a number of lessons that give us a fair idea of preparedness needed against health-related disasters. India managed Covid 19 much better than many advanced countries and it is largely because the Hon Prime Minister led the fight from the front, invoking emergency powers from the Disaster Management Act. He was practically there in all decision making, visible or not, but taking advice from the best experts in the country. The lessons that we can learn from Covid 19 or for any other pandemic that may happen in the future are as follows;

(i) Country needs an early warning mechanism for any outbreak of diseases by keeping a close watch on what is happening anywhere in the world.

(ii) Country needs to be better prepared to face such an occurrence any time in the future with respect to infrastructure like hospital beds, emergency medicine and other supplies like oxygen, syringes etc. The infrastructure created for fighting Covid 19 is already vanishing, though the fear of its retuning is not totally gone.

(iii) We were very lucky that two indigenous vaccines came in time and they were very effective. We had very moderate 3rd wave and practically no fourth wave is largely because of vaccination program on war footing. We need to increase the number (capacity) of laboratories for development of vaccines. Lot more research is needed in this area and a task group needs to be create with participation of DBT and ICMR.

(iv) Yet another health-related disaster may happen due to manmade causes like radiation or biological weapon. INMAS/DRDO is the only laboratory working on protection against radiation and that too largely for defence personnel. We do not have enough screening facilities against any of the two. This aspect has to be addressed, and both research and capacity additions are needed.

(v) ICMR needs to put in place an ever-ready response team to address these issues as a system rather than depending up on PM to actively lead. These issues should in future be tackled by professionals, trained for these tasks.

Advance technologies are transforming the healthcare sector and creating opportunities to build resilience thus creating wide societal impact, including healthcare disaster risk management. During medical emergency, timely delivery of medical supplies is of essence. Breakthrough innovations have the potential to change the ways we use medical technology for public health and change the course of human health.

Possible impact of the disaster in the future:

Both natural or manmade disasters are classified into Earthquake (Mountain and costal), Cyclones, Floods, Fires (including Forests), Biological, Nuclear, Chemicals, Transport (metro, Rail and Road), Construction site and/or Electrical (Domestic High tension line and Thunder) disasters. Theses disasters directly or indirectly have a significant impact on the healthcare system. The potential disasters and their mitigation strategies have been described by Technology Preparedness groups formulated by INAE. However, any potential disasters pose unique challenge for every medical care facility in terms of infrastructure, capacity and preparedness.

Analyzing how these have been addressed (responded by the country) in the recent past.

Under the Indian federal system, rescue and relief measures in the event of any natural calamities are the responsibilities of State Government. The Central Government supplements the State relief efforts and provide supportive action. The National Disaster Management Authority (NDMA), is the apex body for Disaster Management in India and is mandated to lay down the policies, plans and guidelines for Disaster Management. The organisation has drafted National Disaster Management Guidelines for Management of Tsunami [2], Cyclones [3], Chemical [4], Nuclear and radiological [5] or Earthquake [6] related disaster. As per the "Disaster Management Act, 2005" of the Govt of India, it is mandatory for the hospitals to prepare a disaster plan [7]. These Policy frameworks have been prepared keeping in view the National Vision to build a safe and disaster-resilient India by developing a holistic, proactive, multi-disaster and technology-driven strategy for disaster management. The advent of modern technology would come handy at the times of difficulties,

Analyzing the gap areas:

Based on recent experience and subsequent preparedness, what are the gaps we see now and the future. Let us take an example of current pandemic, Covid 19. We were caught totally unaware and unprepared. We did not have test infrastructure, things like ventilators, oxygen supply chain and hospital beds. Today well prepared for perhaps even for another wave, are we? Then there are other medical emergencies like radiation leak.

In case of any novel outbreak such as COVID-19, Zika, Nipa virus or swine flu etc diagnostics kits/ Treatment/ Monitoring and even evaluations supplies are required. Recently during the Covid-19. ICMR developed a List of novel covid testing labs their location and even the kit validation portal was developed immediately. However, these novel diagnostic kits require rapid prototyping and scale-up.

This report focuses on technology preparedness for dealing with medical and health related aspects of the national disasters

Recommendations:

i) Technological innovations and advancements are creating opportunities for improving resilience to disasters and supporting risk reduction. A multi-pronged approach of adopting technologies to tackle Medical and Health Related Disasters. For integration approach (a) fostering development of novel technologies, (b) common testing and prototyping facilities, (c) developing a list of dependable supplies for readily supply of resources in case of any potential disasters and/or (d) Public Private Partnership to rapid scape up of technology in case of any emergency.

ii) Simultaneously, a backward integration approach needs to be adopted incorporating;

(a) Readiness of existing technologies which can cater to any medical emergencies.

b) Disruptive technologies such as artificial intelligence (AI), unmanned aerial vehicle or drones, predictive analytics software or risk modelling are transforming the healthcare domain and disaster risk reduction and management.

iii) Drones: In the healthcare sector, timely delivery of medical supplies are an essence. Unmanned Aerial Vehicles (UAVs) or commonly known as drones are known for their rapid, cost-effective and safe delivery of goods even to hard-to-reach terrains compared to other air transportation systems. Drone operations can leapfrog the last mile logistics solution for transporting medical supplies in hard to reach/ disaster effected region.

iv) Artificial Intelligence: AI based tools and technologies help in predictive analytics or risk modelling of variety of phenomena, and thus holds immense potential in disaster management. AI-powered image recognition plays an important role in disease screening and diagnostics. The AI algorithms not only help in forecasting or modelling but also logistics or mobilisation of resources or supply chain management.

v) Medical Devices Cluster: Government is actively promoting medical device clusters. In case of any potential disaster the medical device clusters can be harnessed for testing, validation and even upscaling the technology. A scale up eco-system at AMTZ, Vizag is an example of how public private partnership could be used for scaling up RTPCR production from zero in March 2020 to almost 10 lakh test kits per day, by Dec 2020. Similarly use of container based mobile ICUs, mobile PSA oxygen plants and mobile RTPCR laboratory vans being built at AMTZ are of enormous benefit in rapid response. Such common infrastructures could be considered as focal points for supply sourcing by government.

vi) Dependable supplies: A list of immediate and dependable suppliers is required which can quickly provide bulk units to the Government. Spaces for medical exigencies could be identified and a geo-location database for such spaces could be included.

vii) Industry-Academia Collaboration: is essential for efficient R& D and rapid scape up of technologies in case of any outbreak or healthcare emergency. For e.g, Development, validation and scale-up of 'Covaxin' by ICMR-NIV Pune and M/s Bharat Biotech have setup an example for an efficient Industry-Academia collaboration [8]. A ray of hope exists for the possible vaccine solution to COVID sooner than later. There is also a need to have a well-defined process for testing of the product(s) the innovators come up with, to obtain the needed approvals, human trials, and finally to produce them in millions - all of them are to be engineered to respond to a calamity. Scaling-up in all these systems requires a whole ecosystem. Engineering skills are to be encouraged in consultation with Industries for scaling up, establishing manufacturing capacities and reducing costs.

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Technology Preparedness for dealing with National Disruption: Medical and Health Related Disasters

Members of Drafting Committee (in alphabetical order)

1) Dr. Anand Krishnan, AIIMS, New Delhi

2) Dr. Anil Mishra, INMAS, New Delhi

3) Dr. Chander Shekhar, Former ICMR, New Delhi (Chairperson)

4) Dr. HK Mittal, Former DST, New Delhi

5) Dr. Jitendar K Sharma, AMTZ, Vizag

6) Dr. P Siva Peruman, NIOH, Ahmedabad

7) Dr. Prakamya Gupta, ICMR, New Delhi

8) Dr. Praveen Agrawal, AIIMS, New Delhi

9) Dr. Rajiv Chhibber, AIMED, New Delhi

10) Mr. Rajiv Nath, AIMED, New Delhi

CHAPTER - 5

CYBER SECURITY RELATED DISASTERS

Protection of National Critical Information Infrastructure

Overview and Executive Summary

India is in next phase of Digital Transformation. The digital presence of economic and national security infrastructure is growing in the country at a rapid pace. All critical infrastructures are dependent and have integrated cyber technologies for management, control, and operations. Different types of Software are implemented. The critical systems are under various types of cyber-attacks. The complexity and numbers of attacks against critical information infrastructure are increasing and becoming sophisticated by the day.

Parliament of India passed the Information Technology Act in 2000 and since, there has been an explosive growth in the digital markets. There were many experiments to better manage the emerging issues from cyber space in the last two decades. However, The Indian cyberspace continues to be split into multiple operational spaces, and respective agencies govern each component of the space. These coordination and synchronization among the agencies is not what it should be. This proved to be an inefficient way to solve the whole problem. Correcting the institutional dysfunctionality present in the country would bring about the required effectiveness in the national response.

INAE had constituted a working group to study and assess the current of cyber security posture, structure and recommend measures and steps needed to enhance the resiliency of cyber infrastructure in the country. The working group comprised experts engaged in the activities in government, public, private, industry representing key sectors of economics. The list of members of the group is appended at Annex I.

The group has reviewed many cyber incidents over the past to derive valuable lessons for the future. The group has suggested various critical institutional mechanisms which are necessary to be in place to defend the country from the current and emerging cyber threats.

The group has used the framework of Process, People and Technology to formulate the critical institutional mechanisms. In the interest of efficiency and synergy,

The National Cyber Security Policy, 2013 need to be revised in line with the technological innovations, emerging technologies, the emerging cyber threats, open and unmanaged networks. This is necessary as there has been a sharp, complex, and intensifying trend of cyber-attacks and cyber incidents in the country. An integrated national response, covering the human as well as technical challenges involved in enhancing resiliency of the Indian cyber space is the essence of time.

The group has recommended that CERT-In & NCIIPC may be merged into one agency and a Hub and Spoke model be used for coordinating between different sectoral regulators and the National Agency for Cyber Security on policy making and its adherence to make sure that the People are aligned in this new age warfare. These bodies have to work under and with civilian organizations and therefore be placed under one roof in the civilian sector. CERT-In and NCIIPC need further significant empowerment through legislation so as to enforce cyber policies to prevent cyber incidents.

The group has also recommended that Cyber and ICT infra of critical, sensitive and strategic sectors be thoroughly audited prior to commencement of their operations by NCIIPC. This recommendation may be enforced through appropriate legislation. Incident response is the sole responsibility of CERT-In.

The group has further recommended changes in the curriculum by AICTE and UGC so that industry standard talent is available in plenty to be tapped.

To make sure that the nation's technological prowess can withstand the cyber war, the group recommends that certain platforms be strengthened by the government which are: NATIONAL RESILIENCE CENTRE FOR CYBER, CENTRALIZED MALWARE ANALYSIS PLATFORM, CENTRALIZED DARK WEB MONITORING PLATFORM AND CENTRALIZED STANDARDS BODY. The recommendations also lay down the mechanism to encourage cooperation and coordination between government, Industry, and academia in providing the best tech in the cyber security space.

The National Cyber Security Coordinator (NCSC) be empowered and responsible. His role be expanded to Coordinate all sectors and Regulators including space sector. All Regulators must get their policies vetted, prior to their notification from NCSC.

The cyber capacities of the security agencies be enhanced considerably, particularly the forensic capabilities. Active collaboration is needed between CERT-In, NCIIPC and Security agencies.

All state Police agencies must enhance their Cyber forensic and investigation infra and resources considerably.

Infrastructure to test and certify the infra and equipment w.r.t cyber security is the need of an hour. NCSC must take lead in this direction.

All the entities in government, public, private and academia must mandatorily implement cyber security policies as suited to the risks in their activities and operations.

Cyber Security Law be framed, on priority basis, outlining the legal responsibility and accountability of organizations to implement policies to secure and enhance the resiliency of their respective Cyber Infrastructure in the country.

In the end, the group has expressed its views for the need to future proof the Indian critical information infrastructure against emerging threats providing recommendations to improve the cyber security posture of Critical Information Infrastructure Protection.

Acknowledgement

The group would like to acknowledge and place on record the initiative taken by Dr. P.S. Goel to constitute the group on the important need in the country. He had been actively participating in the meetings of the group and guiding immensely on various concepts and policy measures which need to be taken in the country in this area. We would also express our gratitude to Col. Shobit Rai, Director of INAE and staff for not only participating in the meetings but facilitating the members to participate and interact among each other freely.

Last but not the least, thanks to all members of the working group for sparing their lot of time and contributing to national cause of suggesting measures to enhance the resiliency of Indian Cyber Space and in particular The National Information Infrastructure.

1. Background

Cyberspace has become, perhaps inevitably, a key and risky new environment of statecraft and competition between states in the twenty first century. Cyberspace design is based on the spirit of cooperation and sharing of information and is integral part of all activities. All critical infrastructures are now dependent on cyber and ICT technologies. The share of ICT in the critical systems is rising. The ICT technologies, though a small part of overall cost of critical systems but plays a very important and crucial role in operations, efficiency, and productivity of the critical systems. Due to very sensitive nature of role, the infrastructure is exploited by the attackers to conduct relatively inexpensive attacks against the targets and the cost of defending against such attacks is greatly increased for the defenders.

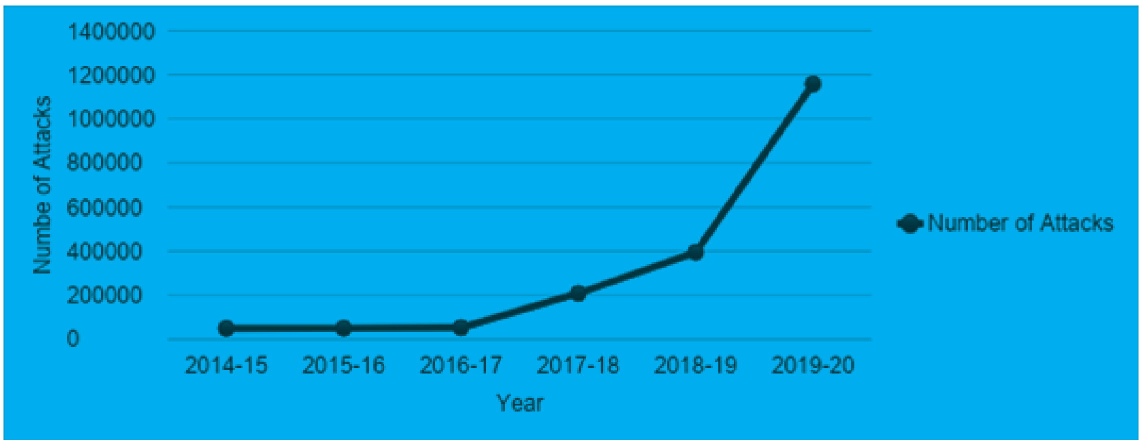


Figure 1: Cyber attacks against Indian Targets (India, Parliament of, 2020)

This situation has worsened in the aftermath of the pandemic. Due to the pandemic situation, all businesses have been forced to move to cyberspace for business. This change has been sudden and has impacted the cyber space of the country in an irreversible manner. This has also attracted lot of attention from the cyber threat actors, who intend to secure their access to the vulnerable networks amidst the pandemic. The recent spike of attacks on Indian enterprises is a case in point – Big basket, Dominos, MobiKwik breaches are too frequent to be ignored or dismissed. India's threats appear to come from sophisticated and motivated state actors with access to large amounts of resources.

The world has witnessed plenty of recent attacks on CIs. One of the most famous is the WannaCry ransom ware crypto worm – a virus encrypting data and demanding money to re- access it – which, in May 2017, infected more than 2,00,000 computers in over 150 countries.

The National Health Services in England and Scotland, with over one-third of the trusts being disrupted, was one of the largest organizations hit by the attack, together with the German national railway operator Deutsche Bahn and Spanish telecommunications company Telefonic.

After just a couple of weeks, the Petya ransom ware spread globally, causing tremendous disruptions to big firms in the US and Europe (including food company Mondelez and shipping giant Maersk) and dozens of key organizations in Ukraine (among those, state power plants, banks, airports, and metro). India's busiest port JNPT was forced to shut down one of the terminals, which was managed by Maersk, as their systems got compromised, which were located in Copenhagen.

Financial institutions, although comparatively having stringent privacy and security protocols aren't completely safe either. One of the biggest breaches in 2017 of Equifax saw hackers steal the personal data – including credit card details and social security numbers – of 143 million US citizens when they took advantage of a security vulnerability in the open-source framework Apache Struts, which formed part of Equifax's IT infrastructure. This vulnerability had been discovered two months previously, but Equifax had not installed the required patch that had been issued to close this vulnerability. Equifax has paid the price now for its negligence, racking up a recent $700m fine from the Federal Trade Commission. In India, Hitachi payment services was impacted due to a malware attack in May 2016 which resulted in 3.2 Million debit cards being compromised. Customers of many banks lost more than 15 crores rupees in this attack. In

August 2018, Cosmos Bank, Pune was attacked by cybercriminals and the bank lost Rs. 94 Crores.

On 4th September 2019, the Kudankulam Nuclear Power Plant, one of the county's most advanced such stations in India was under cyber-attack. Though it was contained immediately, and no damage was caused, there was every chance of massive damage had the attack gone unnoticed.

On October 12, 2020, a power grid failure in Mumbai resulted in a massive power outage, stopping trains on tracks, hampering those working from home amidst the COVID-19 pandemic, and hitting the economic activity hard. Later, this was traced to unknown Chinese entities in mounting a cyber-attack on Indian electricity infrastructure, leading to a large-scale power failure in Mumbai.

It is not just the Mumbai outage. The government also confirmed that the number of cyber-attacks on the power grid and the cases and sources of malware found in the energy supply system have gone up heavily. In the recent past, cyber incidents have been reported at Southern Region Load Dispatch Centre 1(SRLDC), Western Region Load Dispatch Centre (WRLDC) and North-eastern Region Load Dispatch Centre (NERLDC) of Power System Operation Corporation (POSOCO), NTPC Kudgi and Telangana State Transco.

In May 2021, two major cyber-attacks on the supply chain and healthcare infrastructure were reported. On 10th May 2021, the USA declared a state of emergency as a cyber-attack shut down major pipeline Colonial, which operates the largest fuel pipeline in the USA. On 7th May

2021, the pipeline was hacked, and operations shut down, which led to fuel shortages and lines at gas stations as it delivers roughly 45% of the fuel consumed on the East Coast. This attack is considered to be the worst cyber-attack to date on critical U.S. infrastructure. It is understood that after paying $5 Million as ransom money in Bitcoin, the pipeline started functioning after almost 5 days.

In the second incident, on 14th May 2021, Ireland's health service was forced to shut down IT systems over ransom ware attacks by 'international criminals". A cyber-attack on Irish health service computer systems was possibly the most significant cybercrime attack on the Irish state as declared by the government. The Health service IT systems would take days to return to normal after being shut down which caused a severe impact on health and social care services especially during the pandemic times.

These two major cyber incidents have clearly shown us that, increasingly, critical infrastructure and essential services are more vulnerable to widespread cyber threats. As a result, cyber security is becoming a strategic challenge requiring the highest level of oversight in the complex global industrial environment.

Looking at the intensity of cyber-attacks on critical infrastructure and the damage it can cause to the nation, it is now almost compulsory to continuously raise the bar to protect mission-critical systems from these threats by implementing best security practices, best of the technology, and highly skilled manpower. It may be very pertinent to note that the current philosophy of restraining the adversaries out, or the assumption that they will be detected if they get through the first line of defence, is no longer valid.

With the exponential growth of ICT and the value offered by digitalization, businesses and governments must reimagine how we use and manage our critical infrastructure to mitigate potential risks. This involves calibrating the national blueprint to protect our critical infrastructure, allocation of adequate budget, augmentation of skilled resources and importantly make it bureaucracy-free. This is needed to be implemented on top priority to ensure a collective, reinforced and an established framework for shared responsibility.

1.1 Rationale for Report

Indian Cyberspace as a domain now appears to be **fully weaponized**. It is generally accepted that in the cyber domain, skill to cause damage to the infrastructure is easier to recruit but the will to do damage is the key missing point. Now in the fast-changing economics and geo-political scenario, that is no longer the case.

This calls for a review of the recent cyber-attacks to answer questions from a slightly long-term perspective. The institutional establishment should be able to understand and answer the following questions.

(a) Who are the attackers?

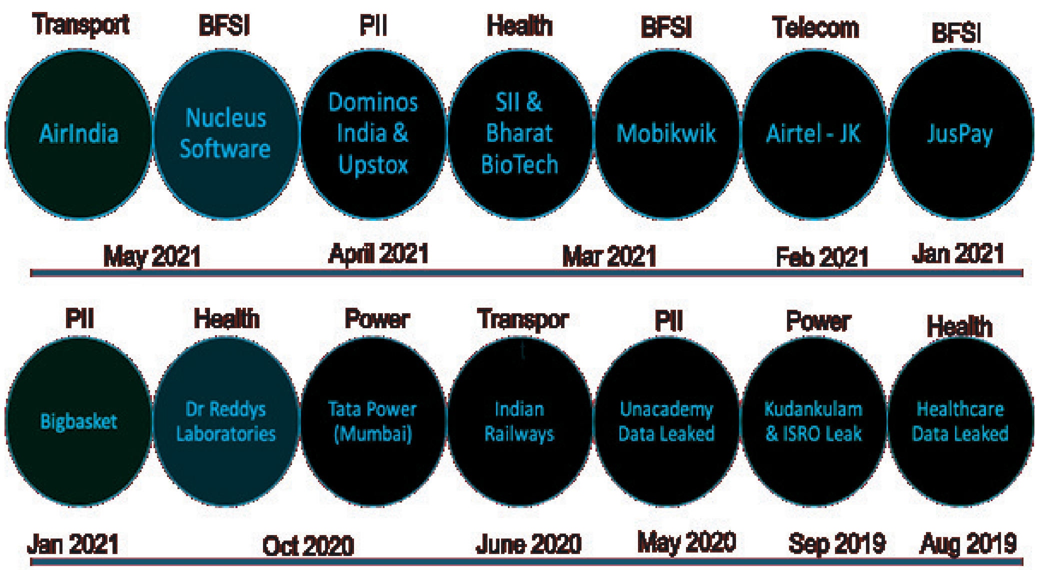
(b) Are the attacks part of a larger design of things? (c) What is the response from the Indian State?

(d) How do the threat actors see the response from the Indian State? (e) What is working in favour of the Indian State?

The focus of this report has been to develop suitable mechanisms and suggest interventions that build the capacity within the institutions of the country to safeguard India's cyberspace with reasonable confidence.

1.2 Recent Cyber attacks in India

Cyber-attacks commonly seen in the recent past fall under two known categories – stealing of sensitive information (commercial and personal) and downright destruction of computer assets (devices/data). It is necessary to state that the list below indicates only the tip of the iceberg. It is still a widely held belief that reporting the cyber incident to law enforcement agencies leads to further scrutiny and reputational risk than any meaningful assistance to the company.



S.No	Victim
1	Air India
2	Nucleus Software
3	Dominos and UpStox
4	SII and Bharat Biotech
5	Mobikwik
6	Airtel - J&K (Airtel Denied.)
7	JusPay
8	Bigbasket
9	Dr Reddy Laboratories
10	Tata Power - Mumbai
11	Indian Railways
12	Unacademy
13	Kudankulam Nuclear Power Plant
14	ISRO
15	Healthcare Data Leakages

Figure 2: Recent Cyber Attacks along with Sector and Timeline

The scope of stealing sensitive information can be gauged through the news of various breaches scooped through the sources in the Dark Web. A review of the recent breaches over the last two years indicates a wide coverage of victims. Most of the victims that have garnered public attention include many top players from the critical sectors, including Banking, Transport, Telecom, Health, and Power. It is tough to verify if the breach is genuine or not due to the nature of the digital data – it is easy to copy but difficult to verify or track the source. However, when seen as a larger trend, it no doubt points to many more leaks that have neither been reported nor noticed by the respective companies.

A more dangerous trend is the use of Ransom ware by various organized crime groups in the country. While there are many cyber groups, the recent spate of attacks is attributed to more extensive campaigns by various dangerous groups such as REVIL. Their ransom ware attacks have disrupted and affected the operations of multiple entities. A study of the ransom ware attack sample seen recently indicates the increased sophistication and its ability to evade detection by most of the commonly seen anti-malware solutions. This sophistication can be possibly seen as a result of two trends.

(a) Ransom ware Operators are running their operations as professional business ventures and hiring high-grade talent.

(b) State Actors are funding and sharing the knowledge of their operations to the ransom ware operators.

From an Indian viewpoint, there has been a sudden surge in cyber-attacks since 2014, the wide variety of breaches, and the spike in ransom ware attacks against entities based out of India. It is also not a pure coincidence that the attackers have been going over most critical infrastructure and entities that collect massive amounts of personal data. This indicates that there could be a method in the madness, and this could be a concerted effort by a motivated threat/state actor.

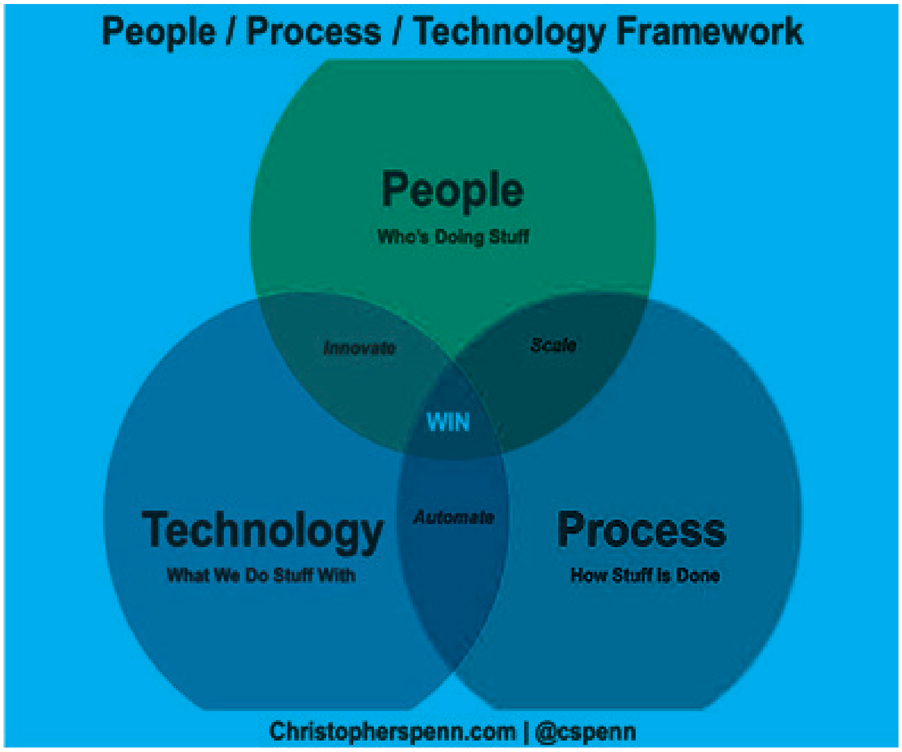
1.3 Framework for Analysis of Security Cyberspace

Digital transformation requires multiple items to come together. **People, Process & Technology** as a model for understanding the current system and proposing suitable interventions aimed at bringing desirable change.

People: Assembling the right team of people in three domains — technology, process, people at leadership roles with organizational change capacity — may be the single most important step that is needed to secure successful transformation.

Technology: In the technology domain, organizations need to make choices that support and develop the potential of the existing people and processes. Leaders of the technology domain with technological depth & breadth and the ability to bring their insights into relevant areas of work/mandate of the organizations must be able to communicate clearly with the big picture in mind.

Processes: Transformation requires an end-to-end mindset, a rethinking of ways to meet the requirements of the various stakeholders, seamless connection of work activities, and the ability to manage across various stakeholders when going forward. Process orientation is a natural fit for these needs. Processes design faces a big challenge in overcoming the hierarchical reporting structures mandatory in the Government infrastructure. This makes the process design a critical task that has to take advantage of technological innovations.



The broader message appears to be the following,

- Scale-up what's working well with better processes.
- Innovate and develop suitable products & solutions.
- Automate as much as possible in the realm of processes to improve reliability and speed.

These three are interconnected systems requiring calibration and coordination in bringing change in all three dimensions to achieve a smoother transformation process.

2. Emerging Technological Trend

All critical infrastructures deploy computer information infrastructures for management, control, and communications. The government defines a critical infrastructure as, systems and assets, whether physical or virtual, so vital to India that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health, or safety. Critical information infrastructure (CII) comprises special equipment like Programmable Logic controller, industrial controllers, software-based Relays, SCADA, computers, communications, load dispatch systems, load distribution and balancer systems and sensors etc. to control or manage production, and many other services important for the economy and daily activity. So far, the infrastructure was deploying proprietary hardware, software, communication protocols. However, the emerging technologies are now being deployed in the Critical systems. The systems are now being designed around open web interfaces, open general-purpose hardware and software and adhering to open standard and open-source products. Artificial intelligence, machine learning, next generation communication, cloud-based systems in different models like SAAS, PAAS etc. and software based on future programming are integral part of critical infrastructure. All applications are now being designed and implemented in micro architecture catering to microservices. This trend is gaining momentum. Dual protocols, both proprietary and open source are embedded in the systems. There is thus, convergence of technologies in the modern critical systems.

2.1 EMERGING THREAT SCENARIO AND IMPACT

The deployment of emerging technology has enhanced the surface and potential for misuse by preparators. Different input vectors exist, and different threats may manifest, depending on different input:

- The technology and devices used in the critical infrastructure
- Intermediate systems and stakeholders
- The overall architecture and connectivity with systems and sub systems

Example of Some of the typical potential cyber-attacks and attack scenario are indicated in the table below.

Technology		
4G/LTE/ WIFI, Cellular and Cellular network	Availability	• Signal jamming; Malicious node interface (physical attacks) • Physical tampering / breakdown of device (physical attacks) • DoS: IP hijacking to disconnect the devices (if IP routing is used) (availability)
	Integrity	• Rouge base stations for man-in-the middle integrity and confidentiality attacks. Requires physical proximity.

TCP/UDP (transport protocol)	Confidentiality	• Eavesdropping of commands and measurements over protocol implementations
DNS (Domain name System) GPS spoofing and blocking	Integrity	• Spoofing and malicious domains, • GPS coordinates injects incorrect phase-angle measurement. Radio Frequency equipment (integrity) • GPS unavailability may trigger fallback to other sources. • Device synchronizes to a spoofed time signal to maintain an incorrect stream of timestamps • Potential drifting of measurements over time. o Need for proximity to PMU equipment. o Changes in synchro phasor and phase angle calculations. • Data manipulation through software (supply chain attack)
	Availability	• DoS on the real-time clock (Malicious/ Accidental insiders)
	Integrity	• Adverse effects on connection to servers (Malicious/Accidental Insiders) • Data manipulation through software (Supply chain attack)
	Confidentiality	• Backdoor access on vendor device (supply chain attack)
NTP/PTP Server	Integrity	• Master announcing wrong time. Manipulation of control loop packets for controlling clocks at slave (Integrity) o Synchronizes to a spoofed time signal to maintain an incorrect stream of timestamps o Affects all kinds of packets (sync, delay-request/-response packets) • Delaying the slave clock causes an offset of us, which escalates in the order in the synchro phasor estimation (software/ component attack)

Industrial Controllers	Availability	• DoS on the real-time clock (Malicious/Accidental insiders)
Malware, web shell in the software and embedded subsystems	Integrity	• Adverse effects on connection to servers (Malicious/Accidental insiders) • Data manipulation through software (supply chain attack)
	Confidentiality, mal functioning, stealing of data, taking over systems	• Backdoor access on vendor device (supply chain attack)

	through remote control	
Relay Controllers	Integrity	• Adverse effects on connection to servers (Malicious /Accidental insiders) • Data manipulation through software (supply chain attack)
	Confidentiality	• Backdoor access on vendor device (supply chain attack)

The Impact of each of the scenario presented in the table varies according to the attack vector, system specifications and the type of services that is affected. Most modern critical information infrastructure utilize higher level of automation that further enhances the attack surfaces. Each of the scenario may result in very high, high, and moderate impact depending on the infra-architecture and grid systems and may impact to disrupt services over wider area and longer times. The introduction of fraudulent activities, as a result of the cyber-attack can trigger different actions (either by accident or on purpose) and even cause instability of the entire infrastructure resulting in heavy losses. There are discussions of the special cyber vulnerabilities found in industrial control systems that operate critical infrastructure facilities. These special vulnerabilities like zero-day vulnerabilities help make important critical infrastructure look like easy targets for possible cyber terrorist attacks. There are numerous recent cyber incidents and attacks on the critical information infrastructure. The gas pipe line attacks in US, Solar winds, the cloud infrastructure compromise in the US. The recent high impact cyber-attacks in India e.g., cyber-attack on power systems in Maharastra resulting in severe long duration power shut down and attack on the atomic power plant etc. Most of the technology and equipment is imported. The technological understanding of design of product, therefore, is weak point in the critical infrastructure in the country.

3. Cyber Security Landscape of Country

3.1 People: Threat Actors

Reports published on the Indian Cyber Space have seen various threat actors attempting to steal information about the 'specific' targets of interest to hostile nation powers of records containing 'personally identifiable information (PII) of the general population. It is broadly agreed that the threats to cyberspace come from the following group of threat actors based on their **competence** to operate in Cyberspace.

(a) Script Kiddies - Low Competence. (b) Hackers – Medium Competence. (c) Crackers – High Competence.

Threat actors who are operating cyberspace can be broadly categorized into three categories based on the nature of their **organization** and **sophistication**.

(b) Unorganized Mobs – Individuals or loose coalitions/factions. (b) Organized Groups – Organized criminal enterprise.

(c) State Actors – Government Agencies or their fronts.

Threat actors' purpose for operating in cyberspace is also another critical pointer, and based on the purpose, threat actors can be grouped into the following categories.

Category of Motive Motive Description		
Profit	Personal Gain – Monetary or Glory	Ransom ware Attackers, Blackmail, Hacktivists etc
Profit	Corporate Espionage	Stealing of Intellectual Property & Confidential Information
War	Planning & Preparing for Cyber Conflict	Disruption, Degradation and Destruction of Infrastructure.
War	Espionage	Collecting classified material or sensitive content for securing state interests

Script Kiddies are usually young and aspiring hackers with rudimentary skill sets in the art of cyber warfare or cyber espionage. They largely rely on the tool kits which are publicly released and ready to use exploits that are released in the public domain. Their capabilities are usually limited to the direct damage of the tool or exploit they are using. They don't leverage the initial access to exploit the network and computer systems to cause more serious damage.

Script kiddies' usual intent as a cyber-threat would be usually driven by either curiosity or an attempt to seek fame or glory among the community. This would usually drive them towards launching attacks using tools without a deeper understanding of the catastrophic impact they would create on an unprepared opponent. They are seen in usually working as a part of unorganized mobs with an aspiration to either join the organized groups or state actors.

Threats posed by the Script Kiddies require the agencies to be quick footed in patching the critical systems that are vulnerable to a publicly released exploit or tool kit. The script kiddies are also usually effective in using the anonymity, that is inherent in the design of cyberspace as a domain and pose a challenge to the investigators. They pose a tough challenge to the investigators to track but they usually lack the skills to leave a significant adverse impact on the security of the network or system. Following the best practices in cyber hygiene and remaining vigilant about network vulnerabilities in light of freshly released vulnerabilities and exploits would keep them away.

Hackers have practical experience in understanding the way cyberspace works. They have significantly toiled and built a deeper understanding of the network architectures, common cyber defence tools and protocols. They are serious attackers who have sufficient competence to plan and launch an attack against an adversary by clearly profiling the target and customizing the exploits or tools they have access to.

Hackers' usual intent as a cyber threat would be usually driven by profit or war. They are usually seen working as a part of organized groups or state actors. When part of an organized group, they see a larger impact of their work in terms of both learning opportunities and profit/glory.

Threats posed by the Hackers are sophisticated and require an active blue team inside the organization to keep track of this infiltration and monitor any attempts to expand the initial access gained in the course of the cyber-attack.

Crackers have a much deeper understanding of the underlying designs of cyberspace and have a very high competence level to understand and manipulate the design of cyberspace. They are the ones who identify critical vulnerabilities and develop patches for securing them. They also usually have a broader understanding of the domain and have usually worked in the past as a part of various organized groups to gain valuable experience.

Crackers' usual intent as a cyber threat would be driven on similar lines as hackers. They are far tougher threats to organizations than hackers are. They understand the design flaws of the security and protection tools seamlessly and have the competence to exploit them. The exploits that are seen in the cyber world are the results of their work and they are also usually adept at chaining multiple low-end vulnerabilities into an opening into the network. They are adversaries that cannot be stopped by deploying products and tools.

They are usually seen among the organized crime gangs, state actors and in rare cases, actively as hacktivists.

Organized Cyber Groups

Organized cyber groups are on a spree of global cybercrime. They have grown from targeting individual computers to corporate networks, Organized Cyber Groups have evolved over the years. They have evolved from traditional ways of bringing together cybercriminals with the necessary skill set, to working on a stand-alone basis where nobody knows anyone in person and all contact is restricted to virtual contact. This allows the members of such groups to be shielded from detection by law enforcement.

Ransomwares have one designated task - to encrypt all data available on a system. As the connectivity throughout the globe increased, so did the dangers of Ransomware attacks. The groups' interests are not limited to money anymore. Such groups now aim at stealing data from the network before encrypting it. This serves two purposes:

a. The threat of leaking data adds the pressure factor on the company to pay the ransom.

The trust of the customers and the reputation of the company in the community should not be compromised at any cost.

b. It acts as an insurance policy. If an organization refuses to pay up, the black market of leaked data is always an option for them.

The complexity has grown too. The attacks are not based on a single malicious binary masquerading as a legitimate file anymore; the attacks nowadays are targeted campaigns.

These groups have built their business strategies with an influence from legitimate B2B models. It is a full-fledged market for professionals, recruiting people from their close circles. These groups have a straightforward playbook. They identify, attack, and then extort targets. Moreover, these attacks are not limited to motivated attackers anymore. Ransomware-as-a-service, or RaaS, is now on the rise. It allows people to buy and/or subscribe to pre-built tools with ready-to-launch ransom ware campaigns.

State Actors

China has the second-largest budget in the defence sector in the world, and they perpetuate a concept called "network warfare" to house their cyber warfare. With more than 20 APT (Advanced Persistent Threats) groups attributed to China, it is an ever-increasing threat to the nations of the world. State-sponsored (speculation) Chinese cyber groups have (allegedly) targeted various verticals of Indian critical infrastructure numerous times. Even though many of those attacks have been thwarted through the intelligence gathered by the Indian cyber agencies, it's not always possible to have the intel and therefore we must be always on guard.

Pakistan has not been inactive in the meantime. Government officials have reported the uncovering of various Pakistani groups interested in attacking the state of India as well. Various reports list website defacement, both government and non-government, by patriotic hackers often publicly claiming responsibility for such operations. These operations are also motivated by and can lead to a physical event that causes friction between the two states.

Pakistani APTs are known to target military and diplomatic personnel to compromise national security as part of espionage. They heavily indulge in spear-phishing attacks to gain access to social media accounts belonging to critical personnel.

3.2 Strategy and Policy

The cyber security policy of India is outlined in the "National Cyber Security Policy, 2013" this policy is supported by several guidelines and directions issued by NCIIPC, CERT-In, Department of Telecommunications, Reserve Bank of India and other regulators of the respective economic and technical segments in the country. Along with the National Cyber Security Policy, 2013 the government had also outlined the responsibilities of the organizations/ministries/ agencies for addressing cyber security challenges. Certain provisions in the Information Technology Act, 2000 also support the cyber security policies in the country. The aim and the intention of the government, at the time of announcing such policies was to establish a system clearly outlining the responsibilities of the different entities to address the cyber security challenges in the country. However, the policy and structure so far has not matured. The synergy between the entities has also not matured. It would not be wrong to infer that the present cyber apparatus of the country needs to be well equipped to handle cyber emergencies and vital resilience planning to address the emerging challenges and sophisticated serious cyber-attacks. Unlike countries like United States, Europe, and some of the Asian countries the base for knowledge of technological product currently deployed in the country is weak.

3.3 Institutions: Cyber Security Establishment

The cyber security system of the country is divided into Defence and Civilian systems. There are predominantly two players in the civilian sector and their counterparts in the defence setup. Each has its own versions of the incident response agency and critical information infrastructure agency. Due to the intimate nature of the activities of protection and remediation/mitigation in the cyber security sphere, both agencies must have overlapping jurisdictions. A new institutional innovation in cyberspace has been undertaken in the country to create the post of National Cyber Security Coordinator.

NCSC: National Cyber Security Coordinator

Cyber Security of the nation as a major concern is shared by multiple stakeholders and there appears to be a critical need felt at the top to streamline the national response by bringing in more focus and synergy. This led to creation of the role of National Cyber Security Coordinator (NCSC) in the National Security Council Secretariat. The primary job of the NCSC is to bring synergy in the functioning of the various agencies which are dealing with cyber security.

NCIIPC: Critical Information Infrastructure Protection Agency

National Critical Information Infrastructure Protection Centre (NCIIPC) is a nodal agency for CIIP. NCIIPC functions under the administrative control of the premier technical intelligence agency NTRO. Its mandate and powers emerge from the Information Technology Act.

Under the Information Technology Act, 2000 amended from time to time, a dedicated section

70A has been incorporated for identification of a Nodal Agency for undertaking the job of Critical Information Infrastructure Protection. Through a Government Notification issued on 16th Jan 2014, this job was assigned to **National Critical Information Infrastructure Protection Centre** (NCIIPC), under the Administrative Control of National Technical Research Organization, a technical intelligence agency working under the control of the Prime Minister's Office. This is very similar to the setup in the USA, and it appears to be intended to provide the office of National Security Advisor and the National Security Council Secretariat a better way at handling the national security-related incidents in the country.

NCIIPC has identified six critical sectors for focusing on the task of Critical Information Infrastructure Protection. The sectors appear to be very clearly focused to ensure they cover maximum.

The sectors are as follows: -

S No	Sector
1	Power & Energy
2	Transport
3	Telecom
4	Banking, Finance, and Insurance
5	Government
6	Strategic Public Enterprises

NCIIPC has published no. of [standards and audit guidelines]. So far most of the focus of NCIIPC has been on Power Sector.

CERT-In Premier Incident Detection & Response Agency

Under section 70B of the Information Technology Act, 2000 as amended from time to time, a dedicated institution of "Indian Computer Emergency Response Team" exists. This is more popularly known as "CERT-In". It is part of the Ministry of Electronics and Information Technology and coordinates activities of various computer emergency response teams located in the country.

The primary responsibility of the agency remains focused on activities around the cyber security incidents, law mentions the following explicitly,

(a) Collection, analysis, and dissemination of information on cyber incidents.

(b) Forecast and alerts of cyber security incidents.

(c) Emergency measures for handling cyber security incidents.

(d) Coordination of cyber incidents response activities.

(e) Issue guidelines, advisories, vulnerability notes and whitepapers relating to information security practices, procedures, prevention, response and reporting of cyber incidents.

CERT-In runs the BOTNET Cleaning Center. It is also known as Cyber Swacch Kendra for detecting botnet infections in India. It does notify, enable cleaning and securing systems of end users so as to prevent further infections.

We also have the National Cyber Coordination Centre working closely with the CERT-IN. It is intended to screen metadata of the traffic inbound and outbound to the sensitive agencies and help in tracking and developing a coherent threat perception to the investigative agencies in protecting and defending the critical information against the threats. NCCC needs to be set up to its full mandate quickly.

3.4 Processs

Identification of Threats

Cyberspace of the country is vast and rapidly growing. There have been some efforts by the government and the private sector to work together in monitoring the threats to the cyber security of the specific sectors in particular and country in general. It appears that the majority of the threat information to the organizations is now coming from the following sources.

(a) **Open Source feeds** – There are multiple places where the information about the malicious files, Internet Protocol Addresses and domains of the various attackers (popularly known as IOCs – Indicators of Compromise) are shared. Companies who are proactive usually monitor these feeds and see if their network shows any indicator of compromise.

(b) **Government Agencies** – Monitoring the Cyber Space on their own or receive tips from anonymous or private parties about the breaches.

(c) **Cyber Security Product Companies** – Receive and Analyze various feeds of data collected open and through their products deployed in customers premises to generate a list of attacks they see. They distribute the threat feeds to all their customers.

(d) **Dark Web Monitoring Companies** – These groups of companies keep continuously and anonymously monitoring chatter about various companies in the dark web forums where the hackers discuss and try to sell the stolen data or access to a network.

In case of any observed breach, it will usually be intimated to the company and either the organization's internal team will investigate and confirm quickly to the CISO or engage a third- party expert to validate and confirm the breach or an attack. This leads the company to a process of reporting.

Protection From Threats

Implementation Controls are for translating the design/conceptualization planning into mechanisms for protecting the CII.

Operational Controls are for ensuring that the desired security posture is maintained in the operational environment

Disaster Recovery Controls for ensuring minimum downtime and the restoration process. Reporting and Accountability Controls for ensuring adequate accountability and oversight exercised by Senior management, as well as reporting to concerned Government agencies where required enforced through compliance controls.

For more detailed information regarding the family of controls please refer to https://nciipc.gov.in/documents/NCIIPC_Guidelines_V2.pdf

Reporting and Follow-Up

Process of reporting of the cyber incident is assigned to the respective CISO - Chief Information Security Officer of the organization under attack and shared with various agencies under whose jurisdiction or license the business is carried out. The agencies then would work with the organization to remediate or mitigate the attack. These instructions are guided by the CERTIN CISO Rules and the Information Technology (NCIIPC) Rules.

a. In case of any security incident, the victim organization should report the same to NCIIPC at the earliest either through email: ir@nciipc.gov.in or through Helpline number (1800114430)

b. The organization must nominate a suitable official and convey his contact information to NCIIPC. This individual must be able to provide technical details related to the incident.

c. All relevant logs to NCIIPC through secure FTP hosted by NCIIPC are to be provided. d. The organization should also arrange meeting with OEM /System Integrator (SI)

These are a summary of the SOP to be followed in case of a cyber incident. For more details refer https://nciipc.gov.in/documents/SOP-Incident_Response.pdf

4. Gaps

Despite increased spending there seems to be little improvement in cyber security posture. National capability in the field of Cyber Security is a simple sum of the Government and Private Sector capabilities. The academic partners are also aiding both the players on a miniscule scale, but need to be involved more in this area. Attacks in cyber security focus primarily on the man behind the machine. Logically, the same type of protection should be available for the personal devices and the network used by the VIPs and other prominent players in the economy, public health and order. Recent breaches of the Pegasus data revealed how easy it is to affect the decision-makers.

4.1 Processes: Complex Guidelines for Securing the Infrastructure & Reporting

Every organization has to follow instructions and directions from various stakeholders, and since the stakeholders see issues from their narrow lens, there is no coherence in their instructions. Therein lies the roots of the chaos in the response. In the case of Banking, Financial, and Insurance sector companies, this includes filing details with the sectoral regulator, Department in the Union Government Level, National Critical Information Infrastructure Protection Centre, CERT-In, CERT-Fin, and local cybercrime wing of the Police. Each agency has its separate form for reporting the incidents.

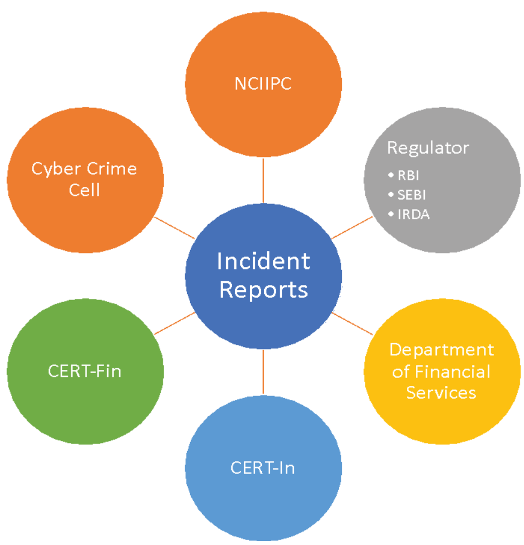


FIGURE 3 Reporting of Cyber Incident to Various Agencies (BFSI Sector)

The time ticks for the CISO from the moment there is a detection of an incident. CISO has to get a quick analysis of the scope of the breach done and report the incident along with the forensic report or malware analysis report to the various agencies in myriad formats. Subsequently, in few cases where the command and control of the attacker is identified, a suitable action would be initiated by CERT-In for blocking the IP address or the domains for quick response.

Another aspect is the general lack of coordination among the various agencies. As such the cyber security landscape is divided among the defence and civilian spaces. There are multiple distinctions among the civilian space too: - intelligence, state level, and union government level organizations. Many organizations are looking at cyberspace from their lens and focus on meeting their mandates. A more extensive outreach by the CIIP Agency with coordination would drastically reduce the amount of effort and improve the quality of the outcomes for everyone.

Ambiguity in Regulations

There are multiple agencies that attempt to regulate the critical information infrastructure members. It starts with their sectoral regulators to local law enforcement officials. Cyber security in the issue of critical information infrastructure is best captured by a quote from Porteus, 1999.[1]

"A Gordian knot around which many stakeholders circle, pulling on the strands that seem most promising and causing the entire thing to tighten even more snugly rather than loosen to reveal its internal structure."

- Porteous in 1999

[1] Porteous, H. (1999) 'Some thoughts on critical information infrastructure protection', Canadian IO Bulletin, October, Vol. 2, No. 4, available at: http://www.ewa-canada.com/ Papers/ IOV2N4.htm.

The agencies span across multiple ministries and cover the presence both at state and national level. While national cyber security policy was released in 2013, the document did not receive wider attention and ministries continued to function without any synergy or unity of purpose in the area of cyber security

Impatient Experiments

An institutional innovation in the form of a National Cyber Security Coordinator was created to coordinate the issue of cyber security at the national level. The organization now exists without any clearly defined roles, responsibilities and without any organic connections with the ministries that are stakeholders in the topic of cyber security. This institution should be empowered in a creative way to be able to plug the gaps in the current cyber security mechanisms of the country. However, as on date it looks like it exists without any backward and forward linkages in the government system.

4.2 People

Lack of Direction for Manpower

The country has experienced rapid growth in the digital era. This growth has given rise to new markets and industries, all in the requirement of skilled cyber security professionals to protect them from cyber threats that are growing into more sophisticated and persistent attacks by the day. Therefore, the faculty responsible for imparting knowledge to the students should keep up with the demands of the constantly changing and updating fields of technology and global trades to offer world-class course materials to match the fierce competition in the global arena.

However, the lack of industry-experienced professionals in academia has created an over-emphasis on theoretical knowledge which has overshadowed hands-on practical experience.

Lack of a well-managed apprenticeship and/or internship structure within educational institutions is a major cause of students lacking real world experience. Professors not being able to incorporate hands-on opportunities within the curriculum itself creates an incomplete learning structure, with a scope limited to textbook material. Few students are able to look outside this influenced learning structure and venture into the environment of realistic cyber security challenges; rest follow a guided path that is compromised with limited expertise.

The irony of the situation is that organizations rate practical experience above all else when hiring cyber security professionals. Therefore, either the student must pursue training and acquire certifications to prove their skills, or else they would be left without any practical experience and deemed as intangible assets. Since the training courses are outdated too, a false notion about lack of opportunities in the industry is created in the minds of the students because the skills they have acquired from both the academic courses and the certifications are no longer in demand.

Lack of Regulation: Institutions & Policy

Training and certification institutions have a key role to play. They connect the aspiring candidates to the industry. The objective of the courses offered by the institutions is to form a bridge between what they were taught in academic courses and the skill sets required in the industry. These trainings are therefore focused on inculcating the candidate with theoretical concepts and practical experience. The candidates may choose which course suits them the best and then pursue that particular skill set.

However, training and certification institutions have not been able to keep up with the demands of the market emerging as a response to sophisticated threats.

Today, there is limited scope in the market to differentiate a qualified candidate from an unqualified one. The courses being offered by the institutions are now outdated and do not reflect the industry requirements to a large extent. A gap has formed between the requirements of the industry and the availability of acceptable manpower where the candidates have certifications of outdated skills, while the organizations hiring are not able to find candidates with suitable skill sets.

Limited expertise in the institutions widens this gap further as it leads to limited options available for training courses and certifications, which produces candidates that have limited skillsets. The direct result of this is a saturated pool of skills where certain options have a huge number of viable candidates, while other options have none that are suitable. This gap is an ever-increasing because the degree of saturation keeps on increasing as per the trend in the market, which causes loss of valuable human resource in the other sectors.

There is a shortage for almost every position within cyber security according to the industry standards. There is a shortage of workforce required to properly maintain systems that have already been deployed, and there is an even greater shortage of workforce that can design new sophisticated security systems or improve on the existing ones.

The institutions have not been able to re-evaluate their courses, due to which their technical materials lack inputs in newer technologies such as smart contracts, blockchains, Artificial Intelligence, Robotics etc. Moreover, they are not able to provide hands-on experience in these emerging areas, so even a certified candidate does not have an exposure of emerging cyber security jobs in the industry. Training material needs to be planned out meticulously for maximized productivity and learning and needs to be revised regularly to ensure that the candidates enrolling in the courses are at par with the changing industry requirements.

Limited Policy Expertise

The aim of the cyber security policies in place is to build a resilient and safe cyberspace for the citizens as well as the government. These policies define procedures and plans of actions on how to protect information and information infrastructure and are drafted by political and administrative leadership that are experienced and well versed with the fundamentals of cyber security. Yet, they are inadequately equipped to deal with the emerging challenges of cyberspace because they lack a fresh perspective on the updated landscape of cyber threats and the trends in the new digital age.

If the updated policies are not aligned with the requirements of the industry based on the current cyberspace capabilities, the academic courses and training certificates would continue to lag behind and the gap would keep widening. This perpetuation worsens an already dire situation.

There is a requirement to tap the expertise available in the local private sector and global community to shape the policy landscape of the country. These experts lead the industry standards on cyber security from the front. These experts can bridge the gap between the leaders' fundamental knowledge and the current situation of cyberspace.

Lack of Open Spaces

There is a lack of spaces for debate and spreading best practices & proactive disclosure. The general environment is more focused on compliance and is more concerned about professional education. This has created a culture of silence among the victims of the cyber- attacks. Suffer in silence seems to be the mantra.

4.3 Technology

Lack of Indian Cyber Eco-System or Products

Cyber security has grown to become an integral part of national security since its requirement is no longer limited to the military domain. The influence of cyber security is now crucial to everyday aspect of a nation's governance and functionality. The pandemic has only quickened this growth.

The Indian cyber ecosystem is practically non-existent due to the Indian law and investigative agencies being out of sync on this subject. They are at a deficit of skilled manpower and there is a lack of robust architecture in cyber security at the national level which results in non-coordination between such agencies. A strong cyber eco-system requires the unification of efforts between such agencies to assess and tackle any oncoming threats. This dysfunctional dynamic is aggravated by the gap in communication between the government and private sector in the field of cyber security that leads to the formation of fault lines within this ecosystem. With the lack of mandates for compliance and regulations to deal with aftermath of attacks, the current security policies are unequipped to protect and endure a large-scale attack on the nation's critical infrastructure.

The lack of cyber security tools in both the software as well as hardware arena makes the indigenous cyber security community dependent on foreign players. On a deeper level, this opens up the nation to motivated attacks by state and non-state actors.

The lack of awareness has the most devastating effects at both the levels, company as well as individual. Data has been coined as the currency or oil of the 21st century, yet the Indian population does not know how to keep their data secure. With the advent of data dependent technologies like Artificial Intelligence, Machine Learning and Data Analytics, the complexity has increased further in the cyber security domain that directly gives rise to techno legal issues. A supervised framework that can guide the nation's citizens on the fundamentals of cyber security is therefore required at the earliest.

Lack of Indigenous Push

Every nation state requires a comprehensive set of policies to govern and follow up action in the field of cyber security. With the difference in the resources that are available in a nation state, their critical infrastructure varies, and so do their policies. These policies shall guide the nation towards cooperation and coordination with friendly states in fighting against espionage, as well as towards responding appropriately to a hostile state's aggressive campaigns. These policies should incorporate resources that would aid in building a dynamic cyber ecosystem, which should not be expensive and inconvenient to implement. Since every nation state must leverage their position in all the aforementioned factors, there does not exist a solution that would fit the bill for everyone. Every nation state needs to build and tailor a security policy that would fit their requirements and protect their resources.

Lack of Investment in Fundamental Research

Majority of the cyber security attacks that are reported are unsophisticated attacks, with techniques that have low difficulty to launch. The inability of organizations in defending against such trivial attacks shows how they fail in implementing even a baseline of comprehensive security measures. A lack of investment in such fundamental security measures leads to non-awareness towards understanding the risks of the land.

As the nation is moving towards digitizing physical infrastructure, the exposure to cyber-attacks is increasing with it. And the agencies that are responsible for securing such infrastructure are suffering from a lack of funding, in both public and private sectors. This inaction leads to a lack of skill set among the workforce as well as the lack of capability to defend and appropriately respond to a cyber-attack. The scarcity of investment thereafter does not allow the Indian cyberspace to grow as the research work is hindered and the chances of any indigenous tool showing up in the market are diminished. This induces a perpetuation where tools are sourced from foreign players, which they in-turn use as funding to improve their platforms while the nation's cyberspace still lags behind.

Organizations that are willing to invest in the field, struggle in determining the budget for cyber security investments, as well as with where the investment should go. And with no concrete data available about the number and nature of cyber-attacks, this makes the process trickier. Even though risk assessment models have been developed, that can guide the organizations in terms of the investments, most organizations fail in hitting the mark, because there is no generally accepted model.

5. Taking it Forward

People, Processes, and Technology are three pillars of any robust cyber security ecosystem. Any change in each one of the three systems requires changes in the other two as well. Otherwise, two systems would weaken the proposed change and work towards restoring the equilibrium or status quo. Successful transformation of the cyber security eco-system requires smoother coordinated actions in all the three categories of process, people, and technology simultaneously. Lack of effort to bring such synergy probably explains why the institutional mechanisms designed and implemented had little success in the past.

Transformational Leadership has been the widely accepted thing for bringing in the much-required change in the cyber security landscape. It can help drive the necessary change through interventions in the three components of People, Processes, and Technology.

5.1 Process

Legal Framework Changes

National cyber security strategy and Policy

The National Cyber Security Policy, 2013 need to be revised in line with the technological innovations, emerging technologies, the emerging cyber threats, on open and unmanaged networks. This is necessary as there has been a sharp, complex, and intensifying trend of cyber-attacks and cyber incidents in the country. An integrated national response, covering the human as well as technical challenges involved in enhancing resiliency of the Indian cyber space is the essence of time.

Audit of Cyber and ICT infra of Critical, sensitive, strategic sector

The group has recommended that Cyber and ICT infra of critical, sensitive and strategic sectors be thoroughly audited prior to commencement of their operations by NCIIPC. This recommendation be enforced through appropriate legislation. Regulations need to be issued under section 70, 70 A and &0 B of the Information Technology Act, 2000. Incident response bethe sole responsibility of CERT-In.

Cyber Security Law

The Cyber security in the country is governed by National Cyber security policy, 2013, regulations by regulators, guidelines by CERT-In and NCIIPC and certain sections of Information Technology Act,2000. Sections 70, 70A. 70B and sections 43A primarily constitute legal framework in the area of cyber security in India. These sections need to be strengthened significantly to empower the state and make entities and organizations accountable to implement cyber security. A Cyber Security Law, similar to that enacted in many countries, is essence of time. The law must provide for accountability of organizations, be it public, private, Government and academia for securing their Cyber Infrastructure.

Bringing Back Robust Institutional Mechanism

The Critical Information Infrastructure sector is increasing in the private sector due to the ongoing processes of Liberalization, Privatization, and Globalization. The interface between the private sector and the government agency implementing the CIIP mandate should be simple and easy to comply with. The design should ensure that the potential objective of regulation of CIIs is done in the national interest and not at a high compliance cost to the businesses.

As discussed in Chapter 3, the biggest worry to the private sector is that too many agencies need to manage an adverse cyber incident. The mandatory nature of reporting to various entities makes the businesses to enforce compliance at a higher value than the objective of ensuring business continuity. Lack of a simpler interface is detrimental to creating a friendly business environment and is also a sign of ineffective regulation.

Currently, CIIP Agency, i.e., National Critical Information Infrastructure Protection Centre, is placed under the administrative control of the National Technical Research Organization, and the Computer Emergency Response Team is established under the Ministry of Electronics, Information Technology (MEITY). The organizations have been created with intent during different timelines for tapping the best possible expertise and resources available in the Government to fulfil the mandate. Much water has gone down the bridge since the creation of CERT-In.

It is important to note that in the early 2000s, where the country was just recovering from the fatigue created by the Y2K bug, MeitY, which has successfully managed the transition inside the Government, appeared as the best place to host Indian CERT.

Indian Computer Emergency Response Team (CERT-In)

CERT-In was created to detect and mitigate threats emerging from the hackers who are essentially computer experts who have gone rogue. It started as a part of a larger global network of CERTs located worldwide for cooperation and coordination. CERT-In has grown into an indispensable organization in the fight against cyber-attacks in the country. However, Cyber- attacks against the nation have undergone a sea change. Cyberspace as a domain has evolved from a sphere reserved for the highly technically qualified experts into a hotly contested domain for nation-states and organized crime groups. The agency needs to significantly upgrade its resources both in terms of types, nature, and number handling of cyber incidents.

National Critical Information Infrastructure Center (NCIIPC)

NCIIPC was created in 2014 under very different circumstances. Cyberspace has emerged as one of the operational domains and is being weaponized, and the country's critical infrastructure has been going through a phase of rapid digital transformation. Another cause of concern is that cyberspace as a domain has a much simpler threshold for acquiring tools that can cause harm to others. Awareness developed in the leadership that due to a relatively low threshold in cyberspace, anti-national elements, hostile powers, would use cyberspace to launch attacks against the country's critical information infrastructure. The key objective of the threat actors would be to reduce the country's ability to wage war and/or to demoralize the nation. This phrase is best captured in the 'debilitating impact' part of the definition of the CIIs under Section 70(1) in the Information Technology Act 2000 law.

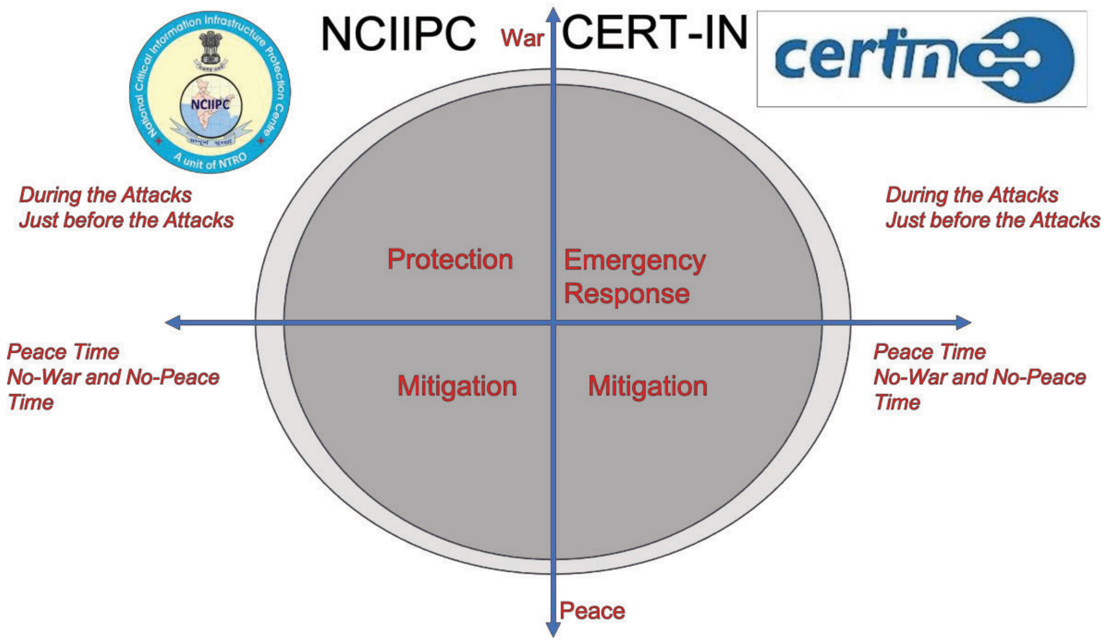


Figure 4: Mapping of the Roles & Responsibilities of NCIIPC and CERT-In

It is also critical to observe that both agencies (NCIIPC and CERT-In) have pretty much complementary roles and responsibilities. The institutional setup of the Critical Information Infrastructure Protection Agency and the Incident Response and Mitigation agency being working and reporting to two different ministries, hinders both units' smooth functioning and ability to utilize their complementary roles and responsibilities effectively.

Undoubtedly, the two organizations have many different backgrounds and mandates and rightfully have 'different DNAs'. However, in executing their respective mandates, they both operate on the same cyberspace and use the same tools and tap the same resource pools.

There is also a need to empower the NCIIPC with accountability and responsibility.

Merging of CERT-In and NCIIPC

In the interests of efficiency and synergy, it is recommended that CERT-In & NCIIPC may be merged into one agency under civilian structure. This is very essential in the present context and also since both the agencies have to deal with civil and other sectors. By creation of a single agency, which can be the focal point of all cyber security activity in the country. NTRO may deal with strategic issue relating to Cyber including sensitive and strategic sectors.

National Cyber Security Coordinator: Negotiating with the Divides

The Cyber Security field in the country is fragmented in multiple ways. Primary divide being the Defence and the Civilian establishments. There are further divisions in the Defence and Civilian institutions depending on their respective jurisdictions. It would be fair to say that the cyber security system in India is fragmented.

Subsequently, it is also essential to set up an institutional mechanism that will help ensure smoother coordination of various departments' policy agendas. Latest institutional innovation, i.e., National Cyber Security Coordinator can act as a critical body located within the Prime Minister's Office and provide a single point of advice to the PM as a part of the significant National Security Council Secretariat. NCSC has to be a veteran with years of policy experience and technical expertise, so as to have smooth blending of both experience and expertise in overall functioning and also exercise a calming and synergizing influence on the activities of the various ministries. NCSC, as it stands, is one entity in the system that retains a complete picture of the cyber security developments across the Government of India by surpassing all divides (Défense vs. civilian) and has the necessary technical competence to advise the Government of India.

The mandate of the NCSC, as of date, appears to be framing broader policy and coordinating between various agencies, especially NCIIPC and CERT-In to ensure adequate cyber security response as a country. Centralizing the execution of the policies in the hands of the NCSC may be counter=productive. This might lead to unnecessary inefficiencies and avoidable turf wars, and NCSC may not be able to secure the coordination. The senior leaders of the ministries and Government must strengthen the institution by not circumventing or ignoring the advice of the NCSC. His views should be taken into consideration on the crucial issues concerning the legislative and institutional mechanisms. Political leadership can strengthen their hands through their actions, which should help set up the institution. Another area where his inputs may be valued would be in approving and designing schemes floated by various funding agencies acting under the banner of the Government of India. This would help resolve turf wars and ensure efficient spending of the grants to develop and equip the country to prepare for the emerging challenges in cyberspace.

The National Cyber Security Coordinator (NCSC), thus, be empowered and made responsible. His role be expanded to coordinate all sectors and Regulators including space sector. Regulators must get their policies vetted, prior to their notification from NCSC.

HUB-AND-SPOKE MODEL FOR CYBER SECURITY

Another issue for resolving is interactions between the sectoral regulators and CIIP. Law provides powers to the CIIP Agency with authority for issuing directions but is silent on what happens when those directions are not implemented. It can be imagined that the order would be to improve the cyber security posture of the CII. It is also necessary to clarify who would bear the cost of following such directions. Another issue that requires attention is coordination between CIIP and various sectoral regulators. Their actions and directions are not in sync and confuse the sector players. For example, RBI and SEBI have issued cyber security frameworks for their constituents, and the framework should be issued within the broad framework of guidelines issued by the CIIP Agency for synergy and clarity to members. On the other hand, IDRBT (Banking Thinktank funded by RBI) has been running a first-of-its-kind security information sharing centre which is neither studied nor connected to other sectoral initiatives. Removing these legal confusions is essential for securing private sector support. Due to the nature of the subject, there are multiple interactions required between the various sectoral regulators and the CIIP Agency. The relationship between the Hub and Spoke is very clearly defined. CIIP Agency is the hub, and it controls the spokes which are part of the various ministries/regulators and works very closely with them.

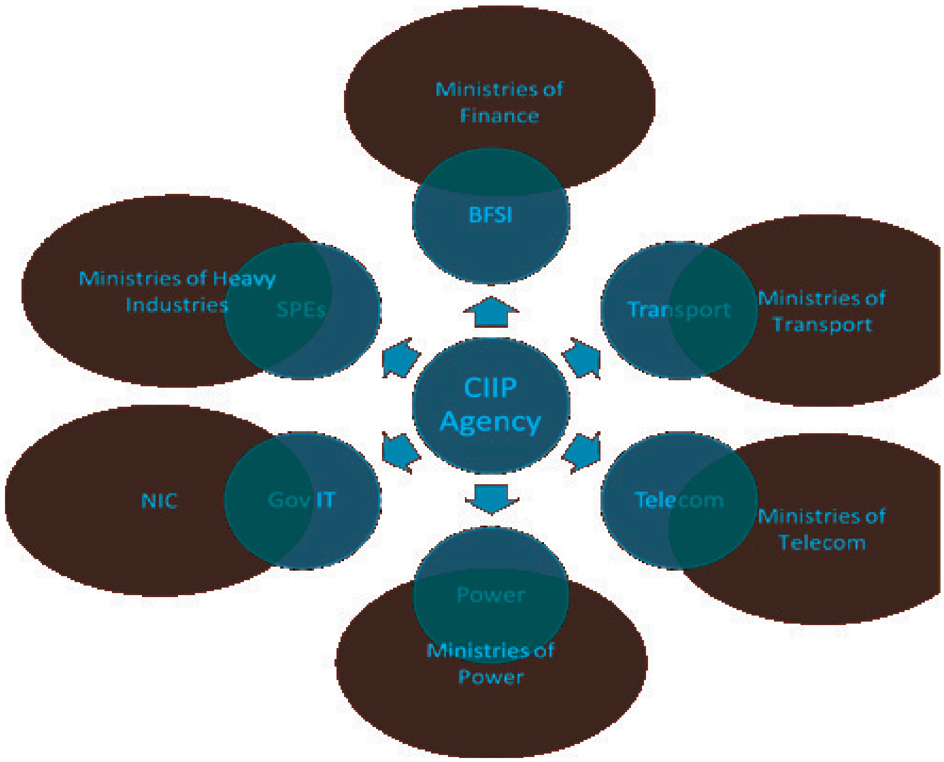


Figure 5: Relationship between Hub and spokes

CIIP Agency, being the hub, would drive all activities that are to be commonly implemented across the sectors, and the spokes located within the respective ministries would undertake activities that are to be customized to the individual sectoral needs. For example, the hub issues the broader national cyber security framework and sets up standards binding on the critical information infrastructure. These standards and the framework will be consolidated and published for the sectoral-specific CIIs by the spokes. The relationship between the Hub and Spokes can be envisaged as High courts and Supreme Court. Sector-related issues should mostly end with the spoke itself, and problems that cross beyond one sector should be necessarily escalated to the Hub level. The Hubs would also act as CERT for the respective sector itself. Since they are part of the ministry, they would be able to benefit from working closely with the sectoral regulator and be in a place to work with the private sector players seamlessly.

The ministry would appoint the head of the spoke in active consultation with the hub. Hub would specify the qualifications essential and would play an active role in running the spokes. The institutional innovation in the form of a Financial Advisor who reports to his department for routine financial matters and to the PMO for important broad matters can be used as a great example. This would ensure that the dual control of the ministry and CIIP Agency are adhered to smoothly. The efficiency of the hub and spoke model could be seen in the functioning of the Sector- Specific SOCs connected to the National SOC. This model serves the sectoral players and the National hub in an excellent way.

HUB Responsibilities	SPOKE Responsibilities
Setting National Standards	Specific sectoral standards
Building National Resource pools	Efficient Utilisation for sector purposes.
Broader Policy Guidelines	Specific Instructions for sectoral players
Coordinating at national level with other stakeholders	Coordinating with sectoral players, regulator and industry lobbies.
Building National level resilience network (focussing on cyber conflict scenarios)	Developing sectoral level mitigation plans and executing & maintaining sectoral resilience network

Enforcing Accountability of the Ciip

As the old management adage goes, people focus on what is measured and not the job description. We need a national index of cyber preparedness prepared and updated regularly. Progress on the index should be a way to measure the effectiveness of the institutions. These findings then require the attention of top Leadership for ensuring progress.

An Inter-ministerial Committee on the lines of China headed by the PM is needed. Xi Jinping has created the Leading Small Group (LSG) equivalent to our cabinet committee handling cyber- related issues. This would make it a platform for bringing and maintaining synergy.

Expanding and Clarifying Scope of "Critical"

Attacks in cyber security focus primarily on the man behind the machine. Logically, the same type of protection should be available for the personal devices and the network used by the VIPs and other prominent players in the economy, public health, and order. Recent breaches of the Pegasus data revealed how easy it is to affect the decision-makers. The attacks also call for inclusion of the personal devices and networks of the Government leadership to the list of critical information infrastructure.

Further, in the times of pandemic and in an interconnected world, many apps such as Zomato, dunzo, big basket and swiggy have become extremely critical in ensuring supplies of groceries, medicines and food. Any disruption on their infrastructure would have led to debilitating impact on the national economy, public health and order. Pharma and vaccine companies and distribution mechanisms for the vaccine raw materials have seen a large number of attacks on their infrastructure. They also fall under the definition of critical information infrastructure.

This Covid-19pandemic has highlighted the need for keeping the definition of critical information infrastructure flexible. The process for notification and in rare cases de-notification should be within the purview of the CIIP Agency and can be reviewed by a larger committee periodically.

5.2 People

People are the pillars and foundations of the organizations and institutional mechanisms that will defend cyberspace from the men and machines. Our dreams of becoming prosperous and strong cyber power would remain as a pipe dream without investments in developing the human resources of the country.

Market and the educational system have a symbiotic relationship. Without a robust market demand for professionals, the educational system is not expected to churn out the candidate who would meet the market's requirements. In the recent past, the focus has shifted from computer science researchers to information security researchers. This shift is created by the pressure coming from the market's rising demand for high-quality information security researchers. Multiple studies have observed that the need for cyber security professionals is very high, and this is one field that the ongoing covid-19 pandemic has not impacted.

If we closely look at the availability of the talent pool of the information security community in India, there is a large amount of diversity in the community. It would be fair to say that a majority of the community members have no background in computer science and engineering in their graduation. Another observation that would be valid would be that most of them have spent considerable amounts of time learning and teaching themselves information security and their topics through internet-based resources and community-based training events.

It is folly to aspire to become a cyber-power without ensuring sufficient numbers of highly trained and qualified manpower available in the country.

Changing the Curriculum

Most of the manpower that is seen currently in the information security industry is self-taught and are doing well in the information security field despite being trained in another field. This transformation happened with a lot of struggle. We can avoid this inefficient and painful process by prescribing specialized courses. They can be approved, and teachers and resource personnel should be trained to meet the emerging demands.

Black Hat and DEFCON are considered as world's best gatherings of the information security community. On the side-lines of these conferences, multiple pieces of training are offered. A cursory look at the trainers indicates that many of them are from the Indian information security industry. It is, in a way, very disappointing to see that the world's best trainers in information security are from India and yet we find Indian students entering the market woefully underprepared.

Bodies such as AICTE and UGC must expedite the following.

a. Creation of a Bachelor of Technology/ Bachelor of Engineering in Artificial Intelligence and Information Security separately.

b. Modules for Training of the Teachers for the curriculum.

c. Model of Engagement with the community to tap the trainers available in the private sector.

d. Encourage the colleges that have adopted these courses and meet quality criteria with better grading on a quality scale or showcased separately.

Career Progression & Planning for Professional Cadre in CIIS

It is also equally important that the specific sectors that fall under the critical information infrastructure category change their human resources policies to ensure that they have continuous access to high-quality cyber talent internally.

This requires changes in the individuals' recruitment, grooming, and career development and regularly calls for periodic on-the-job training, exposure visits, and workshops. Models adopted by various professional bodies for keeping their members relevant would be an excellent model to ensure that the CISOs and their immediate subordinate cadre remain vigilant and relevant.

CIIP Agency should specify minimum criteria for the candidates for the CISO Roles and his immediate subordinate roles. CIIP as an agency should also help the organizations groom and develop their talent with a specific focus on the sector-based cyber threats and creating a virtuous cycle of sharing best practices between the sectoral players and ensuring the sectoral players are also aware of the trends in the attacks etc.

Regulating and Developing the Profession

For building a good cyber security ecosystem, we need to overcome the shortage of qualified employees in software testing, hardware design, and security topics. We need the policy to encourage new generation institutions that create courses relevant to industry and encourage mainstreaming them. Courses such as B.Tech/MTech in Artificial Intelligence, Robotics, and Cyber Security are welcome in the niche segments of the industry and not widely recognized by other players as well. Fixing this will help India overcome the skilled manpower shortage in critical areas in a few years.

On the other hand, there is a need to set up an industry ethics body to ensure that cyber experts don't misuse their knowledge and regulate the practice of Vulnerability Assessment and Penetration Testing. This body can act like ICWA, IMA and promote the development of the profession in general. Efficient industry regulator is the key foundation for realization of the vision as a cyber power.

Synchronizing the Funding

There are lots of Cyber security related projects, and institutions such as the Department of Science &Technology (DST), MEITY through CERT-In, fund research efforts. There is a need to bring synergy between them to foster the community & private sector in this field. The Indian private sector is willing to look away from services after the emergence of the AI boom, which has drastically reduced the requirements of software programmers. Product development is also the next logical step for building national soft power. Our country has enough experience in delivering reliable software to the world. Product development focus could improve security posture, save taxpayers money, and bring jobs and strengthen our national security.

One more thing that requires attention and focus is the Government powered incubators. They get most of the funding grants and use them to build large complexes which remain primarily unused or remain on the side-lines as irrelevant due to their lack of connection with the industry and stringent funding conditions. It is tough to expect government-driven institutions to rapidly adapt to changes in a volatile and nascent industry sector such as start-ups. This approach is required to be re-evaluated keeping in mind the emerging trends in funding. India sees an upsurge in the Venture capital industry. The Government may relook at its role change from being an inefficient funder to an efficient regulator of the venture capital industry in information security.

Creating Public Spaces for Debate & Discussion

Another major problem that affects the growth of the information security community and discussions in India is the secrecy and concerns surrounding cyber incidents.

CISOs and boards don't want to discuss cyber incidents that affected them to avoid negative media coverage or reputational risks. While this is understandable, victims and other sector players can immensely benefit from the lessons learned and solved this. This will only happen if we can create an environment free of fear and attribution. This problem is nothing new, and many platforms have attempted to solve this. On the side-lines of the DEFCON, the top security conference in the USA - a parallel community event occurs called "Sky Talks,". At the event, community members openly discuss cyber incidents they encountered and solved. Attendees are expected to not quote or discuss the specifics of the issues. Think tank Chatham House pioneered "Chatham House Rules," wherein similar discussions with a code of conduct encourage sharing knowledge without creating any controversy.

Just to recap, there is a need for a community-centered platform. This platform will help us tap like-minded experts from the industry with varied experience. Institutions like the VIF should take the lead in giving these voices a direction and shape that would act as input to help the country grow more robust.

On the other hand, there is a large pool of talent available in the industry. There is no platform to tap their shared experience without the domination of bureaucracy, which sets its status quoist agenda. Creating an engaging public space that is not part of the hierarchical setup would help the country tap its talent for national security and nation-building activity.

5.3 Technology

There is a need for promoting the research efforts by the NCIIPC. NCIIPC is required to be empowered to build and develop a nationwide network for tracking and defusing cyber-attacks. The government should focus efforts on building the local cyber ecosystem to develop tools that meet our internet security requirements. The reason for the failure of the National Cyber Coordination Center, National Cyber Swachh Kendra, is apparent. Excessive dependence and lack of indigenous alternatives calls for a broader study on how the research grants are spent and the outcomes are measured. One point that comes out is that there seems to be an apparent mismatch between our requirements and the focus of our R&D.

Encouraging the Private Sector

Most of the cutting-edge research in the world is now happening in the Private sector. Scope of the research grants are limited mainly to few research institutions. Government should widen the grantees network as research institutions are primarily interested in publishing research outcomes. They don't necessarily share the passion for creating usable products. Partnering with the private sector jointly for grants is a better model to build an ecosystem. It would enable true partnership for innovation and commercialization of technology developed in national interest. Partnership and interactions also inform the academia of the demands of the market. This interaction would then also include trickle-downs to make curriculum more relevant.

Government of India can start a national challenge with respect to cyber security products/applications where different needs of the cyber security space would be presented as challenges and companies completing the challenges would get milestone-based grants.

Another way of encouraging the Indian cyber security or tech ecosystem in general is to have a worldwide cyber security/tech/electronics expo on the lines of Dubai Expo where companies, investors, tech enthusiasts would gather at one place to talk about partnerships, latest tech happenings, investments, talent scouting etc.

5.4 Building Foundations: Testing Labs & Fundamental Research

Few national capabilities are urgently required to be built for meeting our requirements of critical information infrastructure protection (CIIP). The key national capabilities are:

Availability of Labs and Techniques for Detection of Embedded Malware:

As of now, techniques or procedures or standards specifying required test for detecting presence of any kind of embedded malware/Trojans/cyber threat (like deliberate hard coded or embedded logic in chip) in the equipment/devices /components used in systems and sub systems of critical systems are not available in India. Published R&D literature suggests a few methods based on heuristic algorithms like power consumption pattern, electromagnetic interference (EMI)/ electromagnetic compatibility (EMC), noise emission, traffic monitoring, physical inspection of chips, internal layout at microscopic level, etc. but all these methods are product specific and not fool proof methods. R&D in the area of testing critical systems is still at nascent stage in the country. The testing of systems and sub systems involves examination at chip level and source code validation. To mitigate cyber security risks for reliable operation of critical systems, most of the Indian entities deploying critical infra have adopted Indian Standards, IEC Standards and North American Electric Reliability Corporation (NERC) reliability standards for Critical Infrastructure Protection (CIP).

The requirement of mandatory testing to check for any kind of embedded malware need to be made applicable to active/intelligent equipment only, and not to passive equipment/components. In the present scenario of the limited availability of cyber testing facilities meeting International benchmark, alternate tests like Common Criteria be adopted for equipment, components, and parts imported for use Critical System and Networks. However, to meet the huge requirement of testing, the testing facility for critical Infrastructure need to be built at three levels:

a. Specialized test labs at Government level.

b. Not so specialized test labs with Public Private Partnership.

c. Day to day test laboratories to be developed by each utility

Testing Labs & Accreditation is essential for creating an ecosystem which will further the objective of creating a high-quality hardware and allied software ecosystem.

Test Suits at National Level

India should develop standards on cyber security test to suit the equipment being designed and developed by Indian industry. International standards even if followed in India may have little relevance since they have been developed based on prevailing conditions in Europe or other countries.

National Resilience Center for Cyber

It is vital to shield the critical information infrastructure from the regular attacks that we see in cyberspace. The CIIP Agency must run a dedicated specialized "whitelisted network" which is a backdoor for providing uninterrupted access of essential services to at least a limited set of citizens and institutions. The network's focus would be to ensure that, as a nation, our critical assets remain resilient, especially in the face of ongoing cyber-attacks.

Centralized Malware Analysis Platform

There is an urgent need to track and profile threats and threat actors at a national level. Accurate identification of the threat actors and their tools would help us come up with remedial actions. This activity requires setting up a national malware repository. The malware samples collected from the various victims' IT infrastructure should be stored and shared among the country's interested information security researchers and enterprises to build local solutions and knowledge about how to combat them.

Centralized Dark Web Monitoring Platform.

A complement to the same would-be national agency level monitoring of the dark web actors and compilation of threat reports. Many private sector players are providing the service, and this is a matter of grave importance and a concern for the whole industry. Imagine a situation where a minor player who is part of a network of critical information infrastructure, i.e., a small bank, is breached. Small banks don't have access to the services of a private sector player who could have alerted them about the breach. This breach of a smaller player would eventually become a beachhead for further attacks against the financial system.

Because of such weaknesses, a dedicated dark web monitoring platform is required at the national and sectoral levels to take care of the sector's requirements in total. Such initiatives will help the CISOs of the sectoral players greatly. Alerting organizations about the attackers' plans and potential breaches of the network and some assistance or guidance in protecting themselves would be great help to CISOs.

Centralized Standards Body

CIIP Agency as a hub is expected to take care of the standards. This specialized job requires bringing together a particular category of people with years of experience in the corporate world, technology pioneers, futurists, and legal experts. It is difficult to engage such a variety of talent continuously within the limitations of the Government. CIIP Agency may run a small, dedicated secretariat to constantly engage with the talent and regularly issue amended standards. The same activity would be undertaken by the spokes located within the ministry to further customize the standards to emerging needs of the sector through interactions with the sectoral regulator.

This guidance would help the national efforts and act as a critical input for the Critical

Information Infrastructure members to get the security right from the beginning.

Future Proofing Against Emerging Threats

The critical information infrastructure sector will continue to face pressures to open up its network to seek synergies, increasing the attack surface. Emerging technologies such as IoT, extensive use of AI in manufacturing, Quantum computing and 5G have the potential to disrupt the nation's economy.

Recent trends also indicate that the attackers are more sophisticated and focused, and the most serious concerns include Ransomware attacks, attacks against cloud platforms. CIIP Agency is expected to take this forward with the help of hackathons and sectoral level discussions which will culminate into meaningful and informed policy decisions that would help the country.

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CHAPTER - 6

FIRE RELATED DISASTERS

1. Introduction

1.1 Indian National Academy of Engineering (INAE) vide order no.--------dated-------constituted an expert committee on Technology Preparedness for dealing with

National Disruptions related to Forest Fire and other fire related disasters.

The Committee has been mandated to address all aspects related to preparedness for:

(i) Forest Fires at any vulnerable location in the country, identify these locations

(ii) Industrial fires, possible hazards

(iii) Fire hazards in congested areas

(iv) Govt. policy interventions related to any kind of fire hazards

(v) Any other issue related to fire hazards

1.2 Fire service is a state subject and has been included as municipal function in the item 7 of Schedule XII under Article 243 W of the Constitution of India. Hence, fire prevention and firefighting services are organised by the concerned States and Union Territories. It may be added here that the fire brigades in India remain heterogeneous in character and majority of them continue to remain ill-equipped and differently organised. The National Building Code (NBC) of India, is the basic model code on matters relating to building construction and fire safety. Since the primary responsibility for fire prevention and fire protection lies with the State Governments, the rules for fire prevention and fire protection are laid in the form of State Regulations or Municipal By-Laws.

1.3 The main objective of NBC is to specify measures that will provide that degree of safety from fire, which is practical and can be reasonably achieved. The code insists upon compliance with minimum standards of fire safety necessary for building occupants and users. For ensuring compliance of fire protection equipment / installations to the laid down quality requirements, it is desirable to use such equipment / installation conforming to BIS.

1.4 Fire pose a major threat to various occupancies in India. Almost every day some fires are reported by media across the country. These fires not only result into the loss of many precious lives and injuries to many but also inflicted heavy property loss. During the last decade rapid modernisation of Indian Industry have made the scenario more complex. Awareness towards fire safety had not been quite forthcoming. As per the statistical data, about 8004 industrial accidents claimed over 6300 lives between 2014 and 2017 in India. While Delhi, Maharashtra and Rajasthan recorded most such industrial incidents in the period but Rajasthan, Gujarat and Maharashtra witnessed the highest number of deaths.

2. Possible impact of the disaster in the future

(I) Forest Fires

2.1 Forest Fires Impact: It has profound impacts on atmospheric chemistry, biogeochemical cycling and ecosystem structure. Forest fire or wild land fire has become intense and more frequent in the last few decades all over the world and is a critical issue in the biosphere-atmosphere interface. The global carbon and nitrogen emissions from fires have been estimated to be 3.53 trillion Kg / year and 8 billion Kg / year respectively. The number of forest fires shot up to 14,107 from 4,225 between November 2018 and February 2019 according to the Real Time Forest Alert System of the Forest Survey of India (FSI) using near real time data from the SNPP-VIIRS satellite. Between 01 January to 26 February 2019, 209 out of 558 forest fires occurred in the five southern states of India - Andhra Pradesh, Karnataka, Tamil Nadu, Telangana and Kerala, which is 37 per cent of the fires.

2.2 Forest fires also pose serious health hazard by creating polluting smoke and noxious gases. The burning of vegetation gives off not only carbon dioxide but also a host of other noxious gases (Greenhouse gases) such as carbon monoxide, methane hydrocarbons, nitric oxide and nitrous oxide, that lead to global warming and ozone layer depletion. So, thousands of people suffer from serious respiratory problems due to these toxic gases. The recent forest fires in Uttarakhand may be only a small part of the overall global problem. But if looked at from the point of view of the fragile Himalayan ecology, they portend a dark future. Already large areas of the Himalayan forests have been cleared indiscriminately for agriculture, making them vulnerable to soil erosion and landslide. The only way to save the fragile Himalayan ecosystem from recurring forest fires is to put in place a viable disaster management action plan.

2.3 State forest departments and the MoEF&CC : The parliamentary standing committee on science and technology, environment and forests criticised the forest departments of the five states for ineffective utilisation of the forest fire prevention funds in its report Status of Forests in India during the year 2017-18. While India loses Rs 1,176 crore a year to forest fires, a mere Rs 45-50 crore is allocated per annum under the Forest Fire prevention and Management Fund, which remains unspent. Nearly 24 per cent of the meager forest fire prevention funds were not released and thus, remained unspent in the two financial years, shows the data provided by the Union Ministry of Environment, Forest and Climate Change (MoEF & CC) in January 2019 in the Lok Sabha. Out of Rs 50 crore allocated during each year, 2017-18 and 2018-19, Rs 35 crore and Rs 38 crore were released respectively. While the recent parliamentary standing committee acknowledged the fund constraints faced by the MoEF &CC to prevent and fight forest fires and that the allocated funds need to be utilised effectively and strategically.

2.4 Comprehensive policy : The National Green Tribunal has repeatedly asked the MoEF & CC to come out with a national policy on forest fires. In fact, the Draft Forest Policy, 2018, does mention forest fires as a threat and has proposed the mapping of vulnerable areas along with developing and strengthening early warning systems. It has also proposed participation of communities. Uncontrolled fires are a complex problem that require a comprehensive and long term policy. This requires more effective coordination with local communities who are the primary forest users in India. It demands proper co-ordination mechanisms between the state governments forest departments and the MoEF&CC. These fires should be treated as disasters so that disaster management authorities can play a major role in preventing them. The National Forest Commission of 2006 too suggested that all fires that burn an area larger than 20 sq km, should be declared a state disaster.

2.5 Causes of Forest Fires : A combination of factors like dry summer, winter rain deficit, low humidity, high temperature and less preparedness lead to the forest fire. It is anthropogenic in nature which gets flamed due to conducive local environment for fire. The possible reasons may be control burning by the locals which go out of hand, casual approach of the locals / visitors while throwing away lighted butts of cigarettes, vested interest group, casual approach of authorities, resource and technology crunch, lack of preparedness for risk reduction etc. Such fires usually start on the ground as the dry litter (senescent leaves and twigs) catches fire easily. Then, flamed by strong winds, the flames soon engulf vast tract forest turning them to ashes and, therefore, cause extensive damage unless controlled in time. Many forest fires start from natural causes such as lightning which sets trees on fire, these types of fires have been recorded periodically in India.

2.6 **Mitigation** Measures: The subject of forests is in the concurrent list of the Constitution of India. The Central Government and State Governments are both competent to legislate on the subject. The issues relating to policy planning and finance are the primary responsibility of the Government of India. The field administration of the forests is the responsibility of the various state governments. The state Government thus has the direct responsibility of the management of forest resources of the country. The state forest departments, therefore, carry out the fire prevention and control measures. Each State and Union Territory has its own separate forest department. At the Government of India level, Director General of Forests & Special Secretary to the Government of India is the head of the professional forest service in the country. The Forest Protection Division in the Ministry, which is headed by an Inspector General of Forests, looks after Forest Fire prevention. The Ministry is implementing a centrally sponsored plan on Intensification of Forest Management Scheme under which the state governments are provided financial assistance for activities including fire prevention and control.

2.7 Technological Preparedness: Forest fires are usually seasonal. These usually start in the dry season and can be prevented by adequate precautions. Different State Governments are aware of the severe damage caused by fires to forests and ecology of the area. Traditional methods of fire control are inadequate and limited in India. The modern methods of fire control are yet to be placed on the ground in the required measure. Generally, the fire in the forest is prevented by creating fire lines. This line prevents fire breaking into the forest from one compartment to another. It proves effectively and the collected litter is burnt in isolation. At the same time, the utility of these leaves should be explored. Generally, the fire spreads only if there is continuous supply of fuel (Dry vegetation) along its path. The best way to control a forest fire is, therefore, to prevent it from spreading, which can be done by creating Fire Breaks in the shape of small clearings of ditches in the forest as well as using fire suppressing gel. Use of water mixed with 0.6 to 0.8 % (v/v) fire suppressing gel is usually the last resort, as spraying water on to the fire in dense forests on hill slopes, is usually a tricky job. In severe fire conditions, special aircrafts equipped with water tanks can be used to drop tons of water mixed with FS Gel on the burning trees. More details are covered in the recommendations.

2.8 Firefighting using Helicopters :

Advance technologies such as use of drones, aircrafts and helicopters should be explored in identification of exact location, intensity & direction of fire to facilitate fire extinguishment at the earliest. The helicopters use special 'Bambi Buckets' suspended by cables for the operation. These buckets are capable of collecting and carrying of 4000 to 5000 litres capacity of water, which can be air dropped on the site of a fire. Indian Air Force deploys MI-17 V5 helicopter to control the fire whenever requisitioned by the State Government.

2.9 National Forest Policy, 1988 - India's National Forest Policy, amended in 1988, presents a visionary strategy for future forest conservation & management laying emphasis on protection of forest against encroachment, fire & grazing. The principle aim of the New National Forest Policy is "to ensure environmental stability and maintenance of ecological balance." The policy addresses the problem of forest fires in the context of forest protection in the specific terms as: "The incidence of the forest fires in the country is high. Standing trees and fodder are destroyed on a large scale and natural regeneration annihilated by such fires. Special precautions should be taken during the fire season. Improved and modern management practices should be adopted to deal with forest fires."

2.10 Research and development for better management of forests while combating forest fire: As a scientific research and capacity building institute, Forest Research of India (FRI) Dehradun has taken up several projects/ studies covering different thematic areas to enhance knowledge about the different ecological processes, forest management issues and developed technologies for better management of forest resources of the country. FRI has also carried out few more specific studies related to forest fire ecology. The institute has enough experience in developing tools and techniques to combat forest fire related disasters such as pathogenic outburst, forest fire mapping, genetic engineering, etc.

(II) Industrial Fires

2.11 The Industrial core sectors include Energy & Power, Petroleum, Gas and Chemical, Metals, Minerals and Steel, Cement, Coal, Defence Production, Telecom & IT, Automobiles, Textiles etc. Industrial accidents are caused by chemical, mechanical, civil, electrical, or other process failures due to accident, negligence or incompetence, in an industrial plant which may spill over to the areas outside the plant causing damage to life and property. Major Threats may be Fire, Explosion, Toxic release, Poisoning or Combinations of these. These may originate in :

i. Manufacturing and formulation installations including during commissioning and process operations; maintenance and disposal.

ii. Material handling and storage in manufacturing facilities, and isolated storages; warehouses and godowns including tank farms in ports and docks and fuel depots.

iii. Transportation (road, rail, air, water, and pipelines).

2.12 Probable causes of accidents:

i. Process deviations i.e pressure, temperature & flow.

ii. Parameters with regard to the state of the substance i.e., solid, liquid or gas, proximity to other toxic substances.

iii. Runaway reaction.

iv. Hardware failure, resulting in large-scale spills of toxic substances.

v. Boiling Liquid Expanding Vapour Explosion (BLEVE) on the chemicals during transportation.

vi. Electrical failure

vii. Cutting and welding

viii. Open flame

ix. Carelessness

x. Poor housekeeping

xi. Smoking

xii. Sabotage

2.13 Compounding effects of accidents are due to meteorology of the area, wind speed and direction, rate of precipitation, toxicity/quantity of chemical released, population in the reach of release, probability of formation of lethal mixtures and other industrial activities in vicinity.

2.14 Impact of Industrial Accidents: Immediate, Short-term and Long-term Effects which may lead to major consequences such as:

i. Loss of life / injuries

ii. Impact on livestock

iii. Damage to Flora/fauna

iv. Environmental Impact (air, soil, water)

v. Financial losses to industry.

(III) Fires in Congested Areas

1.15 Master Plan for Metropolitan cities had been created as an instrument to control the use of land in urban area and protect the welfare of people. The concept of zoning has not yielded desirable results over and above allowing for mixed use and occupancy, authorized as well as unauthorized. Banquet halls in residential areas, cottage industries in congested areas, trade of hazardous chemicals from the highly congested residential/ commercial areas, hazardous and non-hazardous industries in close vicinity are few to mention which have further deteriorated environmental services. This has certainly added to the fire risk already inherited by a particular occupancy. As a result, losses due to fire are increasing to both the life and property. This is developing a dangerous trend. Similar situation has been reported from almost all metropolitan cities in the country. Man-made disasters are likely in these areas.

1.16 Trends:

i. Although the number of calls have only marginally increased, number of deaths have increased potentially. The basic reason is that deaths are not as much due to burning but more because of inhalation of toxic fumes, which get concentrated in high density less open space area. It is the lack of circulation/ventilation within tenements. In industrial areas there is disrespect for the safety measures required and hence large number of deaths or injury due to fires occur.

ii. Number of fire incidents in jhuggis and jhoparis clusters/high-rise buildings have reduced while fire incidents in industrial and residential areas have increased. One of the reasons for such increase is, that industrial areas have started hosting non-confirming industries and residential areas have become haven for illegal storage's and dangerous commercial activities in pursuit of mixed permitting land and occupancy in these areas. Also, disrespect to circulation space and open space and increase in congestion in these areas have caused poor accessibility to the place of tragic incidence, which takes only records to increase.

iii. During analysis of the causes of maximum number of fires in such cities it is observed that 70 percent of calls are due to electric short circuiting. This is alarming because a single cause can be disastrous to life and property that major investments are required mitigating these risks. Short-circuiting is often a result of illegal connections, low quality wiring and therefore, even if single major cause is taken, of, not only would it lead to saving innumerable lives and properties but also cut down on expenditure incurred on fire mitigation.

3. Addressing of Issues / Response Mechanism

3.1 Forest Fire Monitoring Mechanism in India:

i. A fire anywhere in the world is detected by NASA's MODIS (Moderate Resolution Imaging Spectroradiometer) and VIIRS (Visible Infrared Imaging Radiometer Suite) satellites.

ii. Then Forest Survey of India (FSI) analyses such data by overlaying the digitised boundaries of forest areas to pinpoint the location to the exact forest compartment.

iii. The FSI relays news of the fire to the concerned State, so that the Divisional Forest Officer (DFO) in charge of the forest where the fire is raging is informed.

iv. Earlier the time lapse between spotting the fire and the news reaching the DFO was five to six hours, but this has been reduced to about two hours recently.

v. Meanwhile, news of the fire would have reached the DFO from his guards in watchtowers and on patrol and the DFO decides whom to deploy.

vi. There will be a master fire control room which is informed and which sends firefighters from local fire crew stations to fight the blaze.

3.2 Forest Survey of India has launched the beta-version of the **Large Forest Fire Monitoring Programme** on 16-01-2019 using near real time SNPP-VIIRS data. This programme is a part of the FAST 3.0 (FSI Fire Alerts System). Herein, FSI will track large fire events across the country and disseminate specific Large Fire alerts with the objective to identify, track and report serious forest fire incidents so as to help monitor such fires at senior level in the State Forest Department and also seek timely additional assistance that may be required to contain such fires. Large Fire tracking aims to improve tactical as well as strategic response to large forest fires.

Features in FAST 3.0 (FSI Fire Alert System)

i. Large Forest Fire Monitoring Programme: It is based on satellite data (SNPP-VIIRS) to automatically identify and track large forest fire events

ii. FSI Forest Fire Geoportal: to view forest fire related data along with other thematic layers

iii. Web Map Service (WMS): available for integration to State Forest Departments

iv. Customized alerts for 20 states at beat level and 2 states at Range level

Spin-offs

i. Creation of Large Fire Database at National Level.

ii. Development of National Forest Fire Database.

iii. Continuous monitoring of fire affected areas for planning, research etc.

3.3 Policy of Rehabilitation and Response: Every year, about one-third of all forests are damaged or affected by fire. Therefore, an effective policy of forest fire prevention and control is extremely important. It was in this context that the modern forest fire control project was taken up in five districts of Uttarakhand and U.P. viz., Pithoragarh, Nainital, Almora and Rampur & Pilibhit in 1985. The area proposed to be covered was 3,72,693 hectares. The achievements attained through this project included Development and demonstration of modern fire control techniques, Preparation of division wise fire management plans, Estimation of forest fires, Development and application of a forest fire danger rating system, Training of forest personnel, Full fire protection of timber depots and Manufacture of fire finders and hand tools within the country and standardization of fire control equipment.

3.4 Risk control measures :

i. Physical Protection : Strict & rigorous approach in implementing the relevant standards, codes of practice, Built in safety devices and safety system, Venting through tall stacks, Field monitors for different toxic gases and burning waste gases in a flare system, Provision of wind cones, Fire proofing of steel structures, PPEs, Passive protection system and Active protection system.

ii. Procedural Protection : Fire emergency procedure, Disaster preparedness plan, Mutual aid scheme, No smoking policy, Investigation of all accidents, Hazard identification through safety committee, House keeping committee, Safety audit committee, Conducting plant survey, safety survey, Work permit system, Safety promotional activities, Information notes on unsafe conditions, Material safety data sheet, Annual medical check-up of employees, Safe start-up & shut down procedure, Regular and preventive maintenance and Periodic testing of firefighting appliances.

iii. Educational Protection: Periodic training program on safety, Fire safety and hazardous properties of materials, Mock fire drill, Safety manuals, Health & safety news bulletins & leaflets, Safety motivation schemes, Plant operating manual and Educating the public living nearby about the activities in the industry.

3.5 **Issues:** High population density, crowded streets, un-matching mixed occupancies, inadequate water supply, poor electrical services, unplanned siting of fire stations, encroachment are few examples of ineffective planning in the metropolitan cities which adversely affect the fire response time. Under the present circumstances, a response time of 5-7 minutes in urban areas and 20 minutes in rural areas is very difficult to achieve. Mobilizing a large quantity of water to the fire scene especially in walled city area is more than firefighting. Fire safety should, therefore, be an integral part of urban planning process rather than an afterthought in such cities.

4. Gap Analysis

4.1 Fire Station Gap Analysis: As per detailed analysis carried out in India, there is a requirement of about additional 1,300 Fire Stations in urban areas and about 4,250 Fire Stations in rural areas. Hence this study found an overall gap of about 65% in terms of number of Fire Stations in the entire country. For this analysis, response time of 5-7 minutes in urban area and 20 minutes in rural areas was considered.

4.2 Firefighting and Rescue Vehicles and Specialized Equipment Gap Analysis: This, study finds an overall gap of about 83% in the firefighting and rescue vehicles and about 95% in specialized equipment for both operational and new Fire Stations in urban and rural areas.

4.3 Fire Personnel Gap Analysis: Administrative Reform Department norms based on duty pattern (double-shift) have been used for optimization of the fire manpower requirements, the duty pattern of fire personnel varies from state to state, i.e., from 8 hours, 12 hours and 24 hours. However, in this study, double shift duty pattern (12 hours) has been followed for optimizing the fire personnel gaps. Thus, as a whole in entire India, this study finds an overall gap of about 91% in fire personnel considering double shift duty pattern.

4.4 This gap analysis study indicates that there is lot to be done to upgrade the level of state fire services in the country. As regards the fire incidents in industries and forest areas, respective departments have to take care of any fire emergency within the resources available with them, however state fire service would assist them under mutual-aid-scheme in case of any disaster. It is seen that the situation is better in industries since they have independent fire services set up within their premises. As regards the forest department, it needs to introduce latest fire prevention and firefighting technologies as recommended in this report.

5. Recommendations

(I) Forest Fires :

The key recommendations to handle forest fire scenarios are summarized as under: -

i. Creation of fire lines and controlled burning of dry leaves / grass under the management of fire fighters.

ii. Use of operational detection system: Fire towers / watch towers, aerial patrols, electronic lightening detectors and automatic detection system.

iii. Fire-resistant clothing and other PPEs to be provided to the fire fighters.

iv. Mobility & Communication:

   a. The key players who are at the ground confronting the fire (fire watchers, forest guards etc.) have been given large area to monitor but they do not have any facility of mobility and communication. There is a need to strengthen mobility especially during the summer months (February to June).

   b. Two-way radios and mobile phones should be provided to the fire watchers.

v. Hand Tools:

   a. Drip torch

   b. Pulaski

   c. Chainsaw

   d. Shovel, Fire Beaters / Fire Flappers to be made available.

vi. Forest Fire Engines: All Terrain Vehicles (ATVs) fitted with special equipment to spray water, foam and fire-retardant chemicals / gels should be introduced to handle such fires.

vii. Forest fire chemicals: Class 'A' firefighting foam, water gel (water enhancer).

   a. Class 'A' foam: Diethylene Glycol Monobutyl Ether based.

   b. Water Gel / Fire Suppressing Gel / Aqua gel: polyacrylic acid based – developed by CFEES, DRDO should be tried for its effectiveness on forest fires for future applications.

viii. Use of Helicopters / UAVs / Aircrafts with water scooping capability: possibility may be explored for its induction as a long-term measure to tackle similar incidents.

ix. Heavy Equipment:

   a. Bulldozers

   b. Tractor ploughs should be made available for creating fire lines.

x. Training: should be done at regular intervals for Creation of specialized trained manpower / working group / smoke jumpers.

xi. Development of software for fire behavior modeling, Geographic Information Systems (GIS) for better fire mapping, satellite imagery & automated stations for up-to-the-minute weather forecasts and estimates of fuel and moisture.

xii. Development of fire shelters.

xiii. Infrared Wireless Network Sensors for imminent forest fire detection.

xiv. Extensive use of websites and e-mail, which will allow immediate sending & obtaining information and assets to fire managers, fire fighters and the public alike.

xv. Development and demonstration of modern fire control techniques.

xvi. Manufacture of fire finders and hand tools within the country and standardization of fire control equipment.

xvii. As the subject of forest fire is in the concurrent list and is the responsibility of the National Government for its prevention, mitigation and response, the Ministry of Environment, Forests & Climate Change (MoEF & CC) being the nodal agency may create a Working Group especially to monitor the implementation of the National Forest Policy Resolution (NFPR), 1988.

xviii. There is a need to create a Corpus Fund for forest fire prevention, rehabilitation and response and the MoEF may work closely with the States in this regard.

xix. Management of forests has changed over the years and in the present context of some states there are three kinds of forests – Reserve Forests, Civil Forests and Forests controlled by Panchayats. So different strategies have to be adopted for each category of the forests, especially for forests controlled by Panchayats along with other recommendations.

xx. Community's attachment to the forests has drastically come down as they do not own forests and hence there is apathy for contributing in the management of the fire. Therefore, it is imperative that community outreach programmes are designed and implemented to have their participation in the forest fire management.

xxi. As women are working as a support system in providing water, food and other required services to the fire watchers and local villagers so that the fire fighters can continue working for longer periods which is essential at the time of forest fire. Hence, it is recommended that induction of women in the entire firefighting management be carried out and their distinctive role defined to bring them into the mainstream of firefighting management.

(II) Industrial Fires :

i. Provision of Fire safety measures as per the relevant codes.

ii. Obtaining Fire NOC before commencement of Operations.

iii. Providing appropriate fire fighting vehicles like Multipurpose fire tenders, DCP tenders, Foam tenders and Industrial fire tower vehicles, fire fighting robots and remotely controlled monitors to the local Fire Brigade with the grants from Govt. of India.

iv. Fire outpost in every industrial area with minimum no. of fire vehicles and personal protective equipment.

v. Conducting Onsite and offsite emergency exercises / mock drills once in every 6 months.

vi. Surprise inspections and classes by the fire authorities to find out emergency preparedness and suggest any additional measures.

vii. Standardization of SOPs (Standard Operating Procedure) strict compliance.

viii. Whenever Chemical Factory established in habitation areas the Alarm / Siren to be raised in all times as per National Green Tribunal.

ix. The Wind action (or) wind direction to be notified and evacuate the people downside.

x. The Fire fighting / Quick Response Teams to be always alert and available in the Factory premises.

xi. The Fire fighting Teams shall be fully equipped with modern fire fighting equipment

xii. Communication and capacity building in industrial fire service.

xiii. The Chemical Data Sheet of each chemical/ substance made available in Control Room to monitor and take correct preventive steps accordingly.

xiv. The Firefighting equipment installation shall not be worn out or old age.

xv. In Industrial Zones, Buffer Zones to be left between factory and village.

xvi. In light of any accident reported due to failure of safety measures, design fault and lack of training and awareness, immediate action to be taken.

The Fire Safety Audit to be conducted periodically.

xviii. The On-site / Off-site Emergency plans to be updated regularly as per need / change of process of Plant / Industry.

xix. Hazard (or) Risk Analysis and related Mitigation measures to be Displayed / Practiced.

xx. The Employee Safety / Good practices to be adopted.

xxi. Electrical Safety Audit & Independent Assessments by competent Electrical Safety Auditors identify the inadequate preparedness in electrical safety aspects.

(III) Fires in Congested Areas :

i. Strict implementation of laws: Government of India notified "Unified Building Bye Laws for Delhi" on 2nd March 2016, which shall be applicable to all building activities in urban villages/rural villages, unauthorized regularized colonies and for special areas. But these bye-laws are enforced from the date notified and cannot be enforced on buildings constructed prior to the enactment of these bye-laws. On similar lines, the building by-laws framed for other states for the existing buildings should be uniformly implemented pan India.

ii. Awareness about fire safety: Fire safety awareness programmes should be conducted regularly by fire department across the cities for different occupancies especially in high fire risk prone areas like Jhuggi clusters and un-authorized colonies. Special workshops on fire safety for school teachers, Resident Welfare Organizations (residence and market etc) and hospitals should be conducted.

iii. Road network improvement and dedicated lanes for fire tender: Road network has a direct connection with the response time of fire service in case of an incident. This makes it imperative to devote this infrastructure a special status for fire services. Colonies having limited or narrow approach roads can be identified and fire tenders built on small vehicle chassis can be used.

iv. Setting up new sub-fire stations accommodating new infrastructure developments and population distribution: Considering changes in infrastructure development and population distribution over a period, setting up new sub-fire stations or upgrading the existing sub-fire stations will be required. Such infrastructure could have a direct impact on losses occurring due to fire events. Provision of a Fire Post at every 3 kilometer and a Fire Station at every 7 kilometer distance as per Master Plan should be there in all metropolitan cities. It should also have a provision of Disaster Management Centre and Fire Training Institute.

v. Use of latest technology equipment by Fire Department: Latest technology such as water mist has brought much advantageous equipment for firefighting purposes, where large fires can be extinguished by using limited quantity of extinguishing agent like water and foam. Such equipment can be easily carried by fire fighter as back pack or on the small fire vehicle like motorbike. Similarly, remote-controlled robots equipped with thermal imaging cameras for fire-fighting operations in locations that are dangerous for the fire-fighters can also be used.

vi. Use of geo-spatial technologies: Geospatial technologies can contribute in planning for fire services. In addition to giving an idea of land use/ land cover in the jurisdiction area, it can help in generating optimum routes, service area as per the time and distance, asset management. Using Global Positioning System (GPS), responders can plan response route in advance as well as get the updates about the live traffic situation. This can drastically cut down the response time and losses. Live Images/Videos from fire fighters cameras and fire fighting vehicles at fire ground connected with fire control room can make a significant difference. Images or videos from Drones or if possible, satellite images in real time, may contribute. These drones fly over the affected area and give an idea of the spread and intensity of the fire and are also useful for search and rescue operations.

vii. Fire safety regulations as integral part of urban planning: With increased population, infrastructure and resulting congestion, modern cities need to prepare for increased fire risks. Delhi Fire Service Rules, 2010 under Delhi Fire Service Act, 2007 have been framed and notified, making mandatory for certain classes of occupancies to incorporate minimum standards for fire prevention / safety such as access to building, arrangement of exits, fire compartmentation, smoke management system and fire protection systems etc. Similarly, the Acts and Rules notified under Maharashtra Fire Prevention and Life Safety Measures Act, 2006 (Amendment 2015) and Rules, 2009, West Bengal Fire Services (Amendment) Act, 1996 and Rules, 2003, Gujarat Fire Prevention and Life Safety Measures Act, 2013 and Regulations, 2016, Odisha Fire Prevention and Fire Safety Act, 1993 and (Amendment) Rules, 2019, Karnataka Fire Force Act, 1964 (as amended by Karnataka Act 40 of 1994) and other States / UTs which have mandatory fire safety provisions in different type of occupancies should be included in urban planning. Arrangement of Dedicated Underground Water Reservoirs : In the areas of higher fire risk, it is imperative to have dedicated underground water reservoirs for replenishment of fire tenders in time. Locations for such dedicated reservoirs should be identified based on fire risk analysis. Alternatively, water bowsers/water carriers having large capacity of water shall be provided in adequate numbers in such areas. **Requirement of R & D Set Up in India:** There is a need to enhance the capability and strengthen R & D centres working in the areas of fire safety. Some of Institutes in India are as follows:

i. Central Building Research Institute (CBRI), Roorkee: primarily meant for R&D related to building materials testing, evaluation and research in the field of other fire safety related areas.

ii. Forest Research Institute (FRI), Dehradun: as a scientific research and capacity building institute, has taken up several projects/ studies covering different thematic areas to enhance knowledge about the different ecological processes, forest management issues and developed technologies for better management of forest resources of the country. FRI has also carried out few more specific studies related to forest fire ecology.

iii. UL Jain Fire Laboratory, Bengaluru: facility consists of a fire lab of 240 square meter area with a 13 m high roof for testing fire related products like firefighting foams, different classes of fire extinguishers, sprinklers etc, as per UL / Indian standards. The services offered in the facility include foam concentrate, fire extinguishers, fire extinguishing agents, fire extinguishing systems, validation, certification, product development, failure analysis etc.

6. Summary of Recommendations:

I. All Terrain Vehicles (ATVs) fitted with special equipment to spray water, foam and fire retardant chemicals / gels should be introduced to handle forest fires.

II. Application of Drones / UAVs / Aircrafts with water scooping capability may be explored for its induction as a long-term measure to tackle forest fire and congested areas fire incidents.

III. Use of fire fighting Robots equipped with thermal imaging cameras for fire-fighting operations in locations that are dangerous for the fire-fighters in Industries and in Congested areas.

IV. Use of Infrared Wireless Network Sensors for imminent forest fire detection.

V. Development of software for fire behavior modeling, Geographic Information Systems (GIS) for application in forest fires and use of Global Positioning System (GPS) for fires in congested areas.

VI. Providing appropriate fire fighting vehicles like Multipurpose fire tenders, DCP tenders, Foam tenders and Industrial fire tower vehicles to the State Fire Services with the grants from Govt. of India under 15th Finance Commission.

VII. The Fire Safety Audit to be conducted periodically.

VIII. Small Fire Tenders / Motor bikes with water mist back pack system for colonies having limited or narrow approach roads / congested areas in the city.

IX. Provision of a Fire Post at every 3 kilometre and a Fire Station at every 7 kilometer distance as per Master Plan should be there in all metropolitan cities. It should also have a provision of Disaster Management Centre and Fire Training Institute.

X. Strict implementation of the Fire Safety Rules notified in different States / UTs on the mandatory provisions in different occupancies.

XI. Provision of dedicated underground water reservoirs in the areas of higher fire risk for replenishment of fire tenders. Alternatively, water bowsers / water carriers having large capacity of water to be provided in adequate numbers in such areas.

Annexure # 1

Indian National Academy of Engineering (INAE)

White Paper on Technological Preparedness for dealing with National Disruptions

1.0 Introduction

Covid-19 is a revelation in terms of the surprises and hardships it has caused all over the globe. We have faced many Pandemics earlier too, like H1N1 and HIV but their spread was much slower and that is perhaps why the world community failed to gauge the extent of disaster this virus could cause.

Tsunami, dated December 24, 2004 was another such a calamity when the World was taken by surprise. Japan faces Tsunami several times in a year, but the severities were low. This perhaps fooled us and we, in India, totally forgot about Tsunami, till it occurred on Dec. 24, 2004, killing tens of thousands in India and other nations in the region. Having seen this Tsunami, we now established a technological answer in terms of a warning system that is working 24x7 at INCOIS/MoES, Hyderabad. We also have created well-oiled response mechanism, to reduce the loss of life in case such a Tsunami occurs again. This is one good example of building our preparedness to face the disaster with appropriate remedial measures in advance.

India is prone to many natural disasters and the list is long. Heavy sudden downpour like Bombay deluge, Chennai/Kerala Floods, Earthquakes, Cyclones, locust attack, drought, snow avalanches and forest fires are well known to us and happens quite frequently. For deluge and floods well thought of guidelines are available but we need to ensure that they are implemented in time. Sudden spread of diseases due to weather conditions is another threat in some part of the country or other. All these have to be addressed in terms of technological response. We have several agencies like NDMA, NDRF, INCOIS etc to deal with these disasters, but there is a need to have the technological empowerment (for Tsunami from INCOIS for example) for all such agencies. Then there are man-made disasters like accidental oil spillage from tankers (if it happens near the coast, it can play havoc in the vicinity) and intentional cyber-attacks. China is building a big reservoir over Brahmaputra and in case the reservoir bursts (by faulty design or by deliberate act) it will sink a large portion of Assam. We have no technology solution. Even Biological warfare cannot be ruled out. There also could be combinations like natural events causing accidents (for example, the Fukushima accident.)

Both Tsunami and Covid-19 were sort of surprises. Do we anticipate more of such surprises? Therefore, there is an urgent need to anticipate all such possible disruptions and get ourselves prepared technologically.

There is also another dimension to the strategy to deal with it; i.e., the leadership and the organizational preparedness to respond in an agile manner. This is not considered in this white paper as this paper addresses only technological preparedness. However, this dimension itself is a bigger issue and has to dealt with separately.

This paper also attempts to bring in sufficient attention to the engineering and technological infrastructure and architecture that is needed to: i) Warn : establish appropriate warning system about the possible disruption, before it strikes, ii) Respond and Recover: Support critical infrastructure like power systems, communication systems, internet systems, financial/banking systems, rehabilitation systems and public health systems, etc., once the disruption strikes and iii) Learn, Mitigate and if possible Prevent : Once the immediate disruption is over to analyse the causes, learn from experience and attempt to improve the technological responses. It is also important to look at mitigation (reduce chance of occurrences or intensity of impact) as well as evacuation, rescue and relief and essential supplies as a part of engineering and technological infrastructure.

2. Types of Disruptions and Mitigation Technologies

Following are the types of disasters (many will be local and some are national or global in impact) and some related technologies;

(i) Weather and climate related disasters

Heavy rain, floods, cloudbursts, snow avalanches, cyclones and storm surges come under this category. We have good institutional mechanism for forecast in IMD/MoES and response mechanism in the National Disaster Management Authority (NDMA). ISRO plays an important role through its satellites, mapping and communication through satellites. We still lack an adequate coordination mechanism covering all stakeholders. We also miss out sometimes to the well stipulated guidelines. There is also an issue related to man-made obstructions or blockages to passages for storm water discharge that often aggravates the disaster.

(ii) Geology related disasters

Earthquakes and Tsunami happen due to internal processes inside the Earth and our ability for precise forecast for earthquakes is very limited. Tsunami also occurs due to earthquake in the Ocean. However, a lot of understanding has been developed in terms of linking earth movement during an earthquake with its potential to cause tsunami on a real time basis. For India, since the known locations that can create tsunami are a significant distance away, sufficient early warning can be made available particularly as a result of instrumentation that has been established. Today's understanding also enables assessing the potential for damage at each vulnerable location. A large number of laboratories like NGRI, Wadia Institute, MoES and many others have been working on microzonation and other analytical tools to generate codes for civil structures. However, to implement all these a wellorganised and effective coordination mechanism is needed.

(iii) Epidemic and Pandemics spread

We have currently the Covid-19 crisis and we are discovering ourselves, on how to manage it on day-to-day basis. Developed world is no wiser except that they have done much more mathematical modelling work on past pandemics. It is true that no drug or vaccine can be developed in real time though we have best brains working on them. As far as laboratories that have expertise on corona class viruses, we do have excellent laboratories, under ICMR and DBT. NIV, Pune is a good example. We certainly need to enhance the capacity in this area. Already several attempts are being made to develop the medicine in a few labs in the country. While every epidemic at a regional level may not scale up to the level of a global pandemic, each will need careful application of the same techniques at a smaller scale. There certainly are possibilities of new diseases and pandemic emerging due to several reasons. To meet such situations, we should investigate the viruses that are likely to be developed into epidemic or pandemic and establish new laboratory/ies wherever essential to meet the situation under overall umbrella of appropriate Departments. Further this may need inter-ministerial coordination too.

(iv) Locust

It is a very special type of disaster, which originates in Middle East and travels to India through Pakistan. Biological solutions should be safe (indiscriminate spraying may be more dangerous than the Locus itself) and should not be more problematic that the original problem itself. We need to consider establishing a special laboratory to address this disaster and find technology solutions including spray of chemicals which would not cause undue harm to lives from air.

(v) Oil Spill from Oil tankers

Coastguard is a responsible agency in this country but there is no scientific laboratory working on oil spills except some uncoordinated research here and there. Coastguard presently implements solutions given by foreign agencies. A dedicated scientific institute, which can develop the expertise and methods to tackle issues related to oil spills, is needed

(vi) Man-made disasters

There is a huge list of possible man-made disasters, within the country and by adversaries outside. Each will have to be listed and possible technology solution created. There have been cases of dam failures, fires/explosions in refineries and fuel/explosive storages. Nuclear accidents also need attention. All needed designs must be very robust to disallow/exclude such accidents. However, if there is one, its impact on public must be minimised and management plan to deal with it must be in place. A lot of progress has been made in this regard. Highly poisonous/toxic/explosive gas leaks are another kind of manmade disasters (for example LG Polymers in Vizag a few days back or a few decades earlier the Bhopal case).

Cyber-security has perhaps most damaging potential. Imagine a data base of a bank, railways, airlines or power-grid getting compromised. It will play havoc. This area requires much more attention as we are moving more and more into the digital world.

(vii) Natural events leading to failure of infrastructure with potential for disaster

Some disasters have resulted from failure of dams as well as plants as a result of natural events like earthquakes, floods etc. The statutory standards and rules for design of man-made facilities with potential for disaster must be in place to define the design basis event/s and acceptance standards for performance to ensure that there is no unacceptable risk to people during the lifetime of the plant. Such design bases need periodic review to take into account occurrences which might require a review of the original design basis. Natural ones cannot be avoided, but the nation/community must be prepared to face it with minimal loss of life and damage to property through well thought out advance actions and technological interventions.

(viii) Biological/ Chemical Biowarfare

The biological, or, chemical biowarfare is one of the prime areas to deal with in the future world. This problem is as significant as that of water and cybersecurity

3. Technological preparedness for dealing the National disruptions

Each of the disruptions has two important dimensions of preparedness (a) Technology and (b) Implementation on ground, particularly involving public at large.

India is better prepared for (b) and this is not a part of this white paper, we will mainly focus on the (a), i.e. Technological Preparedness for disruptions.

Basically, a number of key capabilities that need to be comprehensively developed. For example, converting historic occurrences and scientific understanding of natural events into an extreme design basis event for which counter measures should be put in place to minimize risk. Scientific understanding of related issues must continuously improve and enable us to assess the situation as close to reality as possible. Over conservatism in such assessments when number of people involved is large could do more harm than good to people affected as well as optimum use of available infrastructure in an overall scene.

We need to identify gap areas where institutions for better scientific understanding as well as those for technical support with adequate capability do not exist and plead for creating them. There are a number of well performing institutions that have already taken shape primarily following major disasters our country has faced.

We should also identify new areas which may become potentially important and for which readiness does not exist. This should for areas for active research and related technology development. There are number of such examples. These require better scientific understanding before one can work out technology solutions.

For example, the prominent Institute at Thiruvananthapuram, Sri Chitra Thirumal Institute of Medical Sciences has come out recently with a very reliable test kit for COVID because they have the necessary R&D facilities with appropriate infrastructure, equipment and trained human resources. It is informed that they were trying to develop fast way of testing for malaria and soon after COVID broke out they concentrated their efforts in that direction and made good progress. Similarly, the Serum Institute in Pune has established a good research lab to carry out research on vaccine and also they have established good collaboration with Oxford University. A ray of hope exists for the possible vaccine solution to COVID sooner than later. CSIR and some private sector labs are also focused developing possible medicines. There is also a need to have a well-defined process for testing of the product(s) the innovators come up with, to obtain the needed approvals, human trials, and finally to produce them in millions - all of them are to be engineered to respond to a calamity. Scaling-up in all these systems requires a whole ecosystem. Engineering skills are to be encouraged in consultation with Industries for scaling up, establishing manufacturing capacities and reducing costs.

Therefore, there is a need to track all such requirements, identify the gap areas and initiate proactive action to identify such well-established labs and establish new premier lab/s wherever essential in the Country, which would come handy at the times of difficulties, as the two Institutions quoted above have proved. Each of the disaster needs multiple technologies to come together and evolve multiple solutions under different varying conditions. But for this we need to visualize and ensure that we have good R&D labs already established with the needed resources. This will enable the Country to address such eventualities quickly and efficiently. Starving for funds in such Institutions will not help and as a Country identified research activities in S&T have to be supported proactively.

It is therefore essential to look at several labs existing in the Country, which would cater to different situations when the need arises. Nevertheless, certainly there will be gaps in some of the critical areas. Furthermore, the existing labs may not be in a position to realize their full potential due to shortfall in terms of infrastructure, equipment or even the number and quality of their human resources. It is therefore essential to critically review and identify the gap areas and ensure that we establish such labs as quickly as possible with least bureaucratic hurdles. The labs so identified can be in their respective nodal ministries depending on the nature of the topic.

During the difficult times the technologies we depend should be available in the Country and total self-reliance is the key word. Hon'ble PM has also been stressing this point recently. We need to make serious efforts to identify such critical technologies which need indigenous development and initiate the necessary action with the support of Indian Industries. The strategic Departments in the Country have taken serious efforts in indigenization and today they are able to manage most of the technologies with the assistance of Indian Industries. (For example, in India we still depend largely on foreign Fabs for electronic devices. As a Country we need to seriously consider the investment in the state-of-the- art technology for electronics fabrication in a suitable location. We are aware of this fact and we have been debating for long with no tangible result)

Being a multi-disciplinary effort, we need to put robust coordinating mechanism linking all possible agencies with one major unit identified as the lead Institution (LI). The LI will coordinate all the efforts with other similar organizations. Robust, pervasive and secure information sharing and collaboration infrastructure is essential. Protocols for 'normal' and 'emergency' operations must also be clear to all stakeholders. All agencies have to be properly linked and the robust response mechanism is to be established. In the case of many such disruptions Space has a role to play, whether through special remote sensing satellites or through satellite communication; for example, the locusts are to be tracked using satellites, much before they enter into Indian territory. They have to be properly tracked and a robust mechanism is to be established to disseminate information and take corrective measures.

4. Recommended National Approach.

a. INAE in consultation with Department of Science and Technology / Office of PSA / DG CSIR etc. should create empowered Committee/s to study all possible disruptions, depending on the categories of the disruption; natural or man-made and recommend areas for further scientific research and technology solutions against each, that need to be developed and make it operational where ever they do not exist. They can be standing committee/s which meet periodically and take stock of technology readiness. The requirement is not only technology but capacity to develop and manufacture products as needed. If necessary empowered committee can have certain budget and financial powers. The members can be from prominent domain experts; Fellows of the Indian Academies (All Science, Engineering, Medical etc), Academe, R&D, and Industries. We can consider adding any other specialist member/s or appropriate Govt representative wherever needed. This group also should include well known social scientists to assess the social acceptability, scalability and the feasibility of its implementation. The study should review all the aspects and make specific recommendations in a time bound manner. This matter needs immediate attention.

b. The Empowered Committee/s should survey the National Laboratories available to respond to each such disruptions and identify the specific gaps. All such identified labs should be recognised as the labs of National Importance and the Government should enable them to keep "battle ready" to respond to the challenges of the situations. Research activities are to be pursued on a continuous basis and funding should not be a constraint. We should also attract young bright Indians who are working abroad. One prominent lab should be identified as a lead Institution (LI) for each challenge and will coordinate all technology solutions, taking a lead role, but involving expertise available throughout the country.

c. These identified LI's will work under a matrix management structure, administratively responsible to the nodal ministry but under technical guidance of an empowered board, that will have representatives from all coordinating agencies. (Just for an illustration, developing a drug for corona family of viruses may be entrusted to laboratory under DBT. It should have an empowered board with representatives from CSIR, ICMR, Ministry of health, NDMA etc.) Similar approach has to be taken for any other disruption under the respective nodal agency.

d. These identified laboratories will have responsibility with associated autonomy to take up time bound technology projects for development and to make available services against a type of disruption. Quality human resources generation is the key enabler for technology solutions.

e. The identified laboratories will have adequate financial support from GoI or any other identified agency and should not be constrained under concepts like find your own resources.

f. Maximum efforts should be made to identify the technologies which should be within the Country so that the supply chain is ensured within the Country as far as possible. The indigenisation should get high priority and each of the nodal ministries has to identify the kind of material or product to be indigenised. Appropriate Indian Industries are to be associated

g. The availability of the capital-intensive test facility/ies is a major hurdle for many R&D labs and MSME's to carry out research or to come out with a viable product. Many times, such a facility is used rarely and also is not affordable by many to establish such expensive labs. It is therefore worthwhile to consider establishing such facilities at different parts of the Country, as a common facility, geographically well spread where any organisation needing such service can walk in and get it against payment.

h. We need to create and maintain an up-to-date Dashboard in the public domain and easy-to-access data base on history, experts, facilities and archive related to all kinds of disaster, threat and challenges faced by the nation or Indian sub-continent in the modern times (say, 1500 onward).

i. Create (or designate) and maintain Empowered Centers under existing Institutes or Organizations who can lead and provide subject-domain specific (medical, defence, agriculture, chemical, climate, engineering, etc.) experts and facilities for testing and characterization of newly developed materials, drugs, devices, instruments and methods to counter such national threats and challenges.

j. Trustworthy, updated multidimensional data sets (e.g. demographics, habitation, buildings, roads, administrative and geophysical) are an essential part of any response. These are currently scattered across multiple agencies. A well-designed national data exchange with the right security and privacy rules is recommended.

5. General remarks

a. As a part of evolutionary process, India has to learn to live with various types of disruptions. But we should not panic and instead face it squarely with the support of the technology solutions which are visualized well ahead as far as possible. In some cases, we may require further active research but this becomes feasible if the needed eco system has been already established. The efforts suggested in this white paper would lead to foreseeing in advance, the needed Technology solutions and try to implementing the same in quickest possible time.

b. India is frequently threatened by a bewildering variety of disasters. The challenge thrown by a disaster becomes even more daunting when it gets fueled by other disasters in real time. Many parts of our country get devastated by more than one disaster at the same time. India therefore has to consider declaring 2020-2030 as the decade of building

Multi-disruptions resilient India the same way as it had declared 2010-2020 as the decade of innovation

c. The country has to ensure that the necessary technology strength is available to face any such disruptions. There is clearly a need to identify the gaps and put in place the right mechanisms to obtain technology solutions as fast as we can. Just for example some of the gap areas which need serious attention are identified below.

1. Genomics and DNA coding (Technologies to code, sequencing, drugs development, treatment line to be tried, related research)
2. Robot nurses and AI diagnosis with high accuracy.
3. Big data analytics, early prediction of disruptions from patterns, spread prediction etc.
4. Development of Advanced and invasive instrumentation.
5. Development and production of medical equipments.

On similar lines we have to identify other specific areas where we lack critical mass in the research and engineering experience and are likely to need them.

d. Another important factor is that, this is the right time to attract our young bright minds who are elsewhere, back to the Country. The suggested action would provide excellent opportunities to many of them and we are certain that they too are eagerly looking forward to come back. An important channel could be to use faculty and alumni networks to reach out to this talent and create the right mix of industry, research and academia sponsored roles to excite and involve them.

e. The mandate of INAE is to focus more on creating systems to find solutions, rather than solutions. It is hoped that the outcome of this white paper would lead to addressing these issues in a very focused manner, suggesting actionable recommendations which are implementable. This would vastly help the Country to keep the S&T sector in a state of readiness to face such grave situations in a much better way in the coming years.

भारतीय राष्ट्रीय अभियांत्रिकी अकादमी
Indian National Academy of Engineering
604–609, छठी मंजिल, टॉवर ए, स्पेज़ आई–टैक पार्क, सैक्टर 49, सोहना रोड, गुड़गाँव–122018 (भारत)
Unit No. 604-609, 6th Floor, Tower A, SPAZE I-Tech Park, Sector 49, Sohna Road, Gurgaon-122018 (INDIA)
दूरभाष/Ph: (91)-0124–4239480, फैक्स/Fax: (91)-0124–4239481, ई–मेल/Email: inaehq@inae.in, वैबसाइट/Website : www.inae.in

लेफ्टिनेंट कर्नल शोभित राय (सेवानिवृत्त)/ Lt Col Shobhit Rai (Retd)
बी.टैक (मकै.), एम.टैक (बायो मैडि.)
B.Tech (Mech), M.Tech (Bio Med)
उप–कार्यकारी निदेशक/Deputy Executive Director

Annexure #2

Ref.: INAE/121/PCND Nov 5, 2020

Subject: Technological Preparedness for dealing with

National Disruptions- Constitution of

Peer Committee

India is prone to many national disruptions time to time and the list is long. Covid-19 is indeed a surprise and the hardships caused by it all over the globe including India is enormous. Technological preparedness to face such situations, plays a predominant role in minimising the hardship encountered by the country. After Tsunami, in 2004 India has put in place a very wellstructured technological response mechanism, to reduce the loss of life in case such a Tsunami occurs again. This is one very good example of building our preparedness to face the disaster with appropriate remedial measures in advance.

Considering these factors, INAE prepared a White Paper on Technological preparedness for dealing with national disruptions with the wider participation of our Fellows. The focus of the White Paper is to study all possible disruptions by a number of groups with domain specialists and to examine our technology preparedness in the Country, identify the gaps and recommend the areas for further scientific research and technology solutions. The INAE White Paper was discussed in a meeting chaired by Shri VK Saraswat, Member, NITI Aayog and it was decided that INAE will set up a "Peer Committee" in consultation with the concerned Departments/ Ministries to carry on this task in a time-bound manner. Accordingly, the following Peer Committee is constituted with terms of reference as detailed below.

Peer Committee:

1	Dr PS Goel Former President, INAE & Former Secretary, MoES	Chairman
2	Prof Indranil Manna President, INAE	Member
3	Dr Sanak Mishra Former President, INAE	Member
4	Dr BN Suresh Former President, INAE	Member
5	Prof. N. Vinod Chandra Menon Founder Member, National Disaster Management Authority (NDMA)	Member
6	Prof. SK Jain Director, IIT Gandhinagar and Fellow, INAE	Member

<u>Representative Members from:</u>

7	Dr Mrutyunjay Mohapatra Director General, India Meteorological Department	Member
8	Dr Neeraj Sinha NITI Aayog, New Delhi	Member
9	DST: Dr. Debapriya Dutta Head (NRDMS- Natural Resources Data Management System), DST	Member
10	CSIR: Dr Vibha Malhotra Sawhney Scientist 'H' and Head (TMD-SEMi), CSIR	Member
11	DRDO: Dr Shiv Kumar Director, ER & IPR (Extramural Research & Intellectual Property Rights)	Member
12	DAE: Shri N Ramesh Scientific Officer-H and Member-Secretary, Crisis Management Group, Department of Atomic Energy (DAE), Mumbai (Level-14)	Member

13	ISRO: Dr JV Thomas Scientist/Engr 'G' & Associate Director (O&M), Earth Observation & Disaster Management Programme Office (EDPO), ISRO HQ Bangalore.	Member
14	ICMR: Dr Chander Shekhar Scientist G and Head, Innovation & Translation Research (ITR) & Intellectual Property Rights (IPR), Division	Member
15	Indian Coast Guard: Commandant Ashok K Bhama Joint Director (Operations)	Member
16	DBT: Dr Nitin Kumar Jain Scientist 'F', Department of Biotechnology	Member
17	Dr Pavan Kumar Singh, Joint Advisor (Operations), NDMA	Member
18	Lt Col Shobhit Rai (Retd), Deputy Executive Director, INAE	Convenor

The office of INAE will provide all necessary secretarial support in carrying out the tasks. NITI Aayog will be consulted on continuous basis and they will be kept informed on the progress made on a regular basis. It is requested that the Peer Committee may complete the task in about three months and submit the final report.

Lt Col Shobhit Rai (Retd)
Deputy Executive Director

Enclosure: Annexure
Distribution: Chairman and Members of Peer Committee

Annexure #3 – Expert Committees;

1. Expert Committee on Technology Preparedness for dealing with National Disruptions: Atmosphere related disasters.

Date 18/01/2021

Please find enclosed a white paper prepared by INAE regarding issues related to preparing the country for National Disasters. In this context, INAE has constituted a Peer Committee for addressing all issues related to preparedness for National Disasters in comprehensive manner. It has further been decided to address possible disasters through an Expert Committee in each sectorial discipline.

The following is hereby constituted to address issues related to Atmosphere related Disasters;

1.	Dr M Mohapatra, DG, IMD	:	Chairman
2.	Dr V Thiruppugazh, Add Secretary NDMA	:	Member
3.	Shri Kamal Kishore, Member NDMA	:	Member
4.	Dr M V Ramanamurthy, Director NCCR	:	Member
5.	Mr M A Atmanand, Ex Director NIOT	:	Member
6.	Dr Debpriya Dutta, DST	:	Member
7.	AVM (Dr) Ajith Tyagi EX DG, IMD	:	Member
8.	Dr L S Rathore, Ex DG, IMD	:	Member
9.	Dr K J Ramesh, Ex DG, IMD	:	Member
10.	Dr SS C Shenoi, Ex Director INCOIS	:	Member
11.	Dr N K Tyagi, Ex director CSSRI	:	Member

The above committee may co-opt any other expert as a special invitee as and when required. Col. Shobhit Rai, Deputy Executive Director, INAE will facilitate the committee with respect to VC or Physical meetings or any other related logistics.The Committee may address all aspect related to preparedness for

(i) Cyclones
(ii) Floods
(iii) Global Warming and related like impact on agriculture, coastal region submersing, health and diseases etc.
(iv) Heavy rain rain / cloud burst like Mumbai deluge
(v) Drought on regional or national level
(vi) Impact of adverse weather on agriculture out put
(vii) Support to expert committee on ocean related disasters like storm surges (Chairman Dr Ravichandran)
(viii) Support to expert committee on geology related disasters like land slide and avalanches (Chairman Dr Tiwari)
(ix) Any other related disaster

Committee may prepare a plan for the activity and keep the Chairman, Peer Committee and INAE informed of the progress. The Committee is requested to complete the task preferably in the next three months. Any financial requirements may also be indicated, though all travel related to this activity will be borne by INAE.

(Dr.P.S.Goel)
Chairman, Peer Committee.

Encl: (i) White Paper
(ii) Peer Committee.

2. Expert Committee on Technology Preparedness for dealing with National Disruptions: Ocean related disasters.

Date: 18/01/2021

Please find enclosed a white paper prepared by INAE regarding issues related to preparing the country for National Disasters. In this context, INAE has constituted a Peer Committee for addressing all issues related to preparedness for National Disasters in comprehensive manner. It has further been decided to address possible disasters through an Expert Committee in each sectorial discipline.

The following Committee is hereby constituted to address issues related to Ocean related Disasters;

1.	Dr. M Ravichandran, Director, NCPOR	: Chairman
2.	Dr. Srinivasa Kumar, Director, INCOIS	: Member
3.	Dr M V Ramanamurthy, Director NCCR	: Member
4.	Mr. Prakash Chauhan, Director, IIRS	: Member
5.	Dr R Venkatesan, Head, Ocean Observations, NIOT	: Member
6.	Prof Prasad Bhaskaran, IIT Kharagpur	: Member
7.	Commodore Abhyankar, Director, DNOM	: Member
8.	Cmdt Ashok K Bhama, Coast Guard	: Member.

The above committee may co-opt any other expert as a special invitee as and when required. Col. Shobhit Rai, Deputy Executive Director, INAE will facilitate the committee with respect to VC or Physical meetings or any other related logistics.

The Committee may address all aspect related to preparedness for

(i) Tsunami.
(ii) Storm Surge due to Tsunami or Cyclone orSwell.
(iii) Oil Spills
(iv) Swell Surge.
(v) Harmful Algal bloom.
(vi) Sea Level rise due to Climate change
(vii) Coastal erosion.
(viii) Coral Bleaching/ Ocean Acidification
(ix) Marine plastics/debris

Committee may prepare a plan for the activity and keep the Chairman, Peer Committee and INAE informed of the progress. The Committee is requested to complete the task preferably in the next three months. Any financial requirements may also be indicated, though all travel related to this activity will be borne by INAE.

(Dr.P.S.Goel)
Chairman, Peer Committee.

Encl: (i) White Paper
(ii) Peer Committee.

3. Expert Committee on Technology Preparedness for dealing with National Disruptions: Geology related disasters.

Date 24/01/2021

Please find enclosed a white paper prepared by INAE regarding issues related to preparing the country for National Disasters. In this context, INAE has constituted a Peer Committee for addressing all issues related to preparedness for National Disasters in comprehensive manner. It has further been decided to address possible disasters through an Expert Committee in each sectorial discipline.

The following Expert Committee is hereby constituted to address issues related to Geology related Disasters;

1.	Dr V M Tiwari, Director NGRI	:	Chairman
2.	Dr T Srinivasa Kumar, Director INCOIS	:	Member
3.	Prof Surya Prakash, NIDM	:	Member
4.	Dr Sumer Chopra, Director ISR, Gandhinagar	:	Member
5.	Prof CVR Murthy, IITM, Former director IIT Jodhpur	:	Member
6.	Prof ID Gupta, IIT Roorki	:	Member
7.	Dr Amit Kumar Verma Associate Prof IIT BHU	:	Member
8.	Dr Srinagesh, Chief Scientist, NGRI	:	Member

The above committee may co-opt any other expert as a special invitee as and when required. Col. Shobhit Rai, Deputy Executive Director, INAE will facilitate the committee with respect to VC or Physical meetings or any other related logistics.

The Committee may address all aspect related to Geology Disaster.

(i) Identify all possible geological disasters that are likely to occur, along with their probability like Earth Quakes, landslides, snow avalanches etc

(ii) Assess preparedness of the country

(iii) Identify gaps

(iv) Identify R&D needs, Institutional support required

(v) Identify capacity building needs

(vi) Policy or institutional recommendations to the GoI

Committee may prepare a plan for the activity and keep the Chairman, Peer Committee and INAE informed of the progress. The Committee is requested to complete the task preferably in the next three months. Any financial requirements may also be indicated, though all travel related to this activity will be borne by INAE.

(Dr.P.S.Goel)
Chairman, Peer Committee.

Encl: (i) White Paper
(ii) Peer Committee.

4. Expert Committee on Technology Preparedness for dealing with National Disruptions: Medical and Health related disasters.

Date 24/01/2021

Please find enclosed a white paper prepared by INAE regarding issues related to preparing the country for National Disasters. In this context, INAE has constituted a Peer Committee for addressing all issues related to preparedness for National Disasters in comprehensive manner. It has further been decided to address possible disasters through an Expert Committee in each sectorial discipline.

The following committee is hereby constituted to address issues related to Medical/Pandemic related Disasters;

1.	Dr Chandra Shekhar, Ex ICMR	:	Chairman
2.	Dr.HK Mittal, DST	:	Member
3.	Shri Navdeep Rinwa J,S,	:	Member
4.	Dr.Jitendar Sharma AMTZ Vizac	:	Member
5.	Prof.Ashish Bhalla, PGIMR, Chandigarh	:	Member
6.	Dr.Praveen Agrawal, Dept. of Emergency medicine	:	Member
7.	Prof. Anand Krishnan, Community medicine	:	Member
8.	Mr.Rajiv Nath, AIMED, MD	:	Member
9.	Dr.P.Siva Perumal, ICMR (NIOH) Ahmedabad	:	Member
10.	Dr.Anil Mishra, INMAS	:	Member.

The above committee may co-opt another expert as a special invitee as and when required. Col. Shobhit Rai, Deputy Executive Director, INAE will facilitate the committee with respect to VC or Physical meetings or any other related logistics.

The Committee may address all aspect related to preparedness for

(i) Identify all possible medical disasters including man made and natural that are likely to occur, along with their probability

(ii) Assess preparedness of the country

(iii) Identify gaps

(iv) Identify R&D needs

(v) Identify capacity building needs

(vi) Policy or institutional recommendations to the GoI

Committee may prepare a plan for the activity and keep the Chairman, Peer Committee and INAE informed of the progress. The Committee is requested to complete the task preferably in the next three months. Any financial requirements may also be indicated, though all travel related to this activity will be borne by INAE.

(Dr.P.S.Goel)
Chairman, Peer Committee.

Encl: (i) White Paper
(ii) Peer Committee.

5. Expert Committee on Technology Preparedness for dealing with National Disruptions: Cyber Security related disasters.

Date 18/01/2021

Please find enclosed a white paper prepared by INAE regarding issues related to preparing the country for National Disasters. In this context, INAE has constituted a Peer Committee for addressing all issues related to preparedness for National Disasters in comprehensive manner. It has further been decided to address possible disasters through an Expert Committee in each sectorial discipline.

The following Committee is hereby constituted to address issues related to cyber security;

1.	Dr. Gulshan Rai	:	Chairman
2.	Gen. Ajit Bajpai, DG, NCII, PC	:	Member
3.	Mr. Sanjay Bahl	:	Member
4.	Mr. Anil Kumar Bhandari, CGM and CISO, SBI	:	Member
5.	Mr Dinesh Chandra, CEA Member, Hydro & Grid	:	Member
6.	Mr. Manish Tiwari, CISO, Airtel	:	Member
7.	Mr. S.K.Basin, CISO, National Stock Exchange	:	Member.
8.	Mr MAKP Singh, CEA, Chief Engineer	:	Member
9.	Mr Sameer Ratolikar, CISO HDFC	:	Member

The above committee may co-opt any other expert as a special invitee as and when required. Col. Shobhit Rai, Deputy Executive Director, INAE will facilitate the committee with respect to VC or Physical meetings or any other related logistics.

The Committee may

(i) Review the Cyber Security status of critical sectors in the country.

(ii) Suggest strategy for security of critical infrastructure (CII) in the country including cyber security setups at each CII.

(iii) Steps and measures to protect CII and identify gaps if any

(iv) Review the current cyber security governance in the country and make recommendations to the government, if needed.

(v) Review R&D need with respect to cyber security and suggest mechanism wherever needed.

(vi) The individuals today depend upon MNCs for protection against Cyber-attacks like hacking of email/computers, could there be a coordinated national level mechanism to protect individual computers/networks?

(vii) Any other issue committee considers important.

Committee may prepare a plan for the activity and keep the Chairman, Peer Committee and INAE informed of the progress. The Committee is requested to complete the task preferably in the next three months. Any financial requirements may also be indicated, though all travel related to this activity will be borne by INAE.

(Dr.P.S.Goel)
Chairman, Peer Committee.

Encl: (i) White Paper
(ii) Peer Committee.

7) Expert Committee on Technology Preparedness for dealing with National Disruptions: Forest Fire and other fire related disasters.

Date 18/01/2021

Please find enclosed a white paper prepared by INAE regarding issues related to preparing the country for National Disasters. In this context, INAE has constituted a Peer Committee for addressing all issues related to preparedness for National Disasters in comprehensive manner. It has further been decided to address possible disasters through an Expert Committee in each sectorial discipline.

The following is hereby constituted to address issues related to Forest Fore and other fire related Disasters;

1.	Dr Rajeev Narang, Director, CFEES	:	Chairman
2.	Mr A D Naik, Director Andhra Fire Services	:	Member
3.	Mr Lakshmi Prasad, Director Telangana Fire Services	:	Member
4.	Mr Sandeep Rana, Director Uttarakhand Fire Services	:	Member
5.	Dr K C Wadhwa, Associate Director, CFEES	:	Member

The above committee may co-opt any other expert as a special invitee as and when required. Col. Shobhit Rai, Deputy Executive Director, INAE will facilitate the committee with respect to VC or Physical meetings or any other related logistics.

The Committee may address all aspect related to preparedness for

(i) Forest Fires at any vulnerable location in the country, identify these locations

(ii) Industrial fires, possible hazards

(iii) Fire hazards in congested areas

(iv) Govt policy interventions related to any kind of fire hazards

(v) Any other issue related to fire hazards

Committee may prepare a plan for the activity and keep the Chairman, Peer Committee and INAE informed of the progress. The Committee is requested to complete the task preferably in the next three months. Any financial requirements may also be indicated, though all travel related to this activity will be borne by INAE.

(Dr.P.S.Goel)
Chairman, Peer Committee.

Encl: (i) White Paper
(ii) Peer Committee.

Annexure #4

11 May 2015 and 4 November 2015

Indian National Academy of Engineering

Roundtable Meetings 1 &2 on

Engineering Interventions in Landslide Risk Reduction

(Organized jointly with CSIR-Central Road Research Institution, New Delhi)

VOLUME-1

RECOMMENDATIONS

Towards building a strong culture of safety against landslides and landslide disasters

Indian National Academy of Engineering
Forum on Engineering Interventions for Disaster Mitigation

ROUNDTABLE MEETINGS 1 & 2 ON ENGINEERING INTERVENTIONS IN LANDSLIDE RISK REDUCTION

New Delhi: 11 May 2015; 4 November 2015

Contents

Indian National Academy of Engineering
Forum on Engineering Interventions for Disaster Mitigation

ROUNDTABLE MEETINGS 1 & 2 ON ENGINEERING INTERVENTIONS IN LANDSLIDE RISK REDUCTION

New Delhi: 11 May 2015; 4 November 2015

Introductory remarks

This document presents a comprehensive set of Recommendations covering all facets of Landslide risk reduction based on the two roundtable meetings organized in New Delhi on 11 May 2015 and 4 November 2015, by the Indian National Academy of Engineering (INAE), the premier body of India's most distinguished engineers, engineering-scientists and technologists. The meetings were held jointly with CSIR-CRRI (Central Road Research Institute), New Delhi.

By design, the roundtable meetings were unique in their architecture and conduct. Unlike the conventional seminars, workshops and conferences, there were no formal talks/lectures and presentation of learned papers, instead, both the roundtable meetings focused entirely on the well researched and pre-circulated Backgrounders based on the responses to the questionnaire surveys, literature review and preparatory meetings with stakeholders and invitees to the Round-table. The Backgrounders of Roundtable 1 and Roundtable 2 were revised four times successively as they passed through the consultative process and the scrutiny of some of India's foremost domain experts and institutions, and the participants were already familiar with backgrounder version 5, which served as the agenda and the stimulus for the meetings.

The Recommendations, which were unanimously passed and signed, are coalesced and presented for the consideration, adoption and implementation by the Government of India. Ad interim, every effort has been made to bring these to the attention of the relevant Ministries, Departments and Agencies of the Government of India, including PMO, Ministry of Home Affairs, National Disaster Management Authority, National Institute of Disaster Management, Department of Science and Technology, CSIR-CRRI, CSIR-CBRI, Ministry of Earth Sciences, Defence Terrain Research Laboratory and the Geological Survey of India, which is currently the National Nodal Agency for Landslides. These have also been publicized through letters, scientific papers, articles and formal presentations.

A digital copy of the Recommendations (Volume 1) and the supporting Backgrounders (Volume 2) can be obtained by addressing requests to *rajmee@yahoo.com*.

R.K.Bhandari, FNAE
Chairman,
On behalf of the INAE Forum on Engineering Interventions for Disaster Mitigation
Email:rajmee@yahoo.com

Preamble

The participants of the Roundtable 1 & 2 on Engineering Interventions for landslide risk reduction thank the Indian National Academy of Engineering for taking suo motu cognizance of the challenges facing India in the area of Landslide risk reduction and mitigation, and for spearheading holistic and in-depth, national level inter-active discussions at the highest level of expertise, on the multi-faceted aspects of this hither-to inadequately dealt subject.

Unlike earthquakes and tsunamis, landslides are predictable, preventable and controllable; these scientific realities will have to be taken more seriously by fellow professionals. There is a need to strengthen, amplify and accelerate the pace of scientific studies on occurrence, distribution, processes, frequency and impact of landslides and link these studies organically and intimately with landslide management in the multi-hazard context. The participants appeal for enhanced investments in institution building, R & D, and on developing the culture of safety in landslide risk reduction

The recommendations made hereunder, are the unanimous outcome of the two Roundtable Meetings based on the collective wisdom. They are all aimed at (a) establishing fully operational, well-coordinated, result-oriented and accountable institutional mechanisms; (b) inculcating scientific temper in landslide investigation and management; and (c) underscoring the importance of multi-disciplinary team-building, education and training to be able to measure up to the growing challenges posed by the relentless pressure of population, urbanization–unregulated constructions – and extreme weather events.

The INAE forwards these Recommendations to the Government of India for consideration, adoption and speedy implementation by the dealing ministries, institutions and agencies with the hope and expectation that policy makers will take a fresh , holistic look at the landslide risk reduction strategies, mainstream landslide risk reduction with the development planning, and would pro-actively convert every disaster into a possible opportunity to test policies, learn lessons and effectively use those lessons to build a strong culture of safety against landslides.

The INAE thanks CSIR-Central Road Research Institute, New Delhi for hosting both the roundtable meetings; and - NDMA, NIDM, GSI, Ministry of Earth Sciences, Defence Terrain Research Laboratory (DRDO), IIRS (ISRO), CSIR-Central Road Research Institute, CSIR-Central Building Research Institute and many other leading Institutions, Universities and domain experts for contributing immensely to pre-roundtable interaction, and for their active participation in the roundtable meetings .Grateful thanks are due to the countless e-participants who were part of the evolving documents of Backgrounders and Recommendations.

Guidance and inputs received from Gen N.C.Vij, formerly, Vice Chairman of the National Disaster Management Authority; Shri J.C.Pant, formerly the Chairman of the High Powered Committee of the Government of India on Disaster Management; Dr Shailesh Nayak, Secretary Ministry of Earth Sciences; Dr T.Ramasami, Former Secretary, Department of Science and Technology; Lt Gen N C Marwah, Member, NDMA; Dr N V C Menon, Former Member, NDMA and Fellows of the Academy are gratefully acknowledged.

Recommendation 1

Establish an autonomous, National Centre for Landslide Research Studies and Management

Establish an autonomous, National Centre for Landslide Research Studies and Management (NCLRSM) to bring about the much awaited transformational change in landslide research, studies and mitigation at the vanguard of Science, Technology and Innovation1, and for improved coordination and accountability.

1.1 An autonomous and empowered NCLRSM, accountable to the nation, should be created by the Government of India very early to serve as an apex institution for landslide mitigation and management. This recommendation, first made by the National Disaster Management Authority in the Guidelines on Management of Landslides and Snow Avalanches issued in June 2009, is considered critically important to ensure focused, well coordinated and holistic attention to the multi-faceted aspects of landslide mitigation and management. Infact, its need has further grown because the existing institutional mechanisms have fallen short of delivery all these years and India needs a powerful institution to reverse the trend of declining scientific culture in present practices.

1.2 The proposed NCLRSM should have the following objectives:

Foster, promote and sustain national capacity towards achieving a paradigm shift from the culture of post-disaster rescue, relief and reconstruction to include the culture of preparedness, prevention, protection, and safety against landslides.

Facilitate mainstreaming of landslide management with environmental protection and development planning, and

Strengthen networking of knowledge repositories, institutions and expertise towards ensuring high-quality collaborative research, education and training, unleashing the synergistic potential of India's knowledge institutions in addressing emerging national priorities and technological innovations.

1.3 The proposed NCLRSM should have the following primary functions:

Provide national vision and proactively stimulate policy formulation.

Conceptualise, develop, promote and ensure continual updating of Science-Technology Innovation-based holistic, eco-friendly, sustainable approaches in addressing the present and future needs challenges and national priorities.

Align landslide risk reduction initiatives with the challenges posed by extreme weather events, natural resource management, urbanisation, industrialisation and constructions that unfortunately remain largely unregulated.

Create pace-setting best practices.

Engage with stakeholders for strengthening education, research and training in landslide management.

Recommendation 2

Prepare Multi-tier, dynamic and holistic Plans anchored to the existing National Guidelines after its thorough review

Prepare multi-tier, dynamic and holistic short-, medium- and long-term landslide management plans anchored to the NDMA Guidelines on Management of Landslides and Snow Avalanches of June 2009, after their thorough review and revision.

2.1 Prepare short- (0-3 years), medium- (3-10 years) and long-term (10-20 years) landslide management plans at the national, state and district levels in the multi-hazard context, through multi-disciplinary teams, within one year. The plans should, inter alia, address the present and the emerging challenges, and provide strategies for coordinated action, capacity development and for large-scale promotion of sound engineering practices.

2.2 These plans must be dynamic in nature. A standing order should be issued to ensure their regular updating, reaffirmation and/or re-notification.

2.3 An independent panel of experts should be tasked to review the existing NDMA Guidelines introduced in June 2009 and analyse their positive and negative impacts, catalogue their deficiencies, examine why some of their recommendations could not be implemented during the last 6 years and how well they were received by the user agencies and stakeholders.

2.4 The same panel of experts, based on the review findings, should recommend the way forward, keeping in view the felt needs in different parts of India, and the emerging national priorities. All indicators suggest that an altogether new set of guidelines is needed to effectively deal with the real-life problems and challenges in landslide management, known for their diversity and complexity.

2.5 Wherever targets and timelines are indicated in the official guidelines and documents such as the NDMA Guidelines, clear responsibilities should be laid down, source of project funding identified and progress monitoring mechanisms should be specified to ensure implementation.

2.6 Introduce Guidelines on writing, scrutiny and process of approval of projects related to landslide risk reduction. Projects on landslide risk reduction should be sought within the framework of national priorities with clear instructions for the submission of projects and their scrutiny. Delivery capacity and implementation mechanism should also be ascertained and made a part of the approval process to rule out teething troubles and project time and cost over-runs. By now, the country has enough experience to catalogue current acute shortfall of capacities at National, State and local levels. If the shortfall is not overcome, it is bound to hurt the national resolve of finding lasting solutions to all major landslide problems threatening life and property. Further, the subject of a landslide investigation being highly specialized, recurring investment is essential in training and retraining of the professionals at the state-of-the-art level, especially the training of trainers.

Recommendations 3-8

Insist on landslide hazard and risk assessment through large scale Hazard Maps for effective and reliable Landslide disaster Prevention and Mitigation

Recommendation 3

Ensure production and delivery of reliable and user-friendly landslide susceptibility/hazard maps for hazard and risk assessment, anchored to logically established, nationally accepted and uniformly enforced landslide terminology, classification system and mapping methodologies.

The issue of terminology and classification has been in and out of the national agenda several times since 1989. A serious note must be taken of the fact that mapping projects being implemented by different institutions for years are not based on a pre-notified, nationally agreed landslide terminology and classification system. Thusfar there is no common understanding of which slope failure must go on to the map as a landslide. By recourse to uniformly adopted landslide terminology2, classification system, and hazardmapping methodologies, landslide hazard mapping work pursued by different institutions at different times will resonate, leading to synergistic gains and equally credible knowledge products.

A 3-step approach is suggested to implement this recommendation:

As the first step, GSI may be requested to constitute a national level, multi-disciplinary Expert Group to formally propose landslide terminology, classification-system and mapping methodologies for macro, meso and larger scales. The well known Global state-of-the-art3, the past native experience, the feedback from the INAE and the power of Science and Technology are strengths of the country which need to be fully tapped to achieve a high quality first draft of the document.

The second step should be to publicize the draft document by wide circulation nationally, soliciting comments for revision and value addition.

And finally, the proposal as a whole should be formally discussed threadbare at a national level meeting, eventually to be cleared by the same multi-disciplinary Expert Group for adoption and implementation by all concerned.

The preparatory ground work to expedite large scale landslide hazard mapping projects and site specific studies do require nationally accepted approaches and hazard mapping methodologies. For India to be in a position to reliably perceive landslide hazards, it is imperative for concerned professionals to consider some of the hitherto unattended, vital slope-destabilizing causative factors such as deforestation, climate change impacts, Glacial Lake Outburst Floods (GLOF),formation bursting and floods caused by landslide dams, nonengineered building and road constructions, unregulated urbanization and abuse of land, earthquake and flood induced slope instability, quarrying and mining, and runout effects which do vary from location to location. It is, therefore, essential to introduce a nationally accepted meso-scale mapping methodology as expeditiously as possible after interactive consultations with domain experts on one hand and the end-users like engineers, architects, builders and disaster managers on the other.

At the stage of implementation, the transition from the present statusquo approach to the new paradigm- reinforced by nationally agreed terminology, classification system and hazard mapping methodologies- will naturally invoke both resentment and resistance to change. This is because many ongoing projects may require

2 This fact also places a question mark on the reports of density distribution of landslides (number of landslides per unit area) projected to infer the severity of landslide hazard. GSI has confirmed that a robust mapping methodology for mesoscale mapping is yet to be developed.

3 The Americans, the Canadians, the Australians, the Swiss and many from other countries have evolved terminologies and classification systems based on their collective judgment.

mid-course corrections and if that is not possible, the projects may have to be reviewed on a case to case basis.

It may perhaps be relatively easy to keep new projects on hold until the nationally accepted common approach to mapping gets established4.

Recommendation 4

Evolve and Implement a national strategy to ensure that macro scale landslide susceptibility zonation maps get regularly updated, validated from time to time and put to effective use.

Many macro-scale landslide susceptibility zonation maps have reportedly been completed quite some time ago using very old topo sheets with large contour intervals, which need to be updated by high resolution satellite images and Digital Elevation Models (DEMs). Further, many of these maps remain unrevised and unutilized for quite some time. Hazard mapping being a work-in-progress, an attempt should be made to place the mapping work on auto-pilot.

The ongoing mapping projects in analog format may be transformed into GIS based digital format with the newly adopted common methodology. Further, the decision of change over to the digital format should apply to all future projects at all scales aiming at production of hazard and risk maps.

The macro-scale landslide susceptibility/hazard zonation mapping being done by the GSI and other knowledge institutions in India, based on integration of Factor Maps, ought to remain the preferred approach because they are in themselves of a great value to the users of the project outputs and provide the best assurance of independent evaluation, easy revision and constant upgradation and revalidation. What is more, the factor mapping approach offers tremendous flexibility to the whole mapping operation as specialist teams can work on different themes, independently or collectively, as a given situation may warrant.

4 In order to ensure the credibility of the completed and the ongoing landslide hazard mapping projects, it is important to pause, introspect and examine the implications of the use of differing approaches in hazard mapping. It is necessary to ask hard questions, learn from the past, think innovatively and make mid-course corrections, besides erasing question marks, adding value, and ensuring user friendly knowledge products. The BIS Code 14496(Part2):1998, being fundamentally inadequate, BIS may be requested again to have it rewritten on a priority basis.

Recommendation 5

The priority currently being assigned to macro-scale landslide susceptibility zonation be reviewed and reordered for effectively meeting the huge pressure of rising national demand for large scale landslide hazard mapping and site-specific studies to facilitate hazard and risk assessments and aid landslide mitigation and management.

Large scale landslide hazard mapping ought to be the national priority because the country urgently needs such maps for meaningful landslide hazard assessment, risk analysis, mitigation and management and location-specific studies. This would mean that instead of continuing monotonously with the macro-scale mapping of limited use, the attention must squarely turn to the mesoscale and location-specific hazard mapping of limitless value.

More than 60,000 sq km of landslide susceptibility zonation mapping has already been completed by the GSI, besides maps at the same scale produced by the other national agencies. GSI additionally proposes to add Landslide Susceptibility Zonation (LSZ) Maps for 4, 20,000 sq km of area by 2020 at the scale of 1:50000 under the National Landslide Susceptibility Mapping (NLSM) programme launched in 2014-15. Whereas no one would deny the desirability to cover all landslide susceptible areas at macro-scale, the priority assigned to the NLSM should be subjected to a review vis-a-vis the large scale landslide hazard mapping.

The macro-scale landslide susceptibility maps should be put to effective use by ensuring (a) their necessary revisions from time to time, despite the handicap posed by the analog format (b) user-friendly packaging, and (c) reliability check on these maps through peerreviews5, especially in the cases where approaches to mapping differ from institution to institution. The already produced macro-scale maps of pilgrim routes, river catchments, communication route corridors etc should also be utilized to guide large scale hazard mapping projects of those areas.

5 GSI has conveyed in its correspondence with the INAE that the methodology of their landslide hazard mapping has been internationally peer-reviewed as the papers were published in journals of repute. A distinction is however necessary between peer-review of finally delivered, validated and certified maps using a particular methodology and the peerreview of the methodology itself by the Journals.

Recommendation 6

Maps of actual landslides should be produced for all landslide prone districts of each of the afflicted States on a priority basis. The value of these maps should thereafter be enhanced by recourse to direct mapping (by multi-disciplinary teams) of the zones of incipient slope instability due to other causative factors

Preparation of the maps can immensely benefit from (a) the landslide inventory at macroscale prepared by the GSI, CRRI, CBRI, CDMM Chennai, DTRL and many other institutions (b) meso and large scale mapping completed to date (c) the numerous study reports of actual landslides available with many agencies[6], State Governments and project authorities, and (d) the published literature including the reports, the Atlases and the research papers . The reliability of an actual landslide map is high because it is based on irrefutable and easily verifiable field evidences. Such maps can also be easily updated as new evidences of slope failures in the area become available.

There was a time when landslide hazard maps were not available and instead large scale slope maps were used as poor substitutes to infer potential zones of danger. Later on, the maps of actual landslides were combined with large scale slope maps to obtain a much improved picture of the high hazard zones. Then came a time when the maps of actual landslides were themselves converted into landslide hazard zonation maps by using the well known direct, one-shot, landslide hazard mapping approach. It is an approach in which, traditionally, a single multidisciplinary team carries out mapping work based on Geological, Geomorphological, Geotechnical, and other relevant aspects.

Large scale landslide hazard maps produced by this route will go a long way in connecting hazard maps with their end-users. Further such maps can also be used to test the reliability of large scale hazard maps as and when they become available. By doing so, it will also be possible to produce the much awaited pacesetter examples of large scale hazard maps.

6 Annexure 2 of Backgrounder5 provides numerous examples. For instance, for Uttarakhand, GSI has mapped Lambagar, Khanera, Bura Kedar, Pipalkoti, Amiyan, Mansa Devi, Malpa, Bhatwari, Uttarakshi and Siab landslides at 1:5000 and Surbee and Sher ka Danda, Nainital at 1:2000 scale. To this list CBRI and CRRI have added Kaliasuar, Phata, Agrakhal and Pakhi Landslides at 1:2000 scale.

Recommendation 7

All the completed landslide hazard maps on the meso-scale and larger, regardless of their date of mapping and format (analog) should be subjected to periodical critical scrutiny (not more than 10 years) which may be decided by the mapping agency for - updating, value addition, user-friendly packaging and certification by peer-review, so that they become useful to planners, architects, engineers, builders, communities, tourists, pilgrims and disaster managers for reliable assessment and management of risks.

Recommendation 8

For every large scale (including meso-scale) landslide hazard map, it should be mandatory to produce the corresponding set of infrastructure maps, population density maps etc., at the same scale not only for quickly spotlighting the hazardous zones, but also to facilitate reliable identification of the elements at risk, and quantification of the associated hazards and risk. High resolution (1 m, 2.5 m, 5.8 m) remote sensing images available from ISRO and other agencies can be used for this purpose.

Recommendation 9

Permanently control all known major Landslides to forestall impending danger and promote development

9.1 A time-bound national programme for permanently controlling all major landslides should be undertaken, for which (a) a National Task Force of expert professionals should be constituted to catalogue, study and decide management strategies for all known problematic landslides in the country in consultation with the State Governments, district administration and the Civil Society, (b) appropriate agencies, institutions and teams should be identified, shortlisted and mandated to implement the programme in a phased manner, (c) rational criteria to classify an individual landslide as minor, medium or major should be prescribed at the outset for uniform adoption and (d) adequate funding should be provided through national landslide management projects or by one-time funding from the Central Government.

9.2 The National Task Force shall formulate guidelines to ensure that even minor incidents of slope failures get immediately reported through community participation, so that the concerned authorities could take timely preventive action.

9.3 The 'Best Practice' examples and success stories of landslide control should be nationally recognised, rewarded and widely disseminated.

Recommendations 10-13

Establish sound engineering practices by recourse to Scientific Landslide Investigation and S-T-I based management

Recommendation 10

Introduce state-of-the-art level Standing Operating Procedures for Landslide investigation, Analysis, Instrumentation, Monitoring and Control

10.1 The comments and reviews on the 2013 version of the Standard Operating Procedure (SOP) in use by GSI since 2013 were recorded in the Backgrounder of the Roundtable 1 and later discussed at the meeting of 11 May 20157. The GSI was formally informed of these comments, consequent of which a revised version of the draft SOP was made available by the GSI to the INAE in July 2015. This new draft was further reviewed in the preparatory phase prior to the Roundtable 2 and finally at the second roundtable meeting held on 4 November 2015. A comprehensive set of comments, recorded in the Backgrounder of Roundtable 2 have been provided to the GSI. From the comments as recorded in the aforesaid Backgrounder, it is clear that the draft SOP needs complete rewriting. The task of producing the revised draft of the SOP should be entrusted to a team of the most qualified and experienced domain specialists, with the coordination function entrusted to a single institute, for timely delivery and accountability8. GSI could consider

7 Annexure3 of the Backgrounder 5 of Roundtable1.

8 The observation that the Geotechnical component of the SOP dated July 2015 is as deficient as the earlier 2013 version has been reported in the Backgrounder of Roundtable 2 and shared with the GSI . The GSI has agreed to have the Geotechnical investigation part of the SOP rewritten by a team of experts. There is a need to take a holistic view on the scope of the SOP which should include items such as instrumentation, field monitoring of existing landslides, reporting of an imminent landslide etc. The INAE Forum will be glad to support GSI's initiatives towards delivering to the country a simple to use state-of-the-art SOP. The task being critical, should be completed in no more than a 6 month long time frame

suspending the present geotechnical investigations segment of the SOP and go by expert guidance until the revised SOP gets notified.

10.2 For all major landslide susceptible projects, a thorough geotechnical investigation should be a mandatory pre-requisite to planning and design of landslide control measures. Guidelines on landslide management at national, State and district levels must underscore this requirement, provide for multi-disciplinary team-building and promote the observational method of design and construction in geotechnical engineering practice.

10.3 State and district level Disaster Management Authorities in every landslide-prone State must identify at least one knowledge institution with expertise in Engineering Geological and Geotechnical Investigations and adequately equip it to undertake scientific investigations of landslides, when needed. The identified institution should also serve as a training centre in Engineering Geological and Geotechnical investigation including in-situ and laboratory testing, and in design of landslide control measures.

10.4 Quality assurance of landslide investigations being critical to design of control measures, all major landslide investigation reports should be subjected to independent peer reviews to be facilitated by CLRSM

Recommendation 11

In the project approval process, comparative cost-benefit analysis of technological options and spotlight on eco-friendly technologies must be mandatory.

11.1 The design package finally approved for fixing a major landslide and its associated hazardous zones should be based on scientific investigation and comparative evaluation of all options after due deliberation by the multi-disciplinary project team of experts.

11.2 Technologies deployed for landslide management shall be eco-friendly as far as possible. All DPRs should mandatorily include an exclusive chapter on positive and negative impacts of the finally selected design with cost-benefit analysis (CBA) in support of the choice and in justification of grey technologies included.

11.3 Landslide management policy must encourage and reward innovation in design and implementation of measures leading to lasting remedy of complex slope instability problems. For instance, if a township is supported on a problematic hill destabilised by several closely-spaced landslides, it will be an inappropriate, ineffective, expensive and unscientific way to stabilise the hill by treating the closely-spaced landslides as individual entities. There will always be innovative alternatives to look at the very same problem holistically and treat the entire disturbed hill zone in a composite manner.

11.4 Every project in landslide-prone areas must provide a set of indicators from which the efficacy of control measures and safety of the area could be monitored beyond the construction phase for early warning and for feedback to designers and disaster managers.

Adequate provision of budget should be made for this purpose.

Recommendation 12

Give major development projects a headstart and smooth run by ensuring right at the very beginning that DPRs are eco-friendly and techno-economically sound.

12.1 Guidelines for the DPRs should be reviewed and strengthened in the light of the following recommendations:

12.1.1 The task of preparing DPR shall be awarded after a stringent scrutiny of the vendors, taking into account adequacy of their in-house multi-disciplinary expertise, delivery capacity and record of past experience. For landslide management projects, expertise in Engineering Geology, Hydro-Geology and Geotechnology lie at the core, which should be supplemented with project-related field experience in tunneling, rail, road, dams and building construction, as required on a case-to-case basis.

12.1.2 Quality and Cost Based Selection (QCBS) of DPR must replace the conventional practice of awarding work on least cost basis.

12.1.3 The time allocated for preparation of a DPR must be decided through a team of experts, on a case-to-case basis. The decision should take into account factors such as likely delays due to inclement weather, the scope and the scale of mapping work and the nature and quantum of requisite field/laboratory investigations.

12.1.4 The ‘Request for Proposal’ (RFP) document for appointment of DPR consultant should form the basis for defining the scope of work and the expected outputs of the report. The RFP should also include the scope of work extended to cover additional mapping and investigation of the surrounding influence areas, from the point of view of landslide management.

12.2 An independent peer-review of DPR's of all major landslide projects should be mandatory.

12.3 Scrutiny of DPRs with respect to laid down guidelines and the usual periodic surprise audit of projects in progress should be mandatory.

12.4 Accreditation of consultancy firms should be introduced to avoid their unnecessary proliferation and ensure capacities, standards, and professional ethics.

12.5 Capacity building of technical agencies within the Government should be done to impart to them the multi-disciplinary expertise essential for credible review of DPRs before implementation.

12.6 The institutional arrangements for vetting and approvals of DPRs should be enlarged and strengthened to enable seeking deployment of accredited agencies and proof consultants, when required.

12.7 Disaster Impact Assessment of all major projects, prior to their approval, should be mandatory.

12.8 A Third Party Inspection and audit should be encouraged at each stage, and made mandatory before proceeding to the next stage.

12.9 A sound engineering practice of permitting mid-course modification of ongoing sanctioned works (as justified by new factors that get revealed as the work progresses) shall be implemented on the recommendations of the Expert Committee of the said project, to guard against recurrence of slope failures and consequent threat to life and property, and for saving recurring expenditure, in the long-term.

Recommendation 13

Fortify landslide management by introducing innovative techno-legal and techno-financial practices.

13.1 For all ongoing and new development projects involving landslide risk management, the project construction and the corrective action for countering the construction-related, visible or anticipated slope failures and environmental damage before, during or after the construction stage, ought to be considered in design as its inseparable parts. In other words, the conventional practice of reflecting costs of corrective actions as separate budget items should be discontinued by recourse to sound engineering design practices and by creating innovative techno-legal and techno-financial enabling environment. It should be mandatory to provide adequate budget for these purposes as a package, which must also include long-term maintenance costs.

13.2 Landslide investigation and design reports for all major landslide management projects should be subjected to a mandatory peer-review by an independent Panel of Experts constituted by CLRSM and other designated authorities, with particular reference to technical merit, financial viability, speed effectiveness, eco-friendliness, and accountability.

13.3 For sustenance of the holistic approach in landslide risk reduction, there is a need to improve interaction between professionals pursuing landslide studies and those looking at other types of natural hazards such as earthquakes, tsunamis and floods. Bridges of effective understanding should be built between professionals dealing with landslides, those who prepare Detailed Project Reports (DPR), and the community at large. This task can be assigned to National Institute of Disaster Management and other competent knowledge institutions and agencies.

13.4 Enforce regulations to make sure that every development work goes hand in hand with minimum impact on protection of local environment.

Recommendations 14-15

Invest in National Capacity Building on a regular basis

Recommendation 14

National capacity building, intensive preparatory groundwork and specialized training of professionals being the pre-requisites to timely, quality and sustained delivery of large scale landslide hazard mapping projects and site specific studies adequate funding of projects in this category be ensured to achieve the national goal.

The Government should invest adequately to overcome the nationally felt acute shortfall of specialized professionals and modern Geotechnical laboratories which constitute a major roadblock in placing landslide hazard mapping, investigations, prediction and prevention on a scientific footing. Since the rigours of hazard mapping at meso-scale and larger call for thinking and care for detail far above the standards of macro-scale mapping, the credibility of meso-scale mapping would depend as much on the competence of multidisciplinary teams as on the robustness of the mapping methodology.[9]

The success of the Government's projected plan to pro-actively control all major landslides will also depend as much on the quality of mapping and Geotechnical Investigation, as it does on the quality of the investigation teams. To start with, on priority, one state-of-theart Geotechnical Laboratory should be established in every landslide prone State. The mapping work to be carried out by multi-disciplinary teams must mandatorily include an Engineering Geologist and a Geo-technical Engineer.

The shortage of trained professionals in the fields of Engineering Geology and Geotechnology should be overcome by (a) organising on a regular basis, comprehensive field-oriented training and skill development programmes at the cutting-edge level; and (b) creating career opportunities for trained Engineering Geologists and Geotechnical engineers at all levels.

Recommendation 15

Give impetus to development projects in landslide-prone areas by organising regular joint crash programmes for senior professionals, development planners and decision makers

15.1 Implementation of development plans, regulated growth of new habitations, execution of landslide risk reduction programmes and such other activities would move much faster if bridges of understanding are built between teams of specialists, development planners, economists, decision makers and community leaders. National Institute of Disaster Management, Indian Institute of Public Administration, IITs, IIMs, GSI, CRRI, CBRI and other related research and knowledge institutions should organise crash joint training programmes to create common understanding and cross fertilisation of ideas between different players for speedy decision making and smoother project implementation.

15.2 To ensure holistic approach in management of landslide disaster risk reduction, the training institutes undertaking these crash joint training programmes on a regular basis should notify in advance the end objective, scope, contents and details of training materials, developed through a consultative process to all stakeholders.

9 There is a need to delete from the GSI proposed methodology a few visible points of disconnect between the suggested approach and the basic principles of geotechnology as highlighted in the Backgrounder5.

Recommendation 16

Promote Community-centric Early Warning Systems

Create pace-setting best practices of scientifically designed and implemented communitycentric early warning systems (EWS)

16.1 A Task Force of eminent experts (an Engineering Geologist and a Geotechnical Engineer included) should be given the responsibility of preparing the Indian State of the Art on EWS for Indian landslides, (a) by inviting full-length peer reviewed papers from the respective institutions/ authors specializing and engaged in EWS, and (b) by critically reviewing the papers so received with particular reference to the approaches followed, technologies deployed, established criteria for early warning thresholds established, data analysis softwares developed, and the community response. The status report of the EWS initiatives in India should be placed on the net for soliciting comments and thereafter deciding on the way forward.

16.2 The terms of reference of the above Task Force should include: (a) articulating the national vision based on felt needs and fullest appreciation of the global State-of The Art in early warning against landslides; (b) pinpointing of the deficiencies of ongoing initiatives and the lessons learned; (c) suggesting mechanisms for spreading the practice of prevention and early warning; (d) cataloguing of national priorities; and (e) preparing guidelines on community-centric, user-friendly EWS against landslides.

16.3 Experts and trainers entrusted with the responsibility of training communities should be trained first and then periodically tested for their competence and, wherever necessary, receive an advance-level training through specially designed senior-level training programmes and field visits.

16.4 The Central and State Governments should create at least one pace-setting example of early warning installation against landslides in each of the landslide-prone States in the next couple of years.

16.5 Early warning thresholds in a given hazardous area should undergo a rigorous scrutiny by an independent team of experts before their adoption for use.

16.6 Communities should be made fully aware of their expected roles and responsibilities, as they are being the first to respond in the times of crisis.

16.7 Unless there is a proposal is to permanently abandon the landslide disaster-prone area in question, EWS should also include the follow-up component of permanent mitigation measures, to save life and assets from possible recurrence of the landslide disaster.

Recommendation 17

Review, Revise and Strengthen Building Codes, Standards and Guidelines and add new codes to support landslide risk reduction initiatives

17.1 NDMA may assign to NIDM, the job of working closely with Professional Organizations like the IRC, IWRS, Indian Hydropower Association, INCOLD, INCID and BIS to ensure fasttrack revision of landslide related codes to bring them at par with the current international State of The Art on one hand, and of the Indian complexities of causative factors arising from developmental activities including urbanisation, industrialisation, on the other. Attention needs to be paid to elements like earthquake-induced landslides, landslide runout effects, glacial lake outburst floods, reservoir rim stability assessments, effects of urbanisation and implications of extreme weather events.

17.2 BIS Codes, Standards and Guidelines related to diverse aspects of landslides need review and revision. BIS Guidelines (1998) in 3 parts (reaffirmed in 2002) for preparation of landslide hazard zonation maps need revision in the backdrop of the complexities of the causative factors and their interplay. IS 14458, IS14496, IS14680, IS14804 and IS 14961, need review and revision as a package, to enable tapping the potential of new knowledge and design software. There is a need for drafting of some new codes, especially to ensure sound engineering practices in geotechnical investigation of landslides, elucidation of boundary shears, measurement of piezometric pressures on boundary shears, undisturbed sampling from landslide boundaries, simulated stress path testing for shear strength parameters, and stability analysis in terms of total and effective stress. The Government of India should consider granting one-time funding for BIS to fast track this work in close consultation with NCLM, National Institute of Disaster Management and other knowledge institutions.

17.3 Landslide disasters occur many a time, because of the non-engineered or illegal constructions. Law should enable enforcing the guidelines and codes with clearly defined unethical, immoral and illegal boundaries on the acts of omission and commission, beyond which the promoters of such actions can be made liable, held accountable by law and brought to justice.

Recommendation 18

Invest in Research and Development on a sustained basis

Accord the highest priority to R&D in landslide risk reduction and Prepare peer-reviewed monographs to document major case records of landslide disasters in India, and highlight lessons learned.

18.1 The highest priority and adequate funding should be accorded for advanced R&D in the hitherto neglected areas, some of which are (a) earthquake-induced landslides; (b) role of extreme weather events in landslide study, occurrence and behaviour; (c) approaches to landslide risk and damage assessment; (d) development of innovative technologies for effective utilisation of landslide waste; and (e) unfolding of fundamental mechanisms of the most problematic of Indian landslides. Additional candidate areas for research should be decided through brainstorming sessions.

18.2 Long-term funding for field-oriented R&D aimed at development of eco-friendly technologies for landslide management also deserves a high priority.

18.3 Government and funding agencies should pro-actively invite proposals from wellestablished teams of experts and assign projects for writing of comprehensive monographs on selected landslide tragedies, such as the Malpa rock avalanche of 17 August 1998, the Alaknanda tragedy of 20 July 1970 and the Kedarnath tragedy of 16 June 2013 to highlight lessons learned for wide-spread dissemination.

18.4 Scientific documentation and publication of peer-reviewed monographs on landslide disasters and success and failure stories should be encouraged and funded.

Operationalising Roundtable Recommendations – the key to success

Roundtable recommendations focus on the need and the urgency to bring about major improvement in the quality and content of professional practice, especially in respect of Engineering Geological and Geotechnical inputs to landslide investigations and risk mitigation in the country.

A careful examination of the set of recommendations which have emerged through the two high level roundtable meetings organized by the INAE reveals that, if implemented, both in letter and spirit, at policy, professional and administrative levels, the intended goal of bringing about very significant improvements in the current level of professional practice, and eventually the transformational change, is both realistic and achievable. The essential condition, however, is that simultaneously as the effort is made to press on with plans to strengthen capacities at all levels, an added attention is paid to certain structural measures that are critical for successful operationalization of these recommendations.

First of all, those engaged in and responsible for landslide risk reduction ought to feel the pain of complacency and must resolve to change systems where they hurt, as a part of their national obligation.

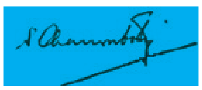
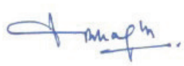
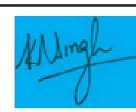
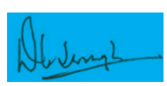
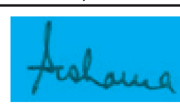
Secondly, a think tank should be created at the national level to ensure high quality domain expertise at NDMA to guide national affairs.

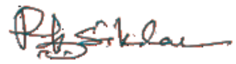
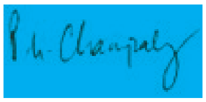
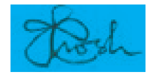
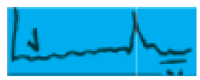
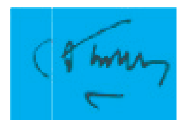
Thirdly, there is the need to invest in capacity building (State-of-The-Art Geotechnical testing facilities included) and ensure availability of expertise in the fields of Engineering Geology and Geotechnical Engineering in at least a few of the knowledge institutions in every landslide prone State.

And finally, the formally trained professional manpower capacity availability at State and District level Disaster Management Agencies must be enhanced, where the policy directives, projects and SOPs are to be implemented.

These may appear to be pre-conditions difficult to reconcile with but unless these critical issues are seriously addressed, it may not be possible to comeout of the quicksand of status quo. Without putting these critical structural measures in place, the current national dispensation to mitigate landslide disasters might remain inadequate and deficient.

Signatories of Recommendations unanimously approved at the INAE Roundtable meeting1 held on 11 May 2015

 **Prof N Vinod Chandra Menon** Formerly, Member National Disaster Management Authority, Government of India	 **Dr. V M Sharma, INAE** Formerly, Director Central Soil & Material Research Station, New Delhi	 **S C Sharma** P P Shrivastav, IAS (Retd.) Formerly, Member North Eastern Council
 **Prof Prem Krishna, FNAE** Formerly, Professor and Head of the Civil Engineering Department Indian Institute of Technology Roorkee	 **Prof D K Paul, FNAE** Emeritus Fellow Department of Earthquake Engineering Indian Institute of Technology Roorkee	 **P P Shrivastav, IAS (Retd.)** Formerly, Member North Eastern Council
 **Prof S S Chakraborty, FNAE** Chairman Emeritus Consulting Engineering Services India Pvt. Ltd. New Delhi	 **U K Guruvittal** Senior Principal Scientist CSIR-Central Road Research Institute	 Prof G V Rao, FNAE Former Professor Indian Institute of Technology Delhi
 **Jai Bhagwan** Chief Scientist & Area Advisor CSIR-Central Road Research Institute	 **Sudhir Mathur** Chief Scientist & Area advisor CSIR-Central Road Research Institute	 **Dr. Shantanu Sarkar** Senior Principal Scientist CSIR-Central Building Research Institute
 **Kanwar Singh** Senior Scientist CSIR-Central Road Research Institute	 **Dr. Kanungo** Principal Scientist CSIR- Central Building Research	 **K P Singh** Formerly, MD, RITES & MD Tata Projects
 **Dr. Surya Prakash** Associate Professor National Institute of Disaster Management, New Delhi	 Prof D V Singh, FNA, FNAE Formerly, Director Indian Institute of Technology Roorkee & Vice Chancellor University of Roorkee	 **T N Gupta** Formerly, Executive Director Building Materials Technology Promotion Council Government of India
 **V.K. Agarwal, FNAE** Formerly, Chairman Railway Board & Ex-officio Principal Secretary, Government of India	 **S C Sharma** Formerly, Director General (Road Development) and Additional Secretary to the Government of India	Prof Yudhbir Formerly, Professor Indian Institute of Technology Kanpur

 Professor N N Som, FNAE Formerly, Professor Department of Civil Engineering Jadavpur University Kolkata	 Professor P K Sikdar, FNAE President, Intercontinental Consultants and Technologies Pvt Ltd	 Dr. Kishor Kumar Chief Scientist & Area advisor CSIR-Central Road Research Institute New Delhi
 Dr. Champati Roy Indian Institute of Remote Sensing, Dehradun	 Dr. B C Rastogi Director General Institute of Seismological Research Gujarat	 Dr. Chandan Ghosh Professor, National Institute of Disaster Management, New Delhi
 Dr. R K. Bhandari, FNAE Chairman Forum on Engineering Intervention in Disaster Mitigation Indian National Academy of Engineering	 Dr. S. Gangopadhyay Director CSIR- Central Building Research Institute	 Dr. C D Thatte, FNAE Formerly, Secretary Water Resources, Government of India ,and Chairman, Roundtable Discussion meeting

The signatories of the Recommendations unanimously approved at the INAE Roundtable meeting 2 held on 4 November 2015

Dr. C D Thatte, FNAE
Formerly,Secretary
Water Resources Government of India, SecyGeneral, ICID

Prof N Vinod Chandra Menon
Formerly, Member
National Disaster Management Authority,
Government of India

Shri. V.K. Agarwal, FNAE
Formerly, Chairman
Railway Board & Ex-officio Principal Secretary, Government of India

Dr M. R. Bhutiyani
Director,
Defence Terrain Research Laboratory (DTRL)

04/11/2016

Mr M Raju
Addl. Director General
Geological Survey of India
Kolkata

04.11.15

Prof Prem Krishna, FNAE
Professor (retd.)
India Institute Of Technology Roorkee
Formerly Vice President INAE

Dr T N Gupta
Former E. D.
Building material and Technology Promotion Council
Govt of India

Prof T.G. Sitharam
Professor in Civil Engineering and KSIIDC Chair
Indian Institute of Science
Bangalore

Dr Kishor Kumar
Chief Scientist and Area Advisor
CSIR - Central Road Research Institute

04/3/15

Shri Ajay Kumar
Manager
THDCIL

Dr Champati Ray
Head, Geo Science Division
India Institute of Remote Sensing
Dehradun

सुनील धर

Shri Sunil Dhar
Addl. Director
DTRL , DRDO

Dr Dinesh Sati
Consulting Geologist
Freelance Consulting Geologist
Dehradun

Dr Debi Kanungo
Principal Scientist
CSIR - Central Building Research Institute, Roorkee

Dr Ravinder Singh
National Disaster Management Authority
Government of India

Prof D V Singh, FNA, FNAE
Formerly, Director
Indian Institute of Technology
Roorkee & Vice Chancellor
University of Roorkee, Roorkee

Prof V K Sharma
Vice-Chairman
Sikkim Disaster Management
Authority, Gangtok, Sikkim

Prof S S Chakraborty, FNAE
Chairman Emeritus
Consulting Engineering Services
India Pvt. Ltd.
New Delhi

Prof D K Paul, FNAE
Emeritus Fellow
Department of Earthquake
Engineering, Indian Institute of
Technology,
Roorkee

Dr G Sankar
Scientist G
Ministry of Earth Sciences
Government of India

Shri P P Shrivastav,
IAS(Retd.)
Former Member
North Eastern Council

Dr V M Sharma , FNAE
Former Director Central Soil &
Material Research Station

Prof Chandan Ghosh
Professor , National Institute of
Disaster Management , New
Delhi

Prof Debasis Roy
Department of Civil Engineering
IIT Kharagpur

Dr Shantanu Sarkar
Senior Principal Scientist
CSIR - Central Building Research
Institute , Roorkee

Dr Surya Prakash
Associate Professor
National Institute Of Disaster
Management, New Delhi

Prof Yudhbir
Former Professor
Indian Institute Of Technology
Kanpur

Prof Harish Chandra
Nainwal
Department of Geology
HNB Garhwal University
Srinagar Garhwal

Dr R K Bhandari , FNAE
Chairman,
INAE Forum on Engineering

Roundtable Meeting 1 on Landslide Risk Reduction

Technology Day: 11 May 2015; Venue: CSIR- CRRI, New Delhi

Programme

0930	**Pre-roundtable Session**
	Chair : Professor Vinod Menon, Founder Member, NDMA
	Welcome
	Finalization of the overall roundtable programme and its adoption
	Finalization of plan for Inaugural, Discussion and Valedictory Sessions
	Review of documents to be tabled at the roundtable Adoption of the Backgrounder 5, mutatis mutandis Session with BIS.
	Session on IRC Codes
	Closing remarks by the Chairman
	Vote of Thanks
1045	**Introduction of Participants with the Chief Guest**
1100	**Inaugural Session**
	Chief Guest : Gen. N.C.Vij , PVSM,UYSM,AVSM , Founder VC,NDMA
	Welcome of the Chief Guest and a brief introduction to the INAE Forum, and the objectives of the roundtable : Dr R.K.Bhandari, INAE Forum Short remarks by some of the participants
	Address by the Chief Guest
	Vote of thanks by Dr Gangopadhyay, Director CSIR-CRRI. Chief Guest departs
	Roundtable Discussion Session1
1210	Chairman: Dr C.D.Thatte, FNAE, Formerly Secretary, Ministry of Water Resources Welcome by Dr R.K.Bhandari
	Opening remarks by the Chairman
	Introduction to the documents tabled
	Discussion on the Backgrounder with focus on the draft recommendations
	Lunch break
1330	
	Roundtable Discussion Session 2
1400	Discussion on the draft recommendations (continued)
	Finalization of every individual recommendation through interactive discussion
1600	**Introduction of the Participants to the Chair of Concluding Session Concluding Session**
	Chairman : Dr Shailesh Nayak , Secretary, Ministry of Earth Sciences
1615	Welcome by Dr Gangopadhyay , Director CSIR-CRRI
	Presentation of Finalized Recommendations
	Address by the Chief Guest
	Vote of thanks by Dr R.K.Bhandari, INAE Forum
1730	**Signing of Recommendations**

Roundtable Meeting 2 on Landslide Risk Reduction

Venue: CSIR-Central Road Research Institute, Delhi Mathura Road, New Delhi

Wednesday: 04 November 2015

Programme

0900-0930	**Registration**
0930-0955	**Introduction to the Documents for the meeting and related clarifications**
1000 -1100	**Inaugural Session**
	Welcome: Dr S. Gangopadhyay, Director, CSIR-CRRI About the Roundtable and its Objectives : Dr R.K. Bhandari, Chairman, INAE Forum Interaction with the Delegates Presidential Address by Dr Prem Krishna, Former Vice President, INAE (On behalf of the President, INAE) Inaugural Address by the Chief Guest : Lt Gen N C Marwah , Member NDMA
1100-1115	**Vote of Thanks : Brigadier, Rajan Minocha , Executive Director, INAE**
1120-1400	**Tea Break**
1400-1430	**Roundtable Discussion** **Chair : Dr C.D.Thatte, FNAE**
1430-1630	**Lunch Break**
1630-1655	**Finalization of Recommendations**
1700-1745	**Tea Break**
	Valedictory Session
	Welcome of the Chief Guest and Presentation of Recommendations **Dr R.K. Bhandari, Chairman, INAE Forum** **Interaction with the Delegates** **Felicitation of Dr S. Gangopadhyay, Director, CSIR-CRRI** **Valedictory Address by the Chief Guest : Dr T. Ramasami, Former Secretary, DST** **Vote of thanks: Dr Kishor Kumar, Co-Cordinator**

Roundtable Meeting 1
on Engineering Interventions in Landslide Risk Reduction

Date: 11 March 2015

List of Participants

1. General N.C.Vij, PVSM, UYSM, AVSM, Former Chief of Army Staff and VC, NDMA
2. Dr Shailesh Nayak, Secretary, Ministry of Earth Sciences.
3. Professor Vinod Menon, Formerly Member, NDMA
4. Dr C.D.Thatte, FNAE,Formerly, Secretary , Ministry of Water Resources
5. Dr Subhamay Gangopadhyay, Director, CSIR-CRRI, Delhi
6. Professor S S Chakraborty, Chairman, CES, New Delhi
7. Shri V.K. Agarwal, FNAE, Former Chairman Railway Board, Gudgaon
8. Shri S.C. Sharma, Former, DG RD and Additional Secretary , GOI
9. Professor Prem Krishna, FNAE, Chairman, Research Council of CSIR-CBRI
10. Professor D.K.Paul, FNAE,Emeritus Fellow, IIT, Roorkee
11. Professor D.V.Singh, FNAE, FNAE, Former Director, IIT, Roorkee
12. Dr. V.M. Sharma, FNAE, Former Director, CSMRS, New Delhi
13. Professor P.K.Sikdar, FNAE, Former Director, CSIR-CRRI , New Delhi
14. Shri K. P. Singh, Former M.D.RITES and M.D Tata Projects
15. Professor N.N. Som, FNAE, Formerly, Professor, Jadavpur University
16. Professor G.V.Rao, FNAE, Former Professor, IIT, New Delhi
17. Shri P P Shrivastav, IAS, Former Member, NEHC
18. Professor Yudhbir, Formerly, Professor, IIT, Kanpur
19. Dr B.C.Rastogi, Director General, ISR, Ahmadabad
20. Professor R.Nagarajan, IIT, Bombay
21. Dr Champati Ray, IIRS
22. Professor Chandan Ghosh, Professor, NIDM
23. Dr Kishor Kumar, Chief Scientist, CSIR-CRRI
24. Dr Sudhir Mathur, Chief Scientist, CSIR- CRRI
25. Shri Jai Bhagwan, Chief Scientist, CSIR-CRRI
26. Shri U K Guruvittal, Senior Principal Scientist CSIR-CRRI

27. Dr Sanjay Pant, Bureau of Indian Standards
28. Dr Surya Prakash, Associate Prof NIDM
29. Dr Santanu Sarkar, Senior Principal Scientist CSIR-CBRI
30. Dr D Kanungo, Principal Scientist, CSIR-CBRI
31. Dr R.K.Bhandari, FNAE, Chairman, INAE Forum

INAE Secretariat

1. Brigadier Rajan Minocha, Executive Director, INAE
2. Dr Geetanjali Sawhney
3. Shri Ramachandran EP

Roundtable Meeting 2
on Engineering Interventions in Landslide Risk Reduction

Date: 11 March 2015

List of Participants

1. Lt. General N.C. Marwah, Member, NDMA
2. Dr T.Ramasami, FNA, FNAE, Former Secretary, Department of S&T
3. Professor Vinod Menon, Formerly Member, NDMA
4. Dr C.D.Thatte, FNAE, Formerly, Secretary, Ministry of Water Resources
5. Dr Subhamay Gangopadhyay, Director, CSIR-CRRI, Delhi
6. Professor S S Chakraborty, Chairman, CES, New Delhi
7. Shri V.K. Agarwal, FNAE, Former Chairman Railway Board, Gudgaon
8. Shri S.C. Sharma, Former, DG RD and Additional Secretary, GOI
9. Professor Prem Krishna, FNAE, Chairman, Research Council of CSIR-CBRI
10. Professor D.K.Paul, FNAE,Emeritus Fellow, IIT, Roorkee
11. Professor D.V. Singh, FNAE, FNAE, Former Director, IIT, Roorkee
12. Dr R.K.Bhandari, FNAE, Chairman, INAE Forum
13. Dr M. Raju, Additional Director General, GSI, Kolkata
14. Shri T.N. Gupta, Former Executive Director, BMTPC
15. Dr. V.M. Sharma, FNAE, Former Director, CSMRS, New Delhi
16. Professor T.G. Sitharam, Professor, Indian Institute of Science, Bangalore
17. Shri K. P. Singh, Former M.D.RITES and M.D Tata Projects
18. Professor H.C.Nainwal, Professor of Geology, Garhwal University
19. Shri P P Shrivastav, IAS, Former Member, NEHC
20. Professor Yudhbir, Formerly, Professor, IIT, Kanpur
21. Dr G.Sankar, Scientist G, Ministry of Earth Sciences
22. Dr Champati Ray, IIRS
23. Professor Chandan Ghosh, Professor, NIDM
24. Dr Kishor Kumar, Chief Scientist, CSIR-CRRI
25. Dr Saibal Ghosh, Geological Survey of India, Kolkata
26. Dr Surya Prakash, Associate Prof NIDM

27. Dr Santanu Sarkar, Senior Principal Scientist CSIR-CBRI
28. Dr D Kanungo, Principal Scientist, CSIR-CBRI
29. Dr Ravinder Singh, NDMA
30. Dr Dinesh Sati, Consulting Geologist, Dehradun
31. Dr Sunil Dhar, DTRL, New Delhi
32. Professor Debasis Roy, IIT Kharagpur
33. Dr Ajay Kumar, Manager, THDCIC

INAE Secretariat

1. Brigadier Rajan Minocha, Executive Director, INAE
2. Dr Geetanjali Sawhney
3. Shri Ramachandran EP

Abbreviations

Abbreviations	Full Form
NMC	Natural Moisture Content
NDMA	National Disaster Management Authority
NIDM	National Institute of Disaster Management
STI	Science Technology and Innovation
NRSC	National Remote Sensing Centre
IIRS	Indian Institute of Remote Sensing
WCE	Working Committee of Experts
IAEG	International Association for Engineering Geology
ICL	International Consortium on Landslides
JTC	Joint Technical Committee
NCLRSM	National Centre for Landslide Studies and Management
GLOF	Glacial Lake Outburst Floods
GSI	Geological Survey of India
DRDO	Defence Research and Development Organisation
ISRO	Indian Space Research Organisation
CSIR	Council of Scientific And Industrial Research
CSIR-CRRI	Central Road Research Institute
CSIR-CBRI	Central Building Research Institute
INAE	Indian National Academy of Engineering
BIS	Bureau of Indian Standards
DEMs	Digital Elevation Models
LSZ	Landslide Susceptibility Zonation
GIS	Geographic Information System
CWC	Central Water Commission
NLSM	National Landslide Susceptibility Mapping
CDMM	Centre for Disaster Mitigation and Management
DTRL	Defence Terrain Research Laboratory
SOP	Standard Operating Procedure

References

Report of the High Power Committee on Disaster Management, Department of Agriculture and cooperation, Ministry of Agriculture, GoI, for National Centre for Disaster Management, October, 2021

Indian National Academy of Engineering

The Indian National Academy of Engineering (INAE), established on April 20, 1987 as a Society under the Societies Registration Act, is an autonomous professional body. INAE was formally inaugurated on 11th April 1988 at New Delhi by the Hon'ble Prime Minister of India. It is supported partly through grant-in-aid by the Department of Science & Technology, Government of India since 1995. INAE comprises India's most distinguished engineers, engineer-scientists and technologists covering the entire spectrum of engineering disciplines.

INAE was established with the mission of providing vital inputs to the planning for the country's development, particularly related to engineering and technological content and depth. The Academy provides a forum for futuristic planning for country's development requiring engineering and technological inputs and brings together specialists from such fields as may be necessary for comprehensive solutions to the needs of the country.

INAE honours Indian and Foreign nationals who are elected by "peer" committees in recognition of their personal achievements in "Engineering" which are of exceptional merit and have demonstrated distinctive eminence in the new and developing fields of technology. In December 2022, INAE has 927 Fellows from India and 99 Foreign Fellows on its rolls identified in ten Engineering Sections. As the only engineering Academy of the country, INAE represents India at the International Council of Academies of Engineering and Technological Sciences (CAETS); a premier non-governmental international organization contributing to the advancement of Science & Technology and sustainable economic growth. INAE has a three-tier interaction with the engineering and technological community, through eminent engineers and technologists who are elected as Fellows, Young Associates and Student Members. The Academy undertakes a large number of meaningful technical activities each year, which have enhanced its visibility in the national engineering domain. The activities of the Academy are carried out through the Fellowship and Young Associates supported by a lean team of professionals at INAE Headquarters.