National Cyclone Risk Mitigation Project (NCRMP)

National Disaster Management Authority (NDMA)

Consulting Services for Hazard, Risk and Vulnerability Assessment for 13 states and UT's in India

Inception Report

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Submitted by

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Executive Summary

The Indian coast is highly vulnerable to natural hazards, particularly to severe cyclones and cyclone induced heavy rain and flooding. The National Cyclone Risk Mitigation Project (NCRMP) is a pioneer project of the Ministry of Home Affairs (MHA), Government of India (GOI) and is being implemented through NDMA with the financial support of the World Bank. The aim of NCRMP is to create suitable physical infrastructure to mitigate/reduce the adverse effects of cyclones. The study is a part of the NCRMP project and aims to carry out Hazard, Vulnerability and Risk Assessment (deterministic approach) of cyclone hazard for the 13 coastal States/UTs of India. As part of the study, it is expected to develop a standardized spatial database maps and a web-based GIS Atlas for decision support that will help decision makers in the States/UTs and Central Government to take mitigation steps to protect the people and assets in these coastal regions.

The study area includes the coastal stretches that lie up to 10 m MSL in the districts of the 13 States/UTs, which are vulnerable to cyclone hazard. These 13 States/UTs will be further classified into two categories, based upon the frequency of cyclone occurrence, size of population and the existing institutional mechanism for disaster management. The categories are as follows:

Category I: Higher vulnerability coastal States/UTs, i.e., Andhra Pradesh, Gujarat, Orissa, Tamil Nadu, and West Bengal

Category II: Lower vulnerability coastal States/UTs, i.e., Maharashtra, Goa, Karnataka, Kerala, Daman & Diu, Puducherry, Lakshadweep, and Andaman & Nicobar Islands

RMSI will carry out the hazard mapping and risk assessment for two pilot States – Andhra Pradesh and Odisha and will present the findings and beta version of DSS to the PMU and the key stakeholders for their feedback.

The present report, the inception report, is the first deliverable of this assignment, and includes review of best practices, methodology proposed for the study, deliverables and timelines. The best practice review is divided into three sections – cyclone/storm surge model, flood model, and web GIS application for risk assessment. Each of these sections explains the best models/applications being used elsewhere, discusses their strengths and weaknesses and concludes by bringing out the best suitable practices that can be adopted for this study.

The cyclone/storm surge model shows that almost all the best models use a combination of various methods and tools to drive the storm surge model. These include cyclone frequency and severity analysis, assessment of wind fields and surge heights and associated flood inundation mapping. For the present assignment, we propose to use the ADCIRC storm surge model along with the customized RMSI model.

In the case of flood hazard, flood due to cyclone induced heavy rain in the study area will be considered. The best models use rainfall analysis, hydrological assessment for rainfall runoff relationships, hydraulic modeling for flood inundation mapping. RMSI‟s approach uses the HEC packages as applied by most open source models as per the requirement of this study. Some of our study areas also include major urban centers such as Chennai, which is highly flood prone and an ideal case for two-dimensional flows. So following this, we are proposing to use two-dimensional hydraulic model CCHE 2D, which is also in open source.

For the Decision Support System (DSS) application for risk assessment, RMSI proposes the web GIS based software, which will be developed on Geonode technology similar to CAPRA Software Initiatives. GeoNode is an open source platform that facilitates the creation, sharing, and collaborative use of geospatial data. It is a spatial data infrastructure solution that extends the OpenGeo architecture with catalog functionality and a sophisticated user interface that will be further customized and is extended.

Our approach for risk assessment will be to apply the identified best risk assessment practices by adapting them to Indian conditions and engaging the key stakeholders in all the key project activities. Information dissemination and capacity building through training and workshops is a key component of the project. The following are the key methodological steps involved for the study.

Hazard mapping: The base for hazard mapping and profiling will emphasize on the severity, frequency and geographical extent of the cyclone hazard and flood hazard due to cyclone induced heavy rainfall. We will use established scientific and robust methodologies based on the best practices review. Hazard information on Historical cyclone track data will be used for analysis and developing the model. RMSI will use the ADCIRC as the primarily model to for modeling the winds and surge associated with cyclones and will use RMSI model for validation purposes. Using historical tracks, wind field and associated parameters, dynamical simulation of storm surges will be carried out by making use of the location specific model. The maximum surge height computed with the model will be calibrated/validated against observed data. The tidal amplitudes and an wave setup will be linearly added to the maximum surge amplitudes, to determine the maximum possible sea level inundation associated with the tropical cyclones at each coastal grid point (spaced at 5-10 km along the coast) of the numerical model. Finally, scenarios of storm surge flooding due to probable maximum surge amplitude will be prepared for all the return periods used in the statistical analysis for the selected districts to identify the flood-prone extent delineation.

Flood hazard will be assessed for major river systems across the study area to estimate the potential inundation from cyclone induced rainfall floods. A deterministic approach will be used to combine the information on (1) the scenarios of flooding, (2) the spatial extent of floods for different severity levels, and (3) the consequences of these floods (e.g. inundated area, and flood depth). Based on data availability, an appropriate approach shall be adopted. In case of flow/discharge data availability, the flood hazard shall be determined using the hydraulic model approach as given in the steps below. These steps include: i) disaggregation of flow/discharge due to impact of cyclone, ii) simulation of deterministic events, iii) two dimensional inundation model (hydraulic modeling), iv) calibration and validation of flood extents, v) derivation of flood extent maps.

Exposure data development: RMSI will emphasize on using the existing spatial and non-spatial data available with various State and National organizations for the compilation of exposure database. The exposure database will essentially consist of demographics, buildings, infrastructure, critical facilities, utilities, cultural heritage sites, and soil and ecological assets. RMSI, with the support PMU, will work with all State and National organizations to collect required data related to exposure. RMSI will carry out sample field surveys for verification of landuse/lancover data collated from various organizations.

For physical vulnerability analysis inputs, RMSI team will carry out a sample survey for housing, commercial buildings and infrastructure. Statistically significant sample will be selected with representation from all types of buildings, which is required for understanding the structural vulnerability by building types. Taking into consideration the entire households in the talukas of the study area (census data) and applying the Analytical Hierarchy Process and weighted ranking technique (weightage applied for hazard as well as roof and wall type of the houses), the total sample household arrived is 2,287 for the structural vulnerability survey, which will be spread across 10 highly vulnerable districts. Except Junagadh district of Gujarat, all other districts are located on the east coast of India.

For exposure data, analysis will mainly follow aggregate data at taluka level. The site-specific information collected through sampling survey will be applied to the entire study area and aggregate level data (mainly from secondary sources) will be organized in GIS for further risk analysis.

Vulnerability assessment: Vulnerability assessment will involve quantifying the damage susceptibility of each class (physical, social, and economic) with respect to the hazard parameters of each hazard. Development of vulnerability functions for the study area will be mainly, but not solely, based on damage data from historical events. An analytical approach complemented by engineering analyses along with expert judgment based on international experience will help in developing vulnerability functions. RMSI team shall work closely with research and scientific organizations to integrate local experiences such as existing building codes, construction practices in general, cultural aspects related to coastal communities, etc. It has been learnt that some of the institutions have worked on the building codes and structural vulnerability aspects. In addition, for specific coastal areas, discussions with key authorities and engineers' associations will be undertaken to understand and document the use of building codes, technical standards for utilities and other infrastructure elements to develop a better understanding of vulnerability. This association will help in deriving more country-specific vulnerability functions.

Damage susceptibility associated with a given level of hazard is measured in terms of a mean damage ratio (MDR) defined as the expected proportion of the monetary value of repair needed to bring back the facility to pre-event condition, over the replacement value of the facility, as a consequence of the hazard. The curve that relates the MDR to the hazard is called a vulnerability function. Vulnerability functions shall be developed for various assets for different perils, using analytical/synthetic and statistical methods complemented with expert engineering or heuristic judgment based on local and/or international experiences.

Social vulnerability analysis will be based on social indicators like population density, gender, children, aged and disabled. GIS based social indicator maps will be developed using the 2011 Census data. Community based vulnerability survey will be carried out in the hotspot location to detailed social vulnerability analysis for the 10 hotspot locations.

Risk Assessment: RMSI shall apply its local and global experience of catastrophe risk assessment for carrying out the risk assessment exercise. The risk assessment shall consider the hazard, vulnerability, and exposure and spatial resolution. Teams will perform the risk assessment at the highest resolution administrative level village or panchayat, which can easily be scaled to mandal, taluka, district, and state levels. Risk Analysis will be carried out in two broad categories: Direct Economic Loss and Social Impact. Direct economic loss will be calculated for every deterministic scenario and for all types of exposures at risk like residential, commercial, industrial buildings, essential facilities, infrastructure and others. Social impact is the quantification of susceptibility of population to mortality and injuries, and needs like shelter, food, rescue/evacuation etc. in the event of a disaster. Finally, risk metrics will be derived as described in the risk assessment section of this proposal. These risk metrics will be estimated for all categories of assets including demography or population. Using risk metrics, vulnerable hotspots will be identified and mapped.

Development of web-based GIS Atlas: Using the outcomes of study and various data, a Web-GIS based dynamic Composite Risk Atlas will be developed based on Geonode technology. This shall include the various data sets such as remote sensing images, DEM, hazard, exposure, vulnerability and hot spot risk maps. The composite risk atlas shall provide a framework for specific decision support needs (evacuation planning, shelter needs, etc.)

The above approach will be first applied to the two Category-I states selected at the time of inception. Once the Risk Assessment and Risk Atlas are finalized for the selected states, the whole process will be replicated for the other states under the study.

Identification of 10 hotspot locations: The identification of 10 hotspots will be based on the risk assessment exercise for the whole study area. The hotspots will be identified based on vulnerability and risk. Detailed field investigations will be carried out in these 10 hotspots for further micro level investigation on exposure and vulnerability for preparing a detailed risk assessment of the hotspot locations. The panchayats/villages will be considered as the administrative units for the hotspot analysis.

Capacity building and information dissemination: The information dissemination will be through state level consultation, training and workshops. During the training sessions, RMSI will demonstrate the model development, data creation, and risk assessment to the key stakeholders. The team will also demonstrate the web-based GIS application development for data storage and decision support.

Final outcomes of study will be disseminated through workshops to all the stakeholders. The workshops will be conducted in three parts. First national workshop will include the beta testing of the Composite Risk Atlas to get feedback. Second national workshop will be held after addressing the feedback on the beta version of the Composite Risk Atlas. This will be a demonstration to a wider audience. Immediately after the second workshop, state level outreach training shall be conducted. This will provide the state level stakeholders a comprehensive training on the use of the risk atlas for future operations. Final national level workshop will be conducted as a part of the closure and handing over of the Atlas to the state and national users. Based on the feedback and subsequent modifications, the final report will be submitted.

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Abbreviations Used

Abbreviation	Expanded Form
ADCIRC	ADvanced CIRCulation
AHP	Analytical Hierarchy Process
ASI	Archeological Survey of India
AIT	Asian Institute of Technology
BMTPC	Building Materials and Technology Promotion Council
CAPRA	Central America Probabilistic Risk Assessment
CCHE	Centre for Computational Hydroscience and Engineering
CR	Consistency Ratio
CWC	Central Water Commission
DAD	Development Assistance Database
DEM	Digital Elevation Model
DRM	Disaster Risk Management
DSS	Decision Support System
DTM	Digital Terrain Model
FARL	Flood Attenuation by Reservoirs and Lakes
FD	Finite Difference
FE	Finite Element
FIA	Federal Insurance Administration
FEMA	Federal Emergency Management Administration
FIT	Flood Information Tool
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
GOI	Government of India
HEC	Hydrological Engineering Centre
HEC-RAS	Hydrologic Engineering Centre – River Analysis System
HMS	Hydrological Modeling System
HTTP	Hyper Text Transfer Protocol
HVRA	Hazard Vulnerability and Risk Assessment
IBTrACS	International Best Track Archive for Climate Stewardship
ICMAM	Integrated Coastal and Marine Area Management
ICZMP	Integrated Coastal Zone Management Project
IDRN	India Disaster Resource Network
IE	Internet Explorer
IITD	Indian Institute of Technology Delhi
IMD	Indian Meteorological Department
INCOIS	Indian National Centre for Ocean Information System
IPET	Interagency Performance Evaluation Task
JTWC	Joint Typhoon Warning Center
LULC	Land Use Land Cover
MDR	Mean Damage Ratio
MEOW	Maximum Envelopes of Water
MHA	Ministry of Home Affairs
MnHPRA	Morocco Natural Hazards Probabilistic Risk Assessment
MoEF	Ministry of Environment and Forest
MSL	Mean Sea Level
NATMO	National Atlas & Thematic Mapping Organization
NBSS&LUP	National Bureau of Soil Survey and Land Use Planning
NCRMP	National Cyclone Risk Mitigation Project
NDMA	National Disaster Management Authority
NED	National Elevation Dataset
NGDC	National Geophysical Data Centre
NHAI	National Highway Authority of India

NHC	National Hurricane Centre
NHO	National Hydrographic Office
NIOT	National Institute of Ocean Technology
NOAA	National Oceanic and Atmospheric Administration
NOI	National Oceanographic Institute
NRSC	National Remote Sensing Centre
NSSO	National Samples Survey Organization
NUIS	National Urban Information System
NWP	Numeric Weather Prediction
OGC	Open Geospatial Consortium
PacRIS	Pacific Risk Information System
PCA	Principle Component Analysis
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PDC	Pacific Disaster Centre
PDSS	Puducherry Decision Support System
PICs	Pacific Island Countries
PMU	Project Management Unit
POM	Princeton Ocean Model
PWD	Public Work department
QC	Quality Control
Q-Q	Quantile-Quantile
RAS	River Analysis System
RIA	Rich Internet Applications
RMS	Risk Management Solution
RQE	Risk Qualification and Engineering
SDI	Spatial Data Infrastructures
SICOM	Society of Integrated Coastal Management
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SOA	Service Oriented Architecture
SOI	Survey of India
SOPAC	South Pacific Applied Geoscience Commission
SoVI	Social Vulnerability Index
SPC	Secretariat of the Pacific Community
SQA	Software Quality Analyst
SRS	System requirement Specification
SRTM	Shuttle Radar Topography Mission
STWAVE	Steady-State Spectral Wave Model
SWAN	Simulating WAves Nearshore
USACE	U.S. Army Corps of Engineers
UH	Unit Hydrograph
UNDP	United Nations Development Programme
UN ISDR	United Nations International Strategy for Disaster Reduction
UNESCO	United Nations Educational, Scientific and Cultural Organization
USA	Unite State of America
USACE	US Army Corps of Engineers
WMO	World Meteorological Organization
WMS	Web Mapping Services

1 Introduction

1.1 Background

The Indian coast is highly vulnerable to natural hazards, particularly to severe cyclone and cyclone induced heavy rain and flooding. An estimated 40% of the total population lives within 100 km of the coast. India is taking initiatives to develop a proactive approach in integrating disaster mitigation in development planning.

The National Cyclone Risk Mitigation Project (NCRMP) is a pioneer project of the Ministry of Home Affairs (MHA), Government of India (GOI) and is being implemented through NDMA with the financial support of the World Bank. The aim of NCRMP is to create suitable physical infrastructure to mitigate/reduce the adverse effects of cyclones. Part of this involves the setting up of a web-based risk assessment system that will inform a risk management framework for decision makers in the States/UTs and the Central Government to take mitigation steps to protect the people and assets of the country.

1.2 Objectives of the Study

The objective of the study is to provide a robust scientific and practical basis for assessing qualitative and quantitative risk for cyclone hazard for the 13 coastal States/UTs of India. The main objectives of the study include:

- Develop standardized spatial databases, maps and a decision support framework for assessing the cyclone and related hydro-meteorological hazards, exposure, and vulnerability.
- Identification of critical "hot-spot" high vulnerability coastal areas for communities' at-risk and detailed development of planning/mitigation and emergency response decision support mechanisms in 10 of the top identified "hot- spot" areas (enable support for land use planning, shelter locations, evacuation routing, and emergency and contingency planning within these hotspot communities).
- Developing a platform for dynamic risk assessment modeling functionalities that will be taken up subsequently under Phase II of the NCRMP Project. (Deterministic hazard and vulnerability data to risk modeling shall be done for phase – I, Probabilistic risk modeling shall be done for phase – II).

1.3 Study Area and Scope of the Study

1.3.1 Study Area

The study area includes the coastal stretches that lie up to 10 m MSL in the districts of the 13 States/UTs, which are vulnerable to cyclone hazard. For the convenience of data access and subsequent project activities, we will consider all the talukas falling within the 10 m contours from Mean Sea Level (MSL). Even if only a portion of the taluka lies up to 10 m MSL limit, the entire taluka will be considered. The total number of talukas, which have land area up to the 10 m MSL limit, is 617; and the names of these selected talukas are provided in Table 8-1 in Annexure 1 and are shown in Figure 1:1. The total area covered by these talukas is around 2,55,000 sq km.

These 13 States/UTs will be further classified into two categories, based upon the frequency of cyclone occurrence, size of population and the existing institutional mechanism for disaster management. The categories are as follows:

Category I: Higher vulnerability coastal States/UTs, i.e., Andhra Pradesh, Gujarat, Orissa, Tamil Nadu, and West Bengal

Category II: Lower vulnerability coastal States/UTs, i.e., Maharashtra, Goa, Karnataka, Kerala, Daman & Diu, Puducherry, Lakshadweep, and Andaman & Nicobar Islands.

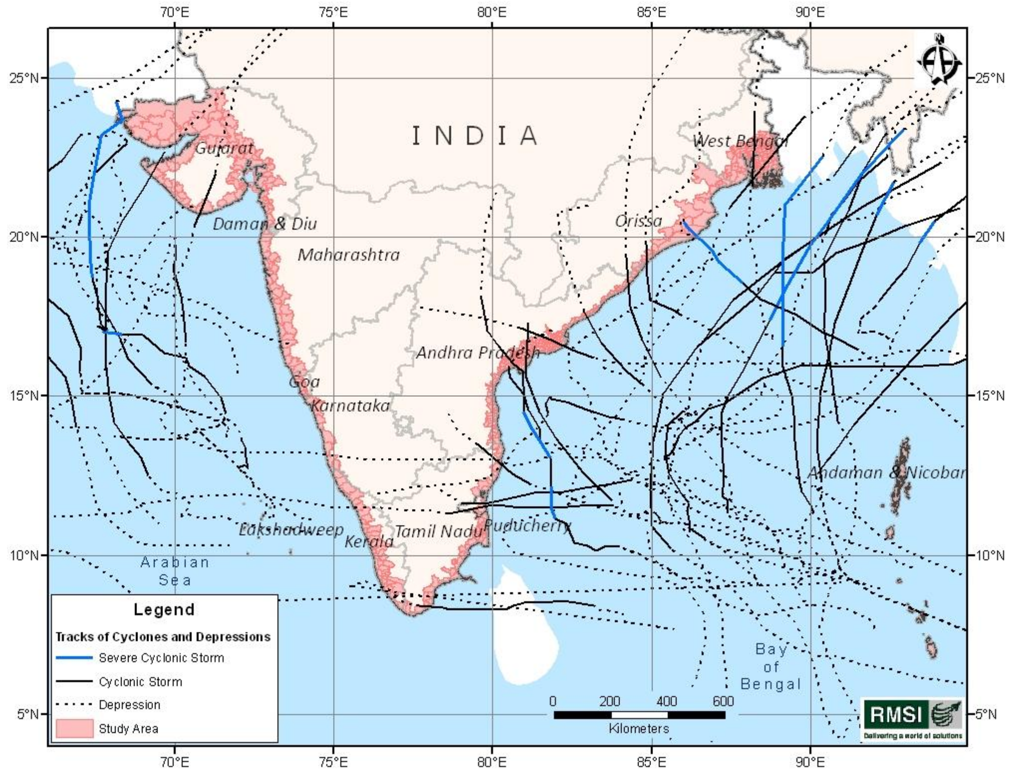


Figure 1:1: States'/UTs' coastal talukas with land area falling up to the 10 m MSL limit along with major cyclone tracks

1.3.2 SCOPE OF THE STUDY

The Scope of Services for the hazard, exposure and vulnerability assessments that will underpin the Composite Risk Atlas for the coastal districts of the 13 coastal States/UTs is provided in the next section and subsections.

1.3.2.1 Best practice review and user requirements

The study evaluates past and ongoing studies of cyclone modeling, hazard, vulnerability and risk assessment in the context of India, and identify best limitations (if any), and recommend improvements with reference to current international best practices. As part of the best practice review, assess their relevance to the NCRMP risk model (for example, in terms of methodology, integration into the system). Consult with the Project Technical User group to confirm decision support requirements and Use Cases, and through this process identify candidates to work with during prototype development.

1.3.2.2 Methodology development

Based on a worked example for one selected area, establish a robust, scientifically founded methodology for assessing multi-peril cyclone hazard, exposure, vulnerability and risk within the 13 States/ UTs, in consultation with the NDMA, SDMAs, the Relief Commissioners, other key stakeholders and current best practice. The methodology will consider risk assessment needs at a hierarchy of spatial scales from macro to micro, spanning state/district/mandal/taluka/village/habitation levels.

1.3.2.3 Data review

Identify and evaluate the utility of pre-existing hazard, exposure and vulnerability data sources for the study area that includes (but is not limited to): scientific data; nationally held data (e.g. NRSC, SOI); DEM datasets; high velocity wind, storm surge, heavy rainfall, and flooding data and maps; census databases; data available with the states; other independent sources of population density data, building inventory and other socio economic databases; damage scales; and local survey results. The observations and suggestions of various research studies on cyclone vulnerability and storm surge in a particular area along with storm surge modeling database developed by National Agencies like INCOIS, NRSC, ICMAM, IMD etc and area specific studies undertaken by State Governments must be integrated while preparing the risk atlas. As per the approval of the Review Committee: (i) suite of "standard" datasets that will be provided by the consultant as a minimum support for the identification of "hotspot" at-risk communities; and (ii) a list of enhanced "higher" resolution datasets that facilitate planning and mitigation decision support within these communities, using a federated architecture (see Section 3.2.9) can be stored locally but accessed through the centralized system (e.g. high resolution DEM datasets already held by the States/UTs).

1.3.2.4 Data standards

Propose and justify data standards and a database structure for hazard, exposure, vulnerability and risk. This should take into account best practice standards being developed through other risk management initiatives (e.g. data standards being used by national agencies like NRSC, SoI, etc., GEM, Digital Coast, ADCIRC, CAPRA,).

1.3.2.5 Data updates

Suggest mechanisms for ensuring that hazard, exposure and vulnerability assessments are updated on a regular basis.

1.3.2.6 IT system specification

Working with the Technical User Group, conduct a technical review of existing risk management tools being used by Indian organizations (e.g. INCOIS, APSDMS, ICMAM – who is using ADCIRC for storm surge modeling) and International risk management tools (e.g. Digital Coast, CAPRA, CDMIS, the Geonode suite, ArcExplorer, Open Platform as a basis for establishing a federated NCRMP risk management platform that allows shared, low-cost access, while providing States/UTs with local storage for pre-existing data within their own partitioned sub-system. Propose a functional system architecture and detailed system specification (both centrally at NDMA and distributed within the States/UTs) that takes into consideration federation, Phase I system priorities and user requirements, establishes a web GIS-based 'Geonode' like platform as the basis of the Composite Risk Atlas, and makes design considerations for future Phase II requirements for dynamic modeling and decision support. The system should be open and utilize existing Indian databases and infrastructure. Early adopters shall be identified for iterative consultation and testing.

1.3.2.7 Documentation and guidelines

Produce a quality publication Technical User Guide for the Composite Risk Atlas and underlying hazard, exposure, vulnerability and risk data. The User guide should be simple, practical and include discussions of the delineation of hazard zones with standard terminologies and examples of the application of the information for physical planning. Produce operationally-focused Decision Support Guidelines aimed at key NDMA, SDMA and DDMA personnel who will be using the system.

1.3.2.8 Training

Produce a Training and Capacity Building plan and relevant materials aimed at key personnel within each of the coastal States/UTs. The training should focus on: (a) operational scenarios where the Composite Risk Atlas will be used; (b) practical use of the

Atlas; (c) federated and collaborative use of the system. The identification of officials to be trained will be done in consultation with the PMU NCRMP NDMA, which shall then conduct the training program for these officials. Consultants will be required to carry out at least three training sessions.

1.3.2.9 Hazard assessment

1.3.2.9.1 Historical review

Collect and analyze historical information on cyclone hazard and related hydro-meteorological risks like high velocity (cyclone) winds, storm surge, flooding on lower areas and regions close to water bodies, hazards associated with heavy rainfall (volume and rate of precipitation) etc., inundation due to storm surge and flooding caused by cyclone induced rain that have occurred in the coastal States/UTs in the past (for example, major occurrences in the past 100 years) in terms of their nature, geographical distribution, severity, frequency and duration.

1.3.2.9.2 Data collection

For all spatial and non-spatial data, collect and produce an inventory of relevant pre-existing datasets from National and State level agencies, including an evaluation of whether pre-existing data are fit-for-purpose, and where this is not the case, propose alternative sources. These data might include digital topographic maps from the Survey of India, storm surge and flood return heights/periods on 13 States/UTs coastal districts and BMTPC (Building Materials and Technology Promotion Council) datasets etc. Bathymetric data already being utilized by SOI/INCOIS should be considered, together with topographic data held by NRSC. The Atlas interface should be able to incorporate higher resolution topographic data (e.g. ICZMP) once it is made available. In all cases, processing required for integration into the hazard database should be fully documented.

1.3.2.9.3 Hazard maps

Define a methodology and prepare digital hazard maps for disaster prone areas, justifying selected hazard levels (e.g. 1:100 year standards) and classification/zonation schemes. Maps should also consider the scenario where hazard levels are the result by physical effects (rainfall etc) that span the boundaries of several states.

1.3.2.10 Exposure and vulnerability assessment

1.3.2.10.1 Vulnerability classes

Conduct a detailed review and quantification of vulnerability classification schemes for physical, social and economic parameters. Define and apply cyclone-specific vulnerability classes (i.e. levels of susceptibility or threat) for the geospatial exposure databases developed in Scope of Service as detailed in Section 1.3.2. Assigned vulnerability classes shall be reviewed and finalized in conjunction with the project review committee.

1.3.2.10.2 Review available exposure databases

Review available databases for exposure and vulnerability assessment, utilizing most-up-to-date resources (e.g. census 2011) for the following physical, social and economic parameters, produce geospatial exposure databases and maps according to the standards and methodology defined as per Section 3.2.4, classified according to the vulnerability classes given in Section 3.2.4. The feasibility of vector data inclusion may also need to be assessed. Vulnerabilities proposed to be covered include:

Physical (Geo-spatial information of the following)

1. Buildings, infrastructure including roads, bridges, railway lines, ports, inland water transports, embankments etc.

2. Critical infrastructures including hazardous material storage structures, power plants etc.
3. Specific cases of low vulnerability structures that could be candidates for shelters or vertical evacuation.
4. Critical and high-risk facilities including: administrative headquarters; police stations, hospitals, schools, existing cyclone/flood shelters, major and hazardous industrial facilities, power plants and sensitive installations etc.
5. Utilities including: water, electricity, telecommunication etc.
6. Landuse (agricultural, open space, industrial areas etc.) as per NUIS standard.
7. Cultural heritage sites
8. The type of soil-strata (granular soil may be eroded in receding flooding due to storm surge. The problem may not be that severe in cohesive soils).
9. Ecological assets (Mangroves, coastal plantations etc.)

Social data and maps:

1. Total population – habitation/village/block/district
2. Density of population
3. Gender
4. Children (below the age of 14 years)
5. Aged (above the age of 60 years)
6. Disability, both physical and mental
7. Listing of "social capital" organizations (during emergency response) for "hot-spot" communities wherever data is available

Economic data and maps:

1. Livelihoods classifications
2. Occupational pattern like farming (per census classification)
3. People below poverty line
4. Livestock numbers
5. GDP/district level if possible
6. Replacement costs

1.3.2.11 Risk assessment methodology

Develop a scientific methodology for determining the risk level for any given geographic unit of interest (state /district/ mandal/ taluka/ village/ habitation level), which models combined effects of multi-hazards, exposure and vulnerability.

The proposed methodology and model for development of Composite Risk Atlas should be well established and well known and accepted by the Expert Committee of NDMA and shall be considered as one of the criteria during the evaluation.

The assessment of damage by a future cyclone should be computed by different models and more than one model should be used for a concordant estimation.

1.3.2.12 Composite Risk Atlas

The development of Composite Risk Atlas should involve the following processes:

1.3.2.12.1 Web-GIS

An online Composite Risk Atlas should be developed (according to the standards and specifications defined in Section 3.2.9) as the extensible, federated and collaboration-oriented decision support and storage platform for cyclone risk management. An immediate priority is to identify "hotspots" of high risk communities for the entire coastline, spanning all 13 States/UTs. This should produce an inclusive catalogue of at-risk communities for which data and planning/mitigation decisions support functionality is provided. The system should be developed through iterating with at least two selected States/UTs that are part of the Technical User Group.

1.3.2.12.2 Data and functional specifications

The Composite Risk Atlas shall include but not be limited to the following:

1. Remote sensing imagery as the standard base data. Where satellite and aerial imagery are used in the development of hazard, vulnerability and exposure data, these should also be stored within the Composite Risk Atlas as a base data layer
2. Digital elevation models used during hazard assessment.
3. Hazard, exposure and vulnerability databases and "hotspot" risk maps
4. Ability to create a custom partitioned sub-system for each participating State, where local datasets and bespoke processing methodologies for planning and mitigation can be developed within the overarching framework
5. Realistic disaster scenario maps for training and decision support where the user can create different scenario and choose hazard levels
6. Options for the user to save and share data and processing methodologies with other Users
7. Specific Use Cases, where composite risk maps (damage and loss potential) are developed for specific decision support needs (e.g. evacuation planning, shelter siting) and different exposure such as housing, infrastructure, crops etc
8. Scalability and compatibility, so that the system provides a compatible infrastructure that can be expanded for Phase II modeling and dynamic decision support

1.3.2.13 Documentation and training

The Technical User guide and Decision Makers Guidelines should support but not be limited to the following operational decision support requirements:

1. Locating "hotspot" high-risk communities
2. Evacuation planning and shelter siting
3. Contingency planning and disaster response plans for the 13 hazard prone coastal States/UTs in India
4. Recommendations on habitat planning and relocation of vulnerable population.
5. Inventory of State/UT Resources for SDMA Plans (spatial & non-spatial) - Disaster Management Information Data sharing for DDMAs

Further, the report should include suggestions for long term and short term State specific mitigation measures required in the identified vulnerable locations. More specifically, the report should include

1. Need analysis for construction of safe shelters like multipurpose cyclone shelters and identification of additional locations after analyzing gaps vis-a-vis the availability of public/private cyclone resistance infrastructure in a particular village/area. The information will help in taking appropriate decision for construction of multipurpose cyclone shelters in future.
2. Gap analysis for Mangroves, Coastal plantation resources and suggest requirement for protection of coastal inhabitants and property. More specifically, the analysis on embankments should be based on land configuration, elevation and historical data on past cyclones/storm surges.
3. A tool should be developed for economic evaluation of damages of various exposed assets due to cyclones of varying intensities in different return period. It will help preparing the long term plans of development activities in a particular area.

1.4 About this Report

This report, the Inception Report is the first deliverable of the Consulting Services for Hazard, Risk and Vulnerability Assessment for 13 states and UT's in India Project.

The report addresses the information requested as per the ToR and includes the following sub sections:

1. Review of Best Practices
2. Methodology used for the Study
3. Deliverables
4. Details of States Selected for Prototype Development
5. References
6. Annexure

2 Review of Best Practices

This section provides an overview of some of the popular models and applications being used by practitioners across the world. The review of best practice section is segregated into three sub sections - cyclone modeling, coastal flood inundation model, and GIS based Decision Support System (DSS) used for viewing and risk analysis. The concluding section for each of the sub sections provides the strengths of each of the models and applications and concludes with the selection of model and application selected from the present study.

2.1 Review of Best Practices for Cyclone/Storm Surg

Weather, climate, and natural catastrophes have always put people at risk. Sophisticated and effective computer modeling tools help make informed decisions about developing appropriate strategies for protecting assets and populations from such natural disasters. Among the various natural disasters, cyclones are the most devastating ones. These are intense low pressure areas of the earth atmosphere coupled system and are extreme weather events of the tropics. Hazards associated with tropical cyclones are long duration rotatory high velocity winds, very heavy rain and storm tide (the combined effect of storm-surge and astronomical tide). Out of these, the storm surge is the greatest hazard associated with cyclone. These hazard occurrences become disasters when they affect man-made structures, systems, and populations, which are not strong enough to resist their onslaught. The result is that many of the societal developments like buildings and related infrastructure on the one hand and the means of agricultural and industrial production and transportation on the other hand get destroyed. This puts tremendous economic burden not only on the local communities but also on the local, state and union governments. Therefore, a robust mathematical model or a tool to assess the risk due to cyclone induced hazards is highly desirable. For identification and application of such a tool or model for a particular region, the best international catastrophic risk assessment tools, models and practices need to be reviewed and studied before adapting them to Indian conditions.

The RMSI team has evaluated the available reports/outcomes of the ongoing modeling studies for cyclone hazard, vulnerability, and risk assessment for the study area. Based on literature survey, we have identified gaps and recommended improvements with reference to current national and international best practices for our approach to be adopted in this project. From internationally available sources, RMSI has reviewed the projects/programs like HAZUS-MH (the hurricane component), Central America Probabilistic Risk Assessment (CAPRA) program, ADvanced CIRCulation (ADCIRC) model, AIR Worldwide model, Princeton Ocean Model (POM), and Sea, Lake, and Overland Surges from Hurricanes (SLOSH) etc. From nationally undertaken studies, RMSI has reviewed the work undertaken in the past for coasts along Orissa, Andhra Pradesh, Gujarat, Puducherry, Tamil Nadu, etc.

The reviewed literature, practices followed, and methodologies adopted for storm surge modeling by the above mentioned organizations have been discussed in the subsections below.

2.1.1 LITERATURE SURVEY: NUMERICAL MODELS FOR INDIAN REGION

During the last few decades, much effort has been directed to the modeling of storm surges generated by intense cyclonic systems in the Bay of Bengal. Das (1972) pioneered the study of numerical storm surge modeling in India. Subsequently, several workers attempted the simulation of storm surge in the Bay of Bengal (Ghosh 1977; Johns and Ali 1980; Johns et al. 1981; Dube et al. 1985; Johns et al. 1985; Dube and Gaur 1995, Murty et al. (1986). Flather (1994) applied a model with 1D equations for narrow channels and 2D equations for the open sea to the northern Bay of Bengal including the coast of Bangladesh to simulate the surge due to April 1991 cyclone. In the last decade, attempts have been made (Jain et al. 2007; Dube et al. 2006, Dube et al.2009, Jain et al.2010) to develop large scale storm surge models for the Bay of Bengal, with most of the works focusing on development of location specific high resolution models. A number of location specific high resolution models have also been developed and successfully applied to the maritime states along the east coast of India such as Chittibabu et al. (2002) (Tamil Nadu), Dube et al. (2000b) (Andhra Pradesh), Dube et al. (2000a, b) and Sinha et al. (2008) (Orissa), Dube et al. (2004) (head bay).

The above modeling studies were performed using the storm surge models based on finite-difference techniques. Rao et al. (2009) computed the extreme water levels and extent of inland inundation based on a 50-year return period data along the coast of Kalpakkam in Tamil Nadu using ADCIRC model. Rao et al. (2009) used ADCIRC model for Andhra Pradesh and described a comprehensive comparison of surge simulations using finite-difference and finite-element. Recently, Rao et al. (2012) configured the ADCIRC model for maritime states of Andhra and Tamil Nadu along the east coast of India for the computation of extreme surges and associated water level. They have simulated the storm surges using the wind stress forcing representative of 1989 Kavali cyclone, November 1996 Andhra cyclone, and 2000 Cuddalore cyclone.

There have been a few attempts to make probabilistic studies, quantitative estimates of the return periods of storm surges along the east coast of India by analyzing a large number of cyclone events. Chittibabu et al. (2004) estimated return periods of storm surges along the coast of Orissa based on model results. Unnikrishnan et al. (2004) analyzed the hourly tide gauge data at three stations, Paradip, Visakhapatnam, and Chennai, for a period of 15 years (1974-1988) and estimated the 100-year return level for these stations. Jakobsen et al. (2006) carried out statistical analysis of the numerically simulated surge heights due to severe cyclonic events that hit the coast of Bangladesh from 1960-2000 in order to estimate the 100 year return period of extreme sea level.

Several other studies have been done using different catastrophe models for identifying the present and future risks due to cyclones and storm surges. A review of the major models used to summarize their capabilities and applicability to the Indian region is essential before deciding which of the models should be used for the present study so as to make the outcomes useful for achieving the project objectives stated in section 1.2. A detail description of each identified model mentioned above is given below:

2.1.1.1 ADCIRC Model

ADCIRC (Advanced CIRCulation) is a finite-element hydrodynamic model developed by Luettich (University of North Carolina) and Westerlink (University of Notre Dame). The algorithms that comprise ADCIRC allow for flexible spatial discretizations that result in a highly effective minimization of the discrete size of any configuration. It can be run either as a two-dimensional depth integrated (2DDI) model or as a three-dimensional (3D) model. It can also be used for modeling tidally-, and wind- and wave-driven circulation in coastal waters for varied applications including forecasting of cyclonic storm surge and flooding. ADCIRC can be applied to computational domains encompassing the deep ocean, continental shelves, coastal seas, estuaries, inlets, floodplains, rivers and beaches. In a single simulation, ADCIRC can provide tide and storm surge elevations and velocities corresponding to each node over a large domain. ADCIRC has been certified by FEMA (USA) for use in performing storm surge analyses. An overview of ADCIRC code structure is shown in Figure 2:1.

The ADCIRC is highly sophisticated professionally designed computer software for simulating the atmospheric motion on a rotating earth. The model equations have been formulated using the hydrostatic pressure with Boussinesq approximations and have been discretized in space and time using the finite element (FE) and the finite difference (FD) method respectively (Luettich et al. 1992). ADCIRC includes a variety of options for boundary forcing (elevation, zero normal boundary fluxes, variable spatial and temporal free surface stress and atmospheric pressure forcing functions in addition to Coriolis and tidal potential forcing terms). Probabilistic inundation maps for coastal surge can be developed based maximum surge heights computed with ADCIRC model at various return periods (2, 5, 10, 25, 50 and 100) and digital elevation model. These maps can further be used in risk modeling and loss assessment.

Wind data is a primary requirement for storm surge modeling associated with tropical cyclone. For this purpose, the wind field at the sea surface can be derived with Holland (1980) wind model that is imbedded with ADCIRC. The inputs required for the wind model are the position of the cyclone, central pressure, ambient pressure, and radii of maximum winds at any fixed interval of times. ADCIRC also has an option to import winds (cyclonic or normal) over the model domain. Coupling with wave models including STWAVE (imbedded with ADCIRC) and SWAN has also been added to the ADCIRC model. The model simulations can be driven by meteorological forcing data extracted from six-hour advisory forecast and observation reports issued by the India Meteorological Department (may be supplemented from data available from NOAA National Hurricane Center (NHC), Unisys, JTWC, and IBTrACS etc. to fill the gaps, if any).

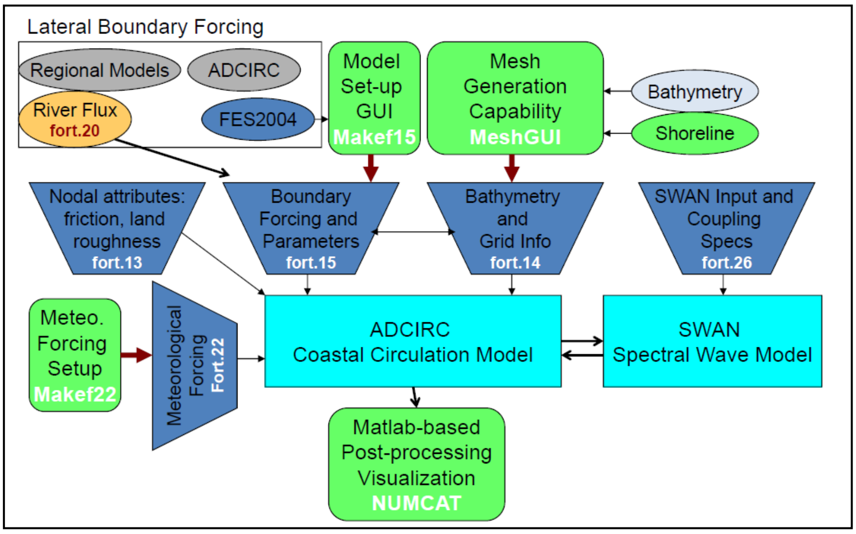


Figure 2:1: ADCIRC code structure

Source: (http://www.bu.edu/pasi-tsunami/files/2013/01/PASIADCIRC_Blain.pdf)

ADCIRC has been extensively applied across the world for the simulation of storm surge and inundation and was part of the performance evaluation of the New Orleans and Southeast Louisiana hurricane protection system being performed by the Interagency Performance Evaluation Task Force (IPET 2006). It has also been applied on regional domains such as the western North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. ADCIRC has been used for simulating the storm surge during Hurricane Ike (Kennedy et al., 2011) and Hurricane Isabel in 2003 in North Carolina (Weaver and Luettich, 2010). In India, it is widely used by Governmental Agencies like the Indian National Centre for Ocean Information Services (INCOIS), Integrated Coastal and Marine Area Management Project Directorate (ICMAM), National Institute of Ocean Technology (NIOT) and Indian Institute of Technology Delhi (IITD).

Hence, the application of ADCIRC model is considered most appropriate for this project as it simulates maximum surge amplitude based on the interaction of storm surge with tides and wind waves over large computational domains and thus clearly demarcates the risk zones due to inundation and flooding. Further details of the model and the numerical solution procedure adopted therein are available on the website (http://www.adcirc.org; Luettich et al. 1992).

2.1.1.2 RMSI Storm Surge Model

A vertically integrated storm surge model developed in RMSI comprises of dynamic storm model and surge model. The model computes storm surge heights and depth-average velocities based on cyclonic wind field. The model is fully non-linear and consists of a system of vertically integrated mass continuity equation and the equation of motion. The model development is on similar lines as the vertically integrated numerical storm surge models developed earlier by the group (Johns et al. 1981, 1983; Dube et al. 1985a, b). One of the significant features of this storm surge model is its ability to investigate multiple forecast scenarios to be made in real time. This has an added advantage because the meteorological input needed for surge prediction can be periodically updated with the latest observations and forecast (data assimilation) from the National Weather Services. Only a brief description of the specific features is presented here.

2.1.1.2.1 Dynamic storm model

As described above, the surge is generated by a cyclone, tracking across the analysis area. In view of the strong associated winds and consequent high values of wind stress, the forcing due to barometric changes has been neglected. Thus, the surface wind field associated with the tropical cyclone is the primary requirement for modeling of storm surges. The wind field at the sea surface is derived by using a dynamic storm model of Jelesnianski and Taylor (1973). The input parameters for the storm model are storm track, radius of maximum winds, and the pressure difference between the storm's central pressure and the ambient (or peripheral) pressure at any fixed interval of times. The main component of the storm model is a trajectory model and a wind speed profile approximation scheme. The trajectory model represents a balance among pressure gradient, centrifugal, Coriolis, and surface frictional forces for a stationary storm. A variable pressure deficit, forward speed, and radius of maximum winds are used to compute the wind stress at model grid points to drive the surge model for the entire cyclone track. The storm strength is reduced after the cyclone crosses the coast. Figure 2:2 explains the step-by-step approach of cyclone hazard modeling.

STEP 1

- **Storm Parameters Before Landfall**
  - Track (Lat, Long)
  - Pressure drop
  - Radius of maximum wind
  - Forward velocity
  - Duration of the storm

STEP 2

- **Wind Foot Print**
  - 500 m grid cells over area of interest
    - Land roughness
  - Simulate storm motion using time step process
  - Record maximum wind speed in each cell of the grid
  - Calibration

STEP 3

- **Hazard mapping**
  - Repeat step 2 for all storms
  - Generate hazard map

Figure 2:2: Steps for Cyclone hazard assessment

2.1.1.2.2 Storm Surge Model

The model is fully non-linear and is forced by wind stress and quadratic bottom friction. The applied surface wind-stress is determined from a bulk quadratic law (Johns et al. 1985), in which wind speed and direction are specified. The non-linear advection terms have a significant effect in the shallow coastal waters. Therefore, for operational applications, the non-linear terms cannot be left out. A conditionally stable semi-explicit finite difference scheme with staggered grid is used for the numerical solution of the model equations. The staggered grid consists of three distinct types of computational points on which the sea surface elevations and the zonal and meridional components of depth-averaged currents are computed. The storm model is coupled with surge model, which can be used for the computation of peak surges associated with the tropical cyclone in the model domain for each time step. The output of the surge model is sea surface elevations, depth averaged current fields and peak surge. The computed maximum probable surge amplitude can be projected onto the coastal land using onshore topography data (SRTM) to demarcate the horizontal extent of inundation using GIS techniques. The outcome of the model fields can be displayed on the computer using graphic tools like GIS, GMT, Ferret, Grapher, Surfer and Matlab. The user may select any part of the coastal region to get more detailed features of the results, if needed. The whole process of running the model for a 48-hour forecast takes only a few minutes on a personal computer or Linux platform.

As mentioned above, one of the significant features of this storm surge model is its ability to investigate multiple forecast scenarios to be made in real time. For example, three 48 hour forecasts can be carried out on a PC in about 15 minutes. As the cyclonic storm moves nearer to the coast and India Meteorological Department's forecast of landfall becomes more accurate, the track of the cyclone can be updated at regular time intervals. The storm surge hazard modeling methodology is presented in flowchart (Figure 2:3).

The available cyclone tracks data from various sources can be reviewed and used for determining the probabilistic cyclone hazard using storm model. Probabilistic inundation maps for coastal surge can be developed by using surge heights at various return periods and digital elevation model.

The storm surge model has been calibrated and validated with various categories of cyclonic storms, which struck the east and west coasts of India during the period of 1877-2013, including, Thane (Dec 2011), Nilam (Oct 2012) and, very recently, cyclone Phailin (Oct 2013). This model has been successfully applied for the coasts of UT of Puducherry and Yemen. As this model is validated against many cyclonic events including historical and real time events for Indian coasts, therefore the use of this model looks realistic for the present study.

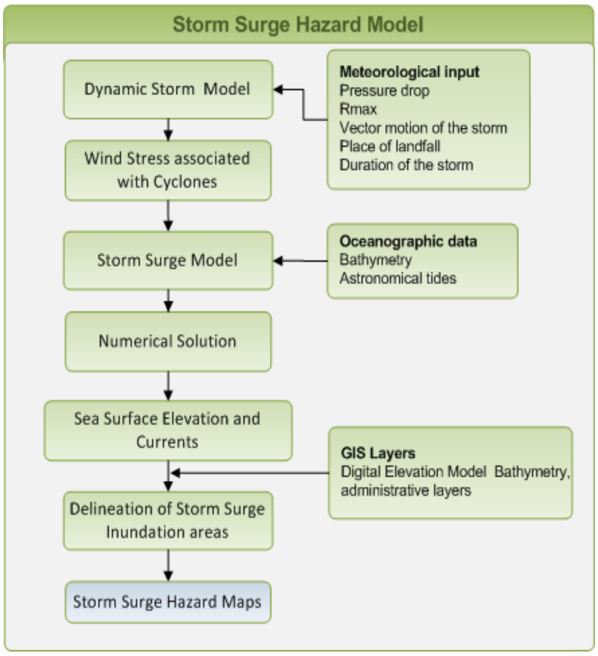


Figure 2:3: Storm surge hazard modeling framework Sea, Lake, and Overland Surges from Hurricanes (SLOSH)

2.1.2 Sea, Lake and Overland Surges from Hurricanes (SLOSH)

The Sea, Lake and Overland Surges from Hurricanes (SLOSH) model is a computerized numerical model used by the National Oceanic and Atmospheric Administration (NOAA) for coastal inundation risk assessment and the operational prediction of storm surge. The SLOSH model consists of a set of physics equations, which are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, levees and other physical features. The SLOSH model computes the maximum potential impact due to storm surge for a particular area from tropical cyclones based on storm intensity, track, and estimates of storm size provided by hurricane specialists/forecasters at the National Hurricane Center. These input parameters are needed to create a model of the wind field. This parameterized wind field is drives the storm surge heights within the SLOSH model. It also creates two composite products, Maximum Envelopes of Water (MEOW) and Maximum of the MEOWs (MOM) to provide manageable datasets for planning. The SLOSH model is computationally efficient and able to resolve flow through barriers, gaps, and passes and models deep passes between bodies of water. It also resolves inland inundation and the overtopping of barrier systems, levees, and roads. However, the SLOSH model does not explicitly model the impacts of waves on top of the surge; it does not account for normal river flow or rain flooding or wind-driven waves, nor does it explicitly model the astronomical tide. The model accounts for astronomical tides by specifying a constant tide level to coincide with landfall. The framework of SLOSH is depicted in Figure 2:4.

More recently, a probabilistic component has been added to the SLOSH family. The Probabilistic Storm Surge model (P-surge) overcomes the limitations of a single deterministic SLOSH storm surge forecast by comprising of an ensemble of SLOSH forecasts. The storm model input parameters are the same as used for deterministic scenarios. Users can run large-scale ensembles of tasks (14,000 instances).

SLOSH has been applied to the entire U.S. Atlantic and Gulf of Mexico coastlines. In addition, coverage extends to Hawaii, Puerto Rico, Virgin Islands, and the Bahamas. The SLOSH model coverage is subdivided into 38 specific coastal regions or basins. SLOSH is also used to create simulation studies to assist in the "hazards analysis" portion of hurricane evacuation planning by the Federal Emergency Management Administration (FEMA), the U.S. Army Corps of Engineers, and state and local emergency managers.

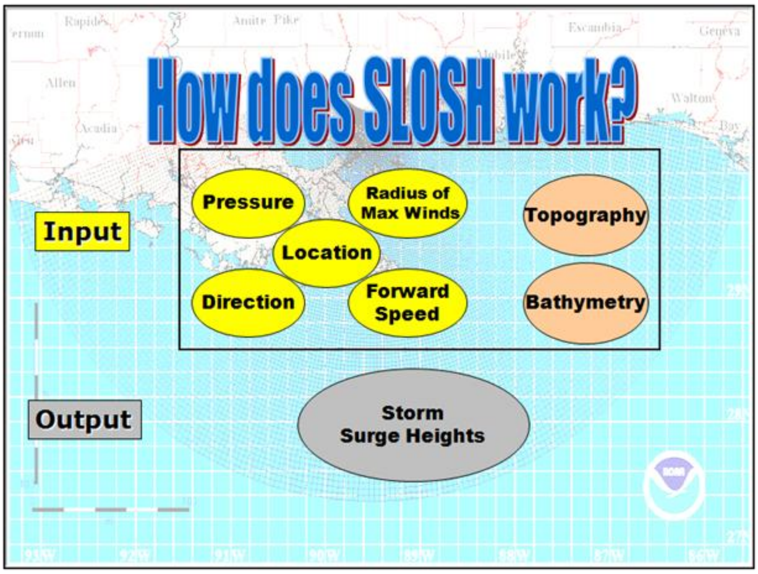


Figure 2:4: SLOSH storm surge model

(Source:http://slosh.nws.noaa.gov/sloshPub/SLOSH-Display-Training.ppt)

2.1.3 POM

The Princeton Ocean Model (POM) is a numerical model that simulates the effects of tides, winds and density gradients on water level and three-dimensional currents. This model was developed in 1977 by Alan Blumberg and George Mellor (Mellor, 1988). POM has the capability to compute storm surge heights at coastal locations using a wetting and drying (WAD) scheme (Oey 2005, 2006), that allows water to inundate dry areas during a simulation. This capability enhances the model's utility for determining areas that get flooded from storm surge. The POM model is based on the hydrodynamic equation, which is a three–dimensional, non-linear, primitive equation using finite difference techniques. The POM uses a mode–splitting technique that solves the barotropic mode (2D) for the free surface and vertically averaged horizontal currents, and the baroclinic mode (3D) for the fully three–dimensional temperature, turbulence, and current structure. The equations are written in the sigma vertical coordinate system and include a turbulence closure parameterization with an implicit time scheme for vertical mixing. The model can suitably be run for the storm surge applications to simulate the storm surges and currents in the 2D and 3D modes respectively. At the sea surface boundary, the model can be forced by wind stress and storm's atmospheric pressure, whereas tidal forcing, current and river outflow at the lateral boundary conditions can also be considered. The POM input parameters includes bathymetry, atmospheric forcing (wind and pressure fields), temperature and salinity at each grid point (Wannawong et al. 2008).The storm's pressure field and surface wind velocity can be created by using any dynamical storm model such as Jelesnianski and Taylor (1973) and Holland (1980). Though this model computes storm surges, it has not been used for real time predictions.

2.1.3.1 The World Bank CAPRA

CAPRA (Central American Probabilistic Risk Assessment) is a multi-hazard open source platform for risk assessment in Central America (El Salvador, Guatemala, Honduras, Costa Rica, Nicaragua, Belize, and Panama), Colombia, Chile, Peru, Bolivia and Mexico. It has been developed with funding from The World Bank and by the ERN-LA consortium. CAPRA is based on a probabilistic risk assessment methodology and is composed of a set of tools for the evaluation and communication of risk at different territorial levels. The CAPRA Platform includes earthquakes, tsunamis, floods, landslides and volcanic activity, and hurricanes hazards.

In CAPRA, hurricane hazard assessment is driven by a tool ERN-Hurricane that is a system of probabilistic modeling of hurricane threat, developed by ERN-AL. Track information from the IBTrACS database of NOAA is used. From each of the tracks in the NOAA cyclone catalogue, a series of "children tracks" are stochastically derived. Based on cyclonic parameters, it calculates the scenarios of hurricane wind, storm surge and hurricane rainfall. It has the capability to generate hazard graphs for families of simulated hurricanes based on historical scenario trajectories or actual historical trajectories. It can also calculate the hazard of an active hurricane about to impact an area of interest.

Hazard information is combined with exposure and physical vulnerability data to determine risk on an inter-related multi-hazard basis. The CAPRA suite of software includes hazard mapping, risk assessment and cost-benefit analysis tools to support pro-active risk management. CAPRA can also be used to design risk-financing strategies. This model allows the evaluation of probabilistic losses on exposed elements using probabilistic metrics, such as the exceedance probability curve, expected annual loss and probable maximum loss, useful for multi-hazard/risk analyses. The platform is conceptually oriented to facilitate decision making. An overview of CAPRA risk assessment is shown in Figure 2:5.

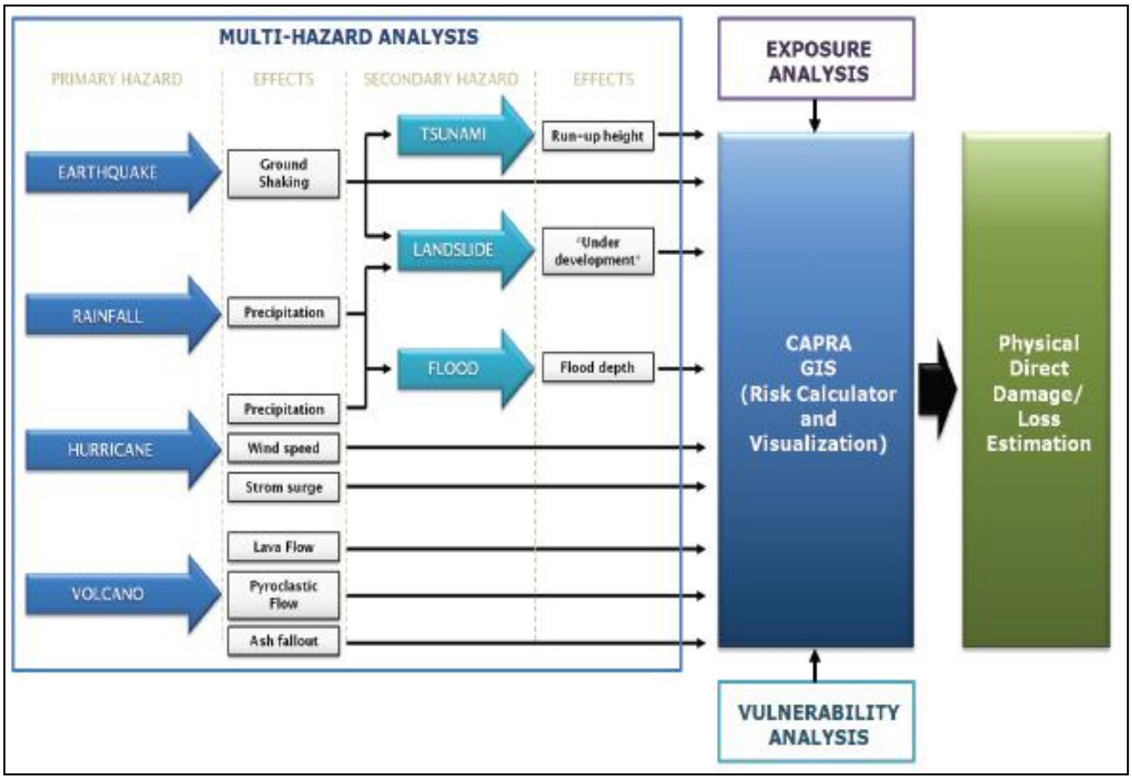


Figure 2:5: CAPRA risk assessment model

(Source: http://www.ecapra.org/)

2.1.3.2 EQECAT

EQECAT's global tropical storm models include the North Atlantic Hurricane Model and Asia Typhoon Model. EQECAT's North Atlantic Hurricane model covers 20 states along the US coastline, the Caribbean, Bermuda, and the Gulf of Mexico whereas Asia Typhoon Model which is a detailed, single basin-wide model covers Japan, South Korea (ROK), China (PRC), including Hong Kong and Macau, Taiwan (ROC), the Philippines, Thailand, and Malaysia.

EQECAT's North Atlantic Hurricane Model is a probabilistic model that uses historical hurricane data available from 1900 to 2011. Its robust probabilistic set includes approximately 110,000 events. In addition, 300,000 simulation years cover gaps in the historical data set to provide a consistent, credible, and realistic view of hurricane risk, particularly for low-probability, high-consequence events. This model provides uniform extreme risk metrics for all locations in the basin. The model also accounts for temporal clustering of hurricane events. The probabilistic set is evaluated against the historical dataset for completeness and validation. The EQECAT numerical storm surge model is based on finite-element technique, and considers bathymetry and wind stress. EQECAT's wind field model and storm surge model are fully integrated. The EQECAT's parametric detailed wind model uses radius-to-maximum winds, profile factors, and translational speeds to compute the sustained wind field at each point on the grid. The computed wind field is used as the input to the finite-element storm surge model. The peak surge height simulated at the coast is compared to the observed or reported surge heights. The model has the capability to calculate probabilistic distribution of storm surge inundation depth for each location based on probabilistic distributions of all significant storm and location parameters using each historical or stochastic event. Inundation is modeled at two zones, the high velocity zone and inland. Flooding due to hurricane rainfall is also included in the model. The rainfall footprint is prepared based on the parameters of the storm, distance to coast, location, and historical flood damage data. Figure 2:6 depicts the EQECAT hurricane storm surge modeling methodology.

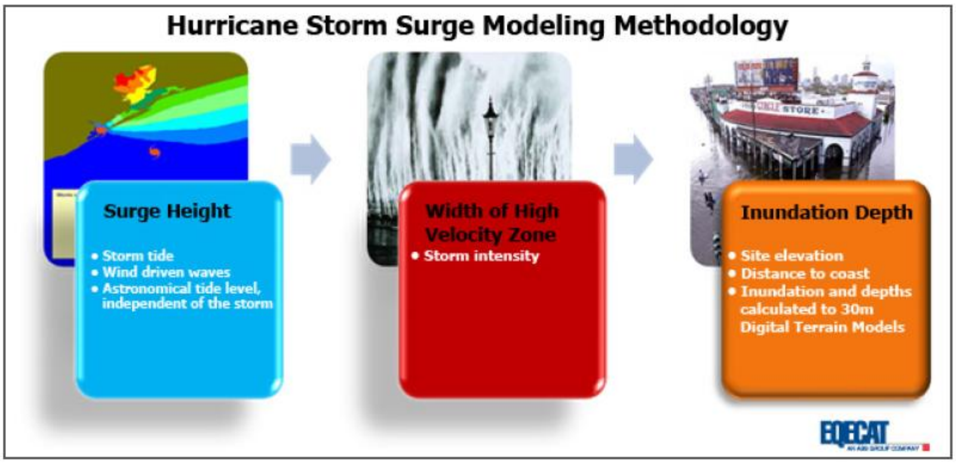


Figure 2:6: EQECAT hurricane storm surge modeling methodology

(Source:http://www.eqecat.com/pdfs/hurricane-storm-surge-modeling-dinesh-2012-08-30.pdf)

2.1.3.3 HAZUS-MH

HAZUS-MH is a regional multi-hazard risk assessment and loss estimation model that was developed by Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences. HAZUS is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes in USA. It uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquake, hurricane, and floods. The Hazus Hurricane Model is designed to produce loss estimation for use by federal, state, regional and local governments in planning for hurricane risk mitigation, emergency preparedness, response and recovery.

HAZUS-MH model estimates combined coastal wind and flood losses for a single hurricane event; but a new coastal storm surge model capability has been introduced in HAZUS that integrates two industry standard models SLOSH and SWAN (Simulating WAves Nearshore). This allows HAZUS to predict the physical and economic impacts of hurricane scenarios on coastal flood regions. A single consistent hurricane wind model drives storm surge (SLOSH), waves (SWAN), and wind damage (Existing HAZUS Hurricane Model). In addition to estimating the separate impacts of coastal flooding and high winds, the coastal surge scenario methodology estimates the combined economic losses to the general building stock in a manner that avoids double counting of flood and wind losses. This model does not take into account rain water inundation. Hazus presently has a hurricane module capability for the eastern states of United States and Hawaii only. That is because the topography for those areas is included in Hazus.

HAZUS can be used in the assessment step in the mitigation planning process, which is the foundation for a community's long-term strategy to reduce disaster losses and break the cycle of disaster damage, reconstruction, and repeated damage. The overall approach used in the development of the HAZUS HM is described in Figure 2:7. Coastal surge analysis has not been implemented for probabilistic modeling.

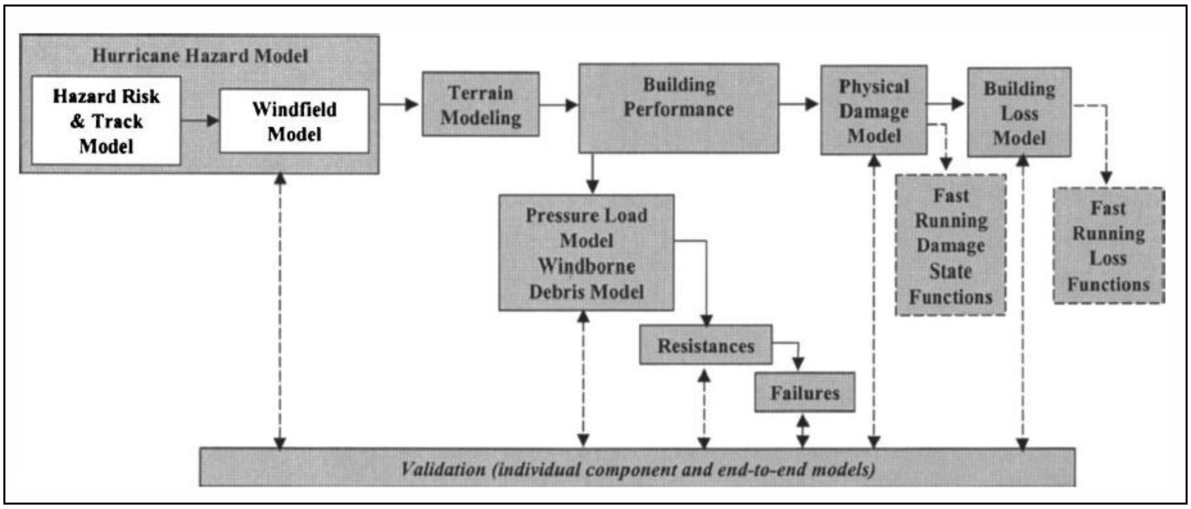


Figure 2:7: Overview of approach used for HAZUS

(Source: http://www.cs.rice.edu/~devika/evac/papers/Hazus_HurricaneI.pdf)

2.1.3.4 AIR Worldwide

AIR is the provider of risk modeling software and consulting services. AIR's model consists of computer programs that can simulate the effects of catastrophes such as hurricanes, tornadoes, earthquakes, and floods, produce full range of potential future events. AIR has developed a fully probabilistic storm surge model for the United States. It estimates peak surge heights based on the meteorological parameters of hurricane, tidal height, the contours of ocean floor, and high resolution digital elevation data. The wind distribution associated with a hurricane is computed using landfall location, central pressure, radius of maximum winds, forward speed and storm heading. AIR's storm surge model estimates very location specific surge damage. Loss estimates for exposures have fewer address attributes and modeled at the ZIP centroid, which may not vary according to the underlying risk. Meteorological parameters and precipitation induced flooding are taken into account that affect the surge. The vulnerability module incorporates damage functions specific to wind, precipitation, and temperature. The model is validated against loss estimates. An overview of the AIR model is shown in Figure 2:8.

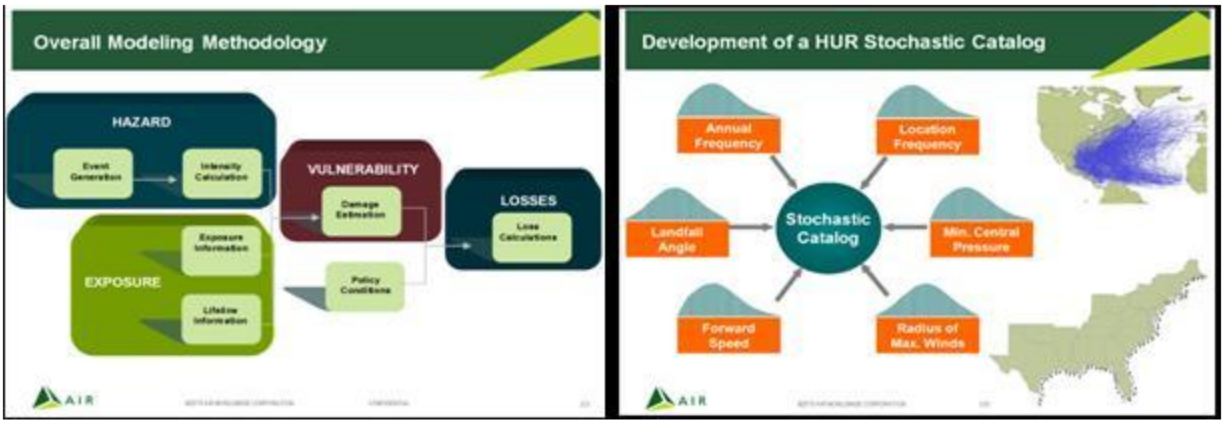


Figure 2:8: Overview of the AIR Model

Data sources used in the development of the AIR hurricane model include the National Weather Service, including the National Hurricane Center. AIR uses the actual storm parameters reported by the National Hurricane Center, as well as forecasted track, landfall location, and wind speeds to produce a realistic distribution of potential industry losses. The AIR hurricane model projects loss costs and probable maximum loss levels for residential property insured damage from hurricane events. The damage functions developed by AIR are based on published engineering research, findings from post-disaster surveys, and have been rigorously validated through extensive analysis of detailed insurance claims data.

AIR has used historical data to develop the probability distributions for key model variables such as annual hurricane frequency, landfall location, central pressure, radius of maximum winds, and forward speed and track direction. Spatial smoothing and meteorological adjustments have been done to overcome spatial gaps and other limitations caused by the relative scarcity of historical data. The probability distributions used for individual input variables include Negative Binomial for annual landfall frequency, Weibull for central pressure, and Lognormal for forward speed. The parameters of these distributions have been estimated using the maximum likelihood method. Graphical comparisons using quantile-quantile (Q-Q) plots have been performed to confirm the agreement between historical data and the fitted probability distributions.

Table 2-1: Summary of storm surge models

S. No	Firm	Ownership	Geography	Modeling Approach	Usage/Shortcomings
1	ADCIRC	Proprietary	It has been applied across the world including U.S., India, Korea, Japan, United Kingdom, and The Netherlands, etc.	Hydrodynamic model, tide and STWAVE/SWAN are included, finite element technique, unstructured grid, 2D/3D, model can be forced with Real/Synthetic wind fields	It is a robust storm surge model reviewed and used by many organizations. ADCIRC is being operationalized in INCOIS and is being used by IITD, NIOT, ICMAM etc. Suitable for this project as a primary model.
2	RMSI Storm Surge Model	Proprietary	Yemen and east coast of India, UT of Puducherry	Hydrodynamic model, tide and wave set are linearly included, finite difference technique, staggered grids, 2D, model can be forced with Real/Synthetic wind fields	This model has been implemented for Indian region and tested for many cyclonic events over the North Indian Ocean. This model can also be considered as a secondary model for use in the project.
3	SLOSH	Proprietary	USA	Hydrodynamic model, wave set not is included, finite difference, structured orthogonal curvilinear grid, 2D, model can be forced with synthetic wind fields	SLOSH is a Proprietary model and the effect of wave set up is not included.
4	POM	Open Source	USA, India, and Thailand, etc.	Hydrodynamic model for research purpose, finite difference technique, unstructured grid, 2D/3D, model can be forced with Real/Synthetic wind fields	POM is used by research communities and is not being used for operational purpose

5	World Bank-CAPRA	Open Source	Central American Countries	Hydrodynamic model developed	CAPRA has been implemented for US. It has not been implemented/tested for the Indian region
6	EQECAT	Proprietary	USA and Asia	Hydrodynamic model developed for own purpose	EQECAT is a proprietary model.
7	FEMA-HAZUS	Open Source	USA	Hydrodynamic model developed that integrates SLOSH and SWAN	HAZUS has been implemented for US. It has not been tested for Indian region
8	AIR Worldwide	Proprietary	United States	Hydrodynamic model developed for own purpose	AIR Worldwide is a proprietary model.

2.1.4 CONCLUSION

Based on the review of storm surge models, it has been found that all are highly sophisticated numerical models based on mathematical techniques. These models simulate/predict storm surge height along the coast associated with cyclonic wind field generated by either parametric wind module or real time winds. Almost all reviewed models, mentioned in Table 2-1, used a combination various methods and tools to drive the storm surge hazard. These include stochastic cyclone track analysis, assessment of wind field and surge height and associated flood inundation mapping. Though these models are performing well, they cannot be used because a few of them are proprietary models and use their own packages for hydrodynamic simulations. Similarly, a few models have not been tested and implemented for Indian region yet.

RMSI will use the ADCIRC model as this is operationalized in INCOIS and is found consistent with the best practices being followed by most of the organizations involved in cyclone and storm surge modeling in the country. This is based on the widespread application of ADCIRC storm surge model and its robustness in modeling inundation, its capability to develop the model at finer grids, and a provision to incorporate tidal impact. The RMSI model will be used as a secondary model for validation purposes.

2.2 Review of Best Practices for flood modeling

2.2.1 FLOOD HAZARD AND TYPES OF FLOODING

A flood is defined as “an overflowing of water over land in the areas, which are not usually submerged.” Floods are natural phenomena and are a result of heavy or continuous rainfall. This excess or heavy rainfall causes the floods when absorptive capacity of soil and the flow carrying capacity of rivers, and streams are exceeded.

Based on nature and causes of flooding, the floods can be classified as 1) urban or flash flooding, 2) river or fluvial floods, 3) coastal floods, 4) floods due to failure of artificial systems (Jha et al, 2012). In India, river or fluvial flooding can be because of the rainfall due to monsoon activity or rainfall generated from cyclones after making a landfall. As part of the study, we will be considering river or fluvial floods due to cyclone induced rain in the coastal areas under study.

2.2.2 ORGANIZATIONS IN CATASTROPHE RISK MODELING

Flood hazard, due its loss potential and rather frequent occurrences, is one of the essential parts in the catastrophe risk models. Catastrophe risk models are computer-based models for measuring catastrophe loss potential and were developed by linking scientific studies of natural hazards' measures and historical occurrences with advances in information technology and Geographic Information Systems (GIS) (Grossi et al., 2003). Various organizations have developed flood models for various countries. These organizations include “AIR Worldwide” founded in 1987 in Boston; “Risk Management Solutions (RMS)” formed in 1988 at Stanford University; and “EQECAT”, which began in San Francisco in 1994. These firms have their proprietary models. In the late nineties and early 2000, governments and multilateral funding agencies recognized the importance of assessment of impact of natural hazards. The Federal Emergency Management Agency (FEMA) of USA and The World Bank have developed catastrophe risk models, which are available in open source.

2.2.3 REVIEW OF BEST PRACTICES

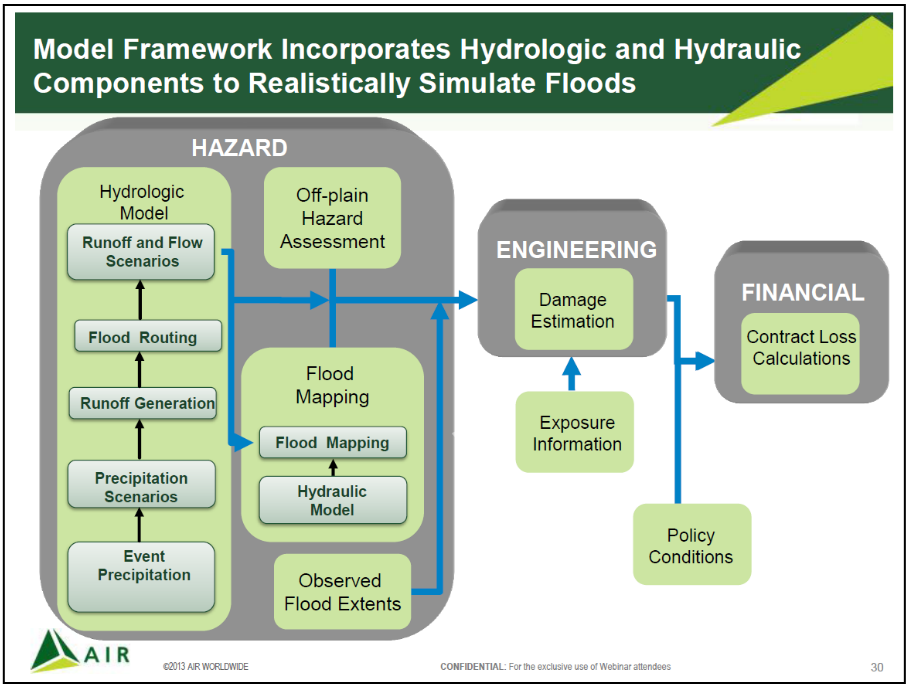
The practices followed and methodologies adopted in flood modeling by the above mentioned organizations have been described in this section.

2.2.3.1 AIR Worldwide

AIR Worldwide has developed flood models for 1) Great Britain and 2) Germany. Each country model has been developed considering two key components, viz.; rainfall generation module and flood plain risk, besides financial and actuarial. The rainfall generation module is based on Numerical Weather Prediction (NWP) to generate realistic rainfall patterns showing spatio temporal variations. It also couples global climate models and mesoscale NWP models to capture large-scale and small-scale precipitation patterns over Europe.

Flood risk part of the model takes into account high-resolution soil, land use/land cover and topographic data as input to the hydrology and hydraulics components. Flood hazard component comprises of hydrological model and flood mapping (Figure 2:9). The hydrological model includes precipitation events and scenarios, runoff generation, and flow routing. A unit hydrograph (UH) approach is used to simulate the catchment response during storms (runoff generation). The parameters of a UH are derived from observed time series data at flow gauges. The attenuation effect of reservoirs and lakes off the river network are considered here using the Flood Attenuation by Reservoirs and Lakes (FARL) index. The Muskingum-Cunge routing scheme is employed to simulate the propagation of the flood wave (Flow Routing). For a reach of river, the input flow is its lateral local contribution and discharges from upstream (Qu et al, 2010).

The runoff and flow scenarios are generated from hydrological model. Using this approach, the peak discharge from each storm in the stochastic catalogue of every affected reach of the network is derived. Flood mapping component includes the hydraulic model, which takes input as runoff and flow scenarios to derive the flood maps. The peak flows generated are transformed to flooding inundation depth by the stage discharge curve (Qu et al, 2010). Finally, flood hazard maps are generated for various stochastic events as the outcome.



(Source: Thum et al 2013)

Figure 2:9: AIR Model framework for simulation of flood hazard

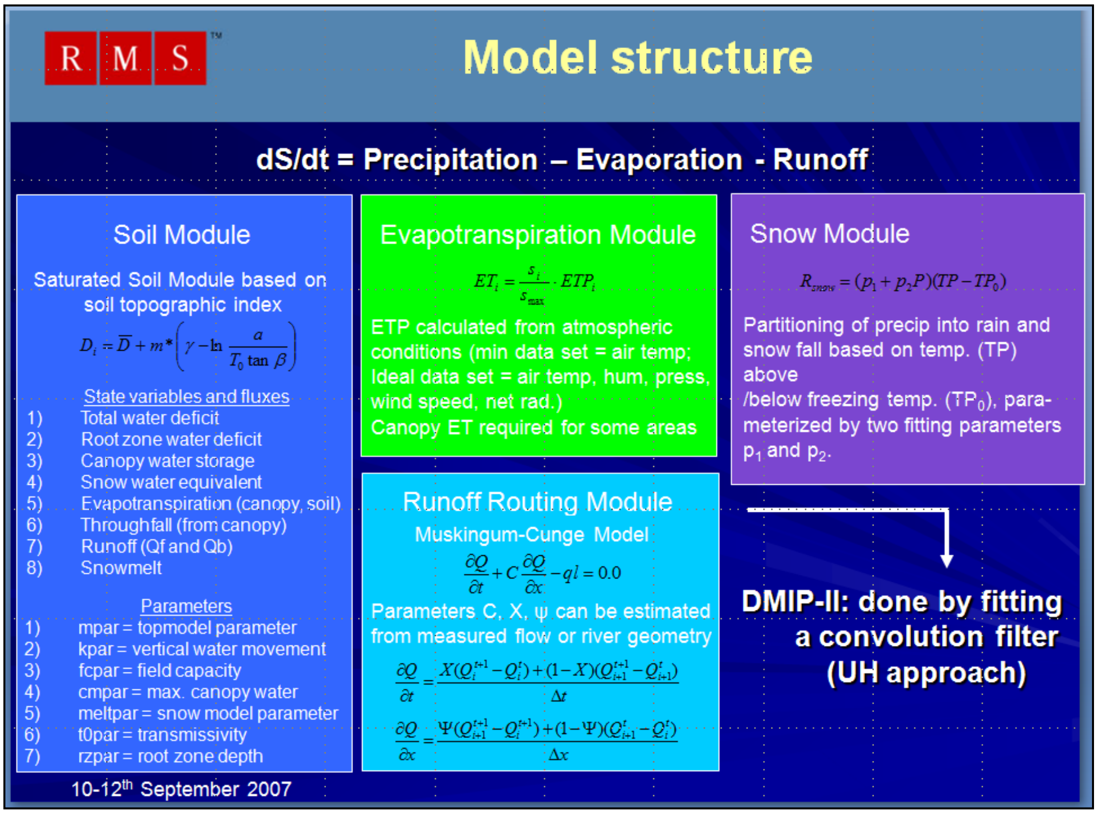
2.2.3.2 EQECAT

EQECAT has developed flood model for USA and Europe (Austria and Germany). Flood hazard model comprises of probabilistic precipitation events, rainfall to runoff conversion, flood hazard mapping (runoff to water height conversion) and off plain flood hazard mapping.

Probabilistic precipitation events are derived based on a sampling of eight different parameters of heavy precipitation systems, such as intensity and area, and detailed historical loss data over a 43-year period. It uses precipitation data from European Centre for Mid-Range Weather Forecasts (ERA – 40) and national meteorological stations. Rainfall to runoff conversion is estimated using unit hydrograph approach, which considers topographic and antecedent precipitation, azimuth, and the potential effect of snow melt. Water discharge rates at points in the river system according to a water routing are calculated. Finally, flood volumes and water heights are calculated for using a detailed Digital Terrain Model (DTM). Off-plain flood hazard is derived from the same precipitation event set. It diverges in approach from the use of a GIS-raster flood definition module to produce water heights outside river floodplains. It combines a hydrodynamic approach with digital terrain model source data (http://www.eqecat.com/pdfs/europe-flood-model-fact-sheet.pdf).

2.2.3.3 RMS

RMS has developed a flood model for Europe. It uses complete hydrodynamic approach of physical rainfall runoff modeling. The model captures all processes in the precipitation-runoff–inundation chain end to end by continuously modeling hydrodynamic processes over long time periods. Hydrological modeling is conducted on a country-wide 10-meter digital terrain model, which has been subject to rigorous quality testing and enhancement. By using long-time series modeling, the seasonality of all components of the water cycle and the impact of antecedent conditions on the next event are also accounted. Hydrodynamic model comprises of soil module, evapotranspiration module, snow module and rainfall routing module (Figure 2:10). The soil module computes the soil saturation based on soil and topographic parameters.



(Source: Eppert et al., 2007)

Figure 2:10: RMS Model Structure for hydrodynamic simulations

Evapo transpiration is calculated from atmospheric and canopy conditions. Snow module differentiates the precipitation into rainfall and snowfall based on the temperature. The runoff routing module estimates the runoff at various locations using Muskingum Cunge model. Finally, cell based inundated in mapped using the flows (runoff) and high resolution topography for stochastic events. Stochastic event set is derived from the RMS time-stepping, pan-European precipitation model, which simulates 100,000 years of flood-causing rainfall across Western Europe. The model represents all possible scenarios from long-duration winter rainfall events (which may fall as snow), summer rainfall events, and localized thunderstorms. RMS has reconstructed 45 years of Europe-wide rainfall to ensure consistent spatial and temporal patterns in the stochastic precipitation fields and realistic correlation of rainfall within the U.K. and across Europe (https://support.rms.com/publications/UK_Inland_Flood.pdf).

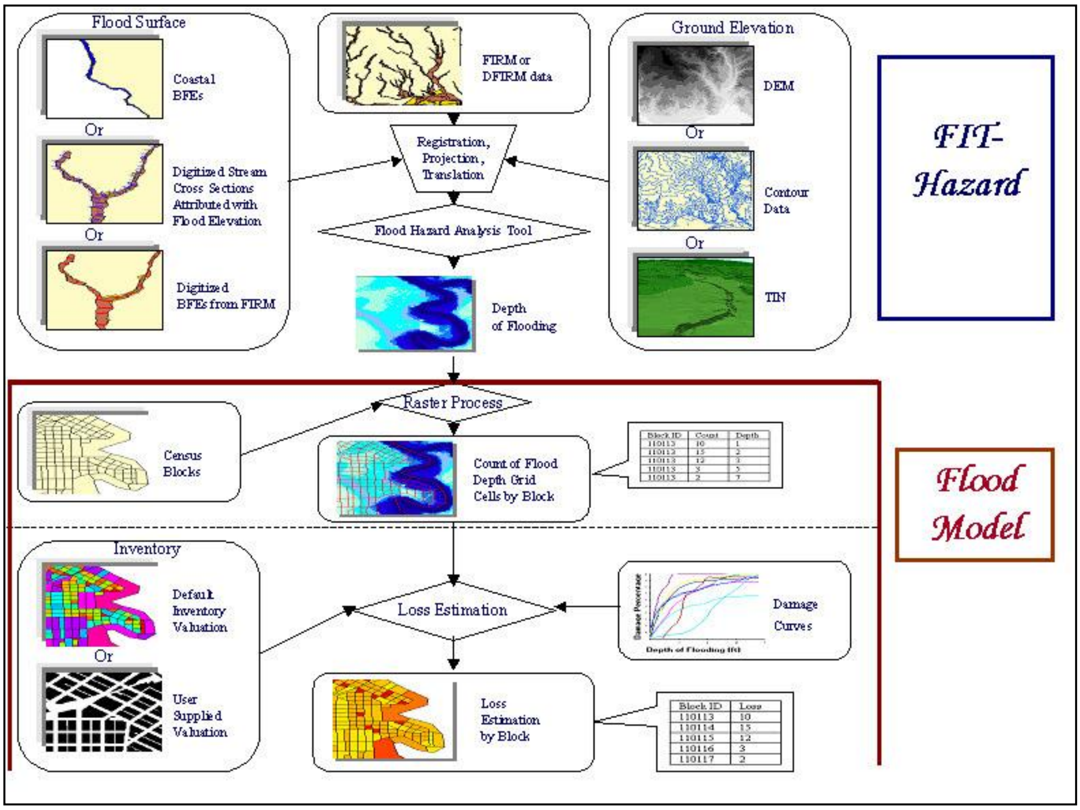
2.2.3.4 FEMA -HAZUS

HAZUS is GIS based model for loss estimation due to various natural hazards in USA developed by FEMA. It contains nationally applicable standardized methodology for earthquake, flood and hurricanes. HAZUS Flood Model allows carrying out a wide range of flood hazard analyses. The flood hazard analysis module uses characteristics such as frequency, discharge, and ground elevation to estimate flood depth, flood elevation, and flow velocity. The hazard analysis portion of the model characterizes the spatial variation in flood depth and velocity in a given study area.

Depending on the degree of user expertise, the Flood Model is designed to operate at two levels. Level 1 requires minimal user interface and data, while Level 2 requires user-supplied local data for performing more detailed analyses, with the assistance of the Flood Information Tool (FIT).

Both Analyses require ESRI's ArcGIS software and the Spatial Analyst extension and a Digital Elevation Model (DEM) for terrain characterization. At Level 1, the DEM is imported by the Flood Model through a Web-based link to the USGS National Elevation Dataset (NED) Web site. USGS has developed the NED by merging the highest-resolution, best-quality elevation data available across the United States into a seamless raster format. Level 1 analysis begins with a DEM or equivalent topographic information. This is combined with stream discharge and other data in a hydraulic model to determine a flood surface elevation. The difference between the ground surface and the flood surface provides the boundary and depth of flooding.

For Level 2 analyses, the Flood Information Tool (FIT) is used to preprocess site-specific flood hazard data and facilitate its import into the Flood Model for further analysis of damage and loss. The FIT tool (Figure 2:11) has been designed to operate as an extension within ArcGIS and allows users to create depth grids for various return periods and other parameters. Flood surface data, digitized floodplain boundaries, ground elevation data in a grid format are given as input to the FIT. HAZUS uses HEC-RAS (Hydrologic Engineering Centre – River Analysis System) developed US Army corps of engineers (USACE) for derivation of flood surface data and flood plain boundaries (Scawthorn et al, 2006).

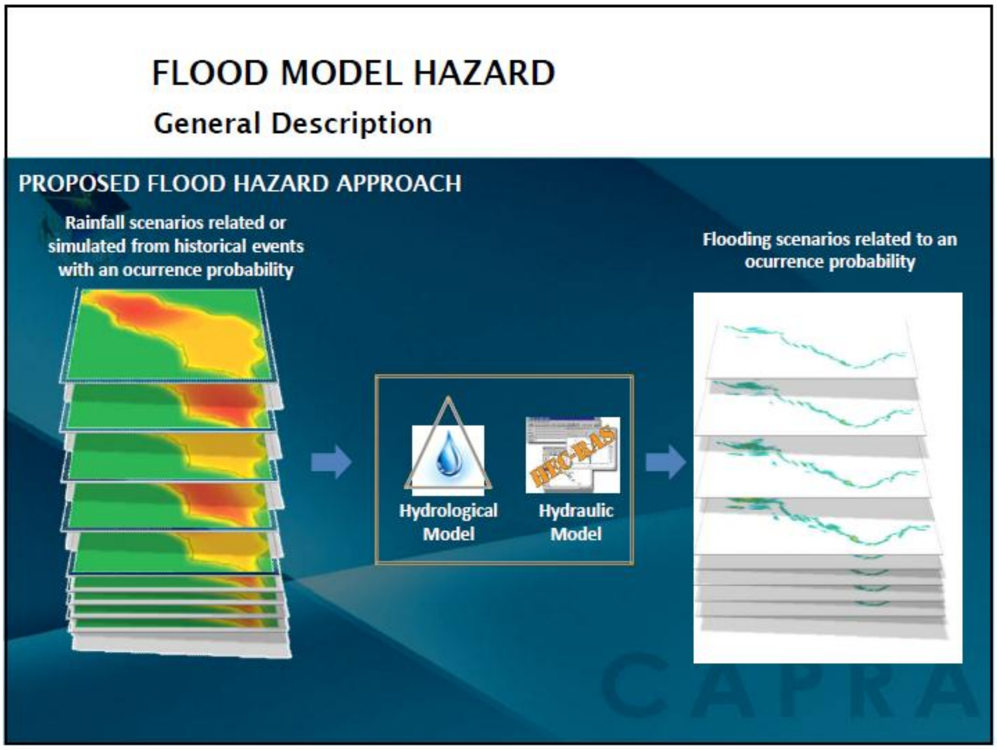


Source: Scawthorn et al, 2006

Figure 2:11: Overview of integration of FIT and HAZUS-MH Flood Model

2.2.3.5 The World Bank-CAPRA

ERN, through The World Bank funding, developed the open source platform for risk assessment in Central America. It has been named as CAPRA (Central America Probabilistic Risk Assessment) which allows probabilistic hazard and loss analysis. It includes earthquakes, tsunamis, cyclones, floods, landslides and volcanic hazards. The flood hazard model in CAPRA comprises of probabilistic rainfall scenarios related or simulated from historical events, hydrological model, hydraulic model, and flood extent maps at various probabilities (Figure 2:12). Probabilistic rainfall scenarios use the daily rainfall data network of stations from nation metrological agencies. These scenarios are also related to hurricanes in both Pacific and Atlantic Ocean. Hydrological model uses the basin information, soil, land use and topography to derive the SCS curve number, which is a parameter related to abstraction. Using the abstraction, the excess precipitation is estimated for further calculation of runoff for the basin using a unit hydrograph approach. Estimated flows are routed through a river system to generate the inundation maps using HEC RAS developed by the US Army Corps of Engineers (USACE). CAPRA uses steady state simulations and peak runoff to derive flood inundation maps showing flood depths.

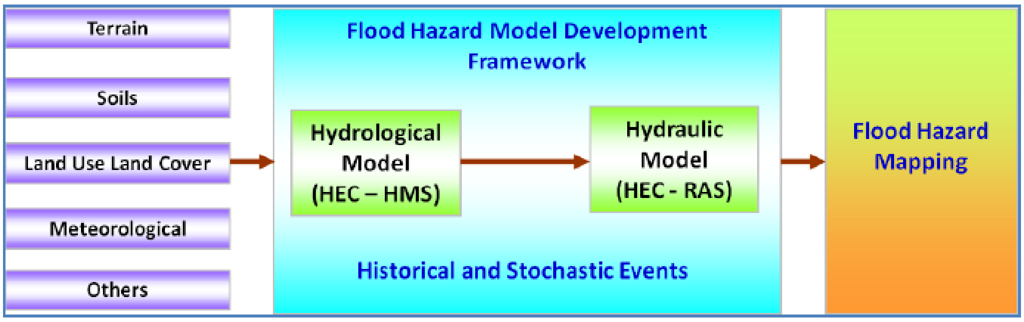


Source: Tores et al, 2012

Figure 2:12: CAPRA Flood Hazard Model

2.2.3.6 The World Bank-MnhPRA

RMSI, through World Bank funding, developed the open source platform for risk assessment in Morocco. It has been named as MnhPRA (Morocco Natural Hazards Probabilistic Risk Assessment) which allows probabilistic hazard and loss analysis. It includes earthquakes, tsunamis, floods, landslides and drought hazards. Flood hazard assessment identifies and demarcates those parts of the study area, which are exposed to floods. It provides information on the extent and depth of flooding throughout flood prone areas for a range of flood magnitudes. The flood hazard model in MnhPRA comprises of probabilistic rainfall scenarios simulated from historical rainfall, hydrological model, hydraulic model, and flood extent maps at various probabilities (Figure 2:13).



Source: RMSI, 2012

Figure 2:13: MnhPRA Flood Hazard Model

The flood hazard model development framework adopted for this study comprises of:

- Identification, acquisition, compilation, and review of all relevant hydro meteorological and biophysical data. These data include terrain, soil, land use land cover, rainfall, and others to form the input for the model.
- Rainfall analysis to estimate temporal and spatial rainfall distribution for stochastic simulation of rainfall at river basin level.
- Hydrological (rainfall-runoff) modeling to estimate flows for a range of stochastic events in each river basin using USACE's HEC-HMS (Hydrological Modeling System).
- Hydraulic modeling to estimate flood levels throughout the basins for various flows generated from stochastic events using HEC – RAS (River Analysis System).
- Flood hazard mapping to show flood extent and flood depth for a range of stochastic events, which is the result of hazard assessment.

2.2.4 HYDROLOGICAL AND HYDRAULIC MODELS IN FLOOD HAZARD ASSESSMENT

Flood Hazard assessment is combination several steps. These steps include probability analysis of rainfall, hydrological assessment for flows, and hydraulic assessment for flood hazard mapping. Hydrological and hydraulic models are most widely used in the hydrological and hydraulic assessment throughout the world. United States Army Corps of Engineer's Hydrologic Engineering Centre (USACE-HEC) developed a set of hydrological and hydraulic models named as Hydrologic Engineering Centre – Hydrological Modeling System (HEC-HMS) and Hydrologic Engineering Centre- River Analysis System (HEC-RAS). Various hydrologic models have been developed in the past to simulate flood inundation in the basin area (Iwasa and Inoue, 1982; Samules, 1985; Gee et al., 1990). These models consider overland and river flows. Only a few models are available to simulate flood inundation in a river basin for real flood events considering all the spatial heterogeneity of physical characteristics of topography such as HEC-HMS, HEC-RAS, MIKE BASIN, MIKE-11, MIKE-FLOOD and other models such as CCHE-2D. While models from MIKE are in proprietary domain, the CCHE-2D is in open source. The models from HEC and CCHE have been reviewed here.

2.2.4.1 HEC Models

HEC-HMS and HEC-RAS are two popular and widely used models developed by USACE. The HEC-HMS model has been widely applied internationally for a range of hydrologic modeling purposes and uses widely accepted standard hydrologic modeling approaches and equations. Background documents reviewed for this study indicate that USACE modeling tools have been applied in the past (Noman et al. 2001, Noman et al. 2003, et al. 2006, World Bank, 2009). The model can provide a water budget for most components of the hydrologic cycle. It is capable of modeling common types of hydraulic control structures, such as weirs, gates, pumps, and spillways. The model is also capable of exchanging data with the HEC Data Storage System (DSS), a database system designed to efficiently store and retrieve scientific data (USACE and South Florida Water Management District, 2002). HEC-HMS is primarily a lumped modeling system in which spatial variations in the physical processes are averaged over the watersheds or sub basins. Most of the models included in HEC-HMS are event based and deterministic (USACE, 2000). The model can also be applied for the continuous, long-term simulation of rainfall-run-off.

In many applications of river flood modeling, a one-dimensional full hydrodynamic modeling system is used (Meena 2009, RMSI 2009).The one-dimensional hydrodynamic model HEC-RAS, developed by the United States Army Corps of Engineer's Hydrologic Engineering Centre (USACE 2010), is being used for performing hydraulic calculations for the river stretches. HEC-RAS is an integrated system of software. It can calculate water surface profiles for both steady and unsteady, gradually varied flows for a full network of natural and constructed channels.

2.2.4.2 CCHE

The coastal and urban areas having presence of flood mitigation measures in place are one of the most complex to assess in terms of flood hazard. To model such complex situations, a 2D river flow model is required. Two options are available to choose from: 1) using proprietary models such as MIKE, 2) using open source models such as CCHE. For in depth assessment of the nature and extent of flood, a two dimensional numerical model CCHE -2D is proposed to be used in this study. This model is being widely used in many of the research applications (Jia and Wang, 2001, Dottori, Francesco; 2012, Altinakar, et al, 2008, FEMA, 2013, Qi et al., 2006). A Numerical 2D hydraulic model developed by the University of Mississippi - The National Center for Computational Hydroscience and Engineering (CCHE2D) is used for prediction and understanding of the floodplain inundation process. CCHE2D model is a two-dimensional depth-averaged, unsteady, flow and sediment model. The resulting set of equations is solved implicitly using the control volume approach and efficient element method. The numerical technique employed ensures an oscillation-free and stable solution. An integrated package of CCHE2D simulates the river flows, non-uniform sediment transport, morphologic processes, coastal processes, and pollutant transport and water quality. These processes are solved with the depth averaged Navier-Strokes equations, transport equations, sediment-sorting equation, and bed load and bed deformation equations.

2.2.5 Probabilistic Flood Hazard Modeling in India

Floods have been a recurrent phenomena in India from time immemorial. Flooding is a major problem in India, causing significant damage each year. Almost every year floods of varying magnitude affect some parts of the country or the other. India's high flood risk and vulnerability is highlighted by the fact that 400 lakh hectares out of a geographical area of 3,290 lakh hectares is prone to floods. On an average every year, 75 lakh hectares of land is affected, 1,600 lives are lost and the damage caused to crops, houses and public utilities is Rs. 1,805 crores due to floods (NDMA, 2008).

Probabilistic flood hazard modeling has been mostly done for various parts of the country pertaining to smaller areas or catchments, which highlights the lack of studies for the entire country. Various government agencies have been involved in flood plain or flood prone area mapping, which does not have probability aspect associated with it. In India, the Central Water Commission - CWC (Flood Atlas of India), the Building Materials and Technology Promotion Council BMTPC (Vulnerability Atlas of India), and the National Atlas and Thematic Mapping Organization - NATMO (Natural Hazard Map of India), have been involved in flood-hazard mapping. Probabilistic flood modeling studies conducted in isolated parts of the country have been reviewed below.

RMSI, 2002 in the World Bank funded project developed catastrophic risk assessment models for Maharashtra, Gujarat, Andhra Pradesh and Orissa for estimation of future losses due to natural disasters (cyclone, earthquake and flood) using scientific principles, probabilistic methods, and global best practices. Probabilistic flood hazard was modeled for Andhra Pradesh and Orissa. The project considered exposed assets for housing and public infrastructure. The risk modeling involved historical catalog compilation, hazard assessment, vulnerability evaluation, exposure development, and loss analysis. The project was a milestone in India's catastrophe risk modeling application research, with results shared with India's state and national governments.

In the study conducted by Gujarat State Disaster Management Agency (GSDMA), the probabilistic flood risk and vulnerability assessment was conducted for four major urban agglomerations of Gujarat state. This study was conducted at municipal ward level (of which there are a substantial numbers in each city). The four major cities for which flood risk and vulnerability were assessed were Ahmedabad, Vadodara, Surat and Rajkot. In this study, flood hazard assessment included collecting and analyzing historical information, GIS mapping, hydrological (using HEC-HMS) and hydraulic (HEC-RAS) modeling, preparation of hazard maps. Vulnerability Assessment included assessing vulnerability to flooding, field assessment, detailed assessment of economic vulnerability, economic analysis report, GIS based flood vulnerability maps. Risk assessment included assessing risks due to flooding hazard, calibrating risk parameters statistically and analytically, producing GIS based flood risk maps, assessing damage for each area, and recommending mitigation mechanisms. The study also included flood risk assessment for dam break scenario. Recommendations phase included identification and evaluation of structural flood mitigation options and suggestions of strengthening of flood forecasting mechanisms with the objective of reducing the impact of future flood risk (RMSI-EGIS India, 2009).

As a part of the World Bank study on strategic basin assessment of the Ganges basin to develop a shared knowledge base and analytical framework to examine basin development options from a regional water systems perspective, scenario based flood modeling for Utter Pradesh and Bihar states were carried out in Ganges basin (RMSI, 2010). This study assessed the biophysical (and socio-economic) implications of various water resources development scenarios from a basin and individual country perspective. It also examined the history and vulnerability of hydro-meteorological disasters (i.e. floods and droughts) in India and helped in understanding the implications that upstream storages can have on vulnerability to hydro-meteorological hazards. The outcome of this study served as a basis for the Strategic Basin Assessment of the Ganges Basin. Flood hazard modeling was conducted for Gandak, Burhi Gandak, Kosi, Bagmati, Ghaghra, and Kamala-Balan river basins in UP and Bihar.

In an OECD funded project, a flood modeling study for Mumbai to assess impacts of climate change on flood risk in the city was conducted by RMSI (Hallegatte, S. et al. 2010). The study was framed around the 2005 flooding in Mumbai. Climate model projections were used to understand how climate change might affect the annual probability of a rainfall event like that which caused the 2005 flooding. This was done to understand if climate change could make events like 2005 more frequent and by how much. Thereafter, a hydraulic model was used to explore the implications of climate change for flood risk in Mumbai, in terms of the changes in population exposed to urban flooding and the potential economic damages. Preliminary estimates suggested that a rainfall event like that which caused the 2005 flooding has an annual probability of occurring of less than 0.5% (or a return period of greater than 200 years) – it is very rare. However, this study finds that the annual probability could double to up to around 1% by the 2080s. Similarly, the more frequent rainfall events, which generally cause less damaging floods, could also become more frequent.

2.2.6 Conclusion

Based on the review of best practices of various firms and organizations developing flood hazard models, the following points can be summarized (Table 2-1).

- Review of best practices indicates that the model development practices of all reviewed models include stochastic rainfall analysis, hydrological assessment for rainfall runoff relationships, hydraulic modeling for flood inundation mapping.
- Stochastic rainfall simulations are carried out based on various datasets such as gridded, observed and climate model based. In case of availability of flow data, stochastic set are estimated based on flows, which is given as input to the hydraulic model directly.
- The models from RMS, AIR Worldwide, and EQECAT are in the proprietary ownership and are available for USA and European countries. For hydrological assessment and hydraulic modeling, above mentioned firms mostly use their in-house developed models. They can be expanded to any other country by developers only as full details are generally not available to everyone. These models are often a costly proposition.
- The models from FEMA and The World Bank (CAPRA, MnhPRA, etc) are in open source and anyone can access and use them. They have been developed using open source

hydrological and hydraulic models mostly from HEC, which can be customized and applied in anywhere in the world.

- During the last decade, HEC packages have become the most popular in application and development of flood hazard models in various geographies.
- RMSI's approach is consistent with the best practices of most of the organizations in open source, which include stochastic rainfall analysis, hydrological assessment and hydraulic model for inundation mapping. RMSI's approach uses the HEC packages as applied by most open source models as per the requirement of this study. Some of our study areas also include major urban centers such as Chennai, which is highly flood prone and an ideal case for two-dimensional flows. On the basis of these conclusions, we are proposing to use the two-dimensional hydraulic model CCHE 2D, which is also in open source.

Table 2-2: Summary of flood models

Sr. No	Firm	Ownership	Geography	Modeling Approach
1	AIR World Wide	Proprietary	Great Britain and Germany	Hydrodynamic model developed for own purpose
2	EQECAT	Proprietary	USA, Austria and Germany	Rainfall Runoff Relationships, Hydrodynamic model developed for own purpose
3	RMS	Proprietary	Europe	Hydrodynamic model developed for own purpose
4	FEMA-HAZUS	Open Source	USA	Rainfall Runoff Relationships, Hydraulic Model HEC-RAS
5	World Bank-CAPRA	Open Source	Central American Countries	Rainfall Runoff Relationships, Hydraulic Model HEC-RAS
6	World Bank-MnhPRA	Open Source	Morocco	Hydrological Model HEC -HMS Hydraulic Model HEC-RAS
7	HEC-HMS and HEC RAS	Open Source	Worldwide	Hydrological and Hydraulic Models
8	CCHE-2D	Open Source	Worldwide	2-Dimensional Hydraulic Model

2.3 Review of Best Practices of Vulnerability Assessment

As per the United Nations International Strategy for Disaster Reduction (UN ISDR), Vulnerability is the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Vulnerability assessment involves quantifying the damage susceptibility of physical and social classes with respect to the hazard parameters. In this review, a brief overview of the best practices for physical and social vulnerability assessment is provided in the below sub sections:

2.3.1 Physical Vulnerability

Estimation of direct damage to the general building stocks (percent damage to structures and their contents) can be accomplished using the vulnerability/damage functions. They depict the relationship between intensity of hazard and consequent damage for a specific peril and exposure type. Damage to exposure resulting from a peril at a location is defined in terms of Mean Damage Ratio (MDR), which is ratio of value of damage incurred to total replacement value of the exposure at the location. Total replacement value is the cost of replacing the exposure at the current price. As an example, a typical vulnerability function is given in Figure 2:14. These damage functions are developed through analytical approach complemented by engineering analyses and expert judgment.

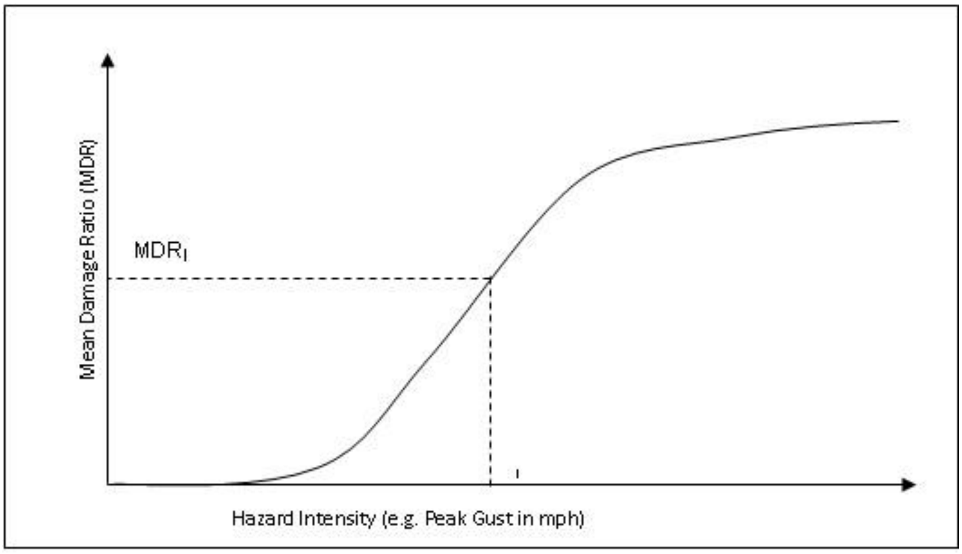


Figure 2:14: Typical Vulnerability Function

The hazard intensity parameter used for development of vulnerability functions vary with the hazard. The hazard intensity parameters considered for various hazards are given below:

Hazard	Intensity Parameter
Wind (cyclone)	Peak Gust (mph)
Surge	Flood Depth (m)
Flood	Flood Depth (m)
Rain	Rainfall intensity (mm/hr) and Duration (hr)

2.3.2 Review of Best Practices for Physical Vulnerability Assessment

2.3.2.1 EQCAT Vulnerability Curves

EQCAT has developed catastrophic models for windstorms and floods for several parts of the world. As part their CAT models they have adopted as set of practices for the development of Vulnerability functions. Vulnerability functions were developed first using a "ground-up" approach with engineering studies, then refined with insurance claims data. An empirical understanding of the effects of a wide range of wind speeds for all relevant building types was combined with investigations into the relative vulnerabilities of different building codes across modeled countries.

For development of vulnerability curves, EQCAT uses an engineering approach, claims data, and expert opinion. Damage from wind and storm surge is calculated using a series of vulnerability functions specific to construction type and occupancy. Vulnerability functions are created to calculate damage impacts for different building heights (low-, mid-, and high-rise). EQECAT vulnerability functions are based on historically observed damage data, and insurance claim data from all the major storms from 1989 to 2008, experimental research conducted by Professors Kishor Mehta and James McDonald at Texas Tech, and structural calculations performed by EQECAT engineers.

Engineering data sources included EQECAT's parent company, ABS Consulting. Forestry risk vulnerabilities are included for Sweden and Finland, based on tree types and heights (http://www.eqecat.com/catastrophe-models/windstorm/europe/#vulnerability-derivation).

2.3.2.2 *AIR Worldwide Vulnerability Curves*

The AIR Worldwide is another The AIR worldwide is another CAT modeling company that has developed hurricane CAT models for different parts of the World. As part of development of Hurricane vulnerability curves, they have adopted a set of practices. The development of Hurricane vulnerability curves in United States was carried out for structures based on their occupancy, construction material, height, roof type, cladding, and opening (Figure 2:15). The building height has been classified into three categories- low rise (1- 3 stories), mid rise (4 - 7 stories), and high rise (8+ stories). The underlying assumptions for developing these vulnerability curves are:

- Commercial residential buildings generally get higher engineering attention than single family homes
- High rise residential buildings are generally well-designed and have high margin of safety factor. Hurricane damage is generally restricted to non-structural components such as cladding
- Low rise commercial wood-frame and masonry residential buildings can suffer significant structural damage similar to single family homes
- Claims data for commercial residential buildings is limited
- Claims data does not always distinguish among condominium association (i.e., commercial residential), condominium unit, and renter insurance policies
- There is no information in the data about the distribution of damage among different floors of an apartment building

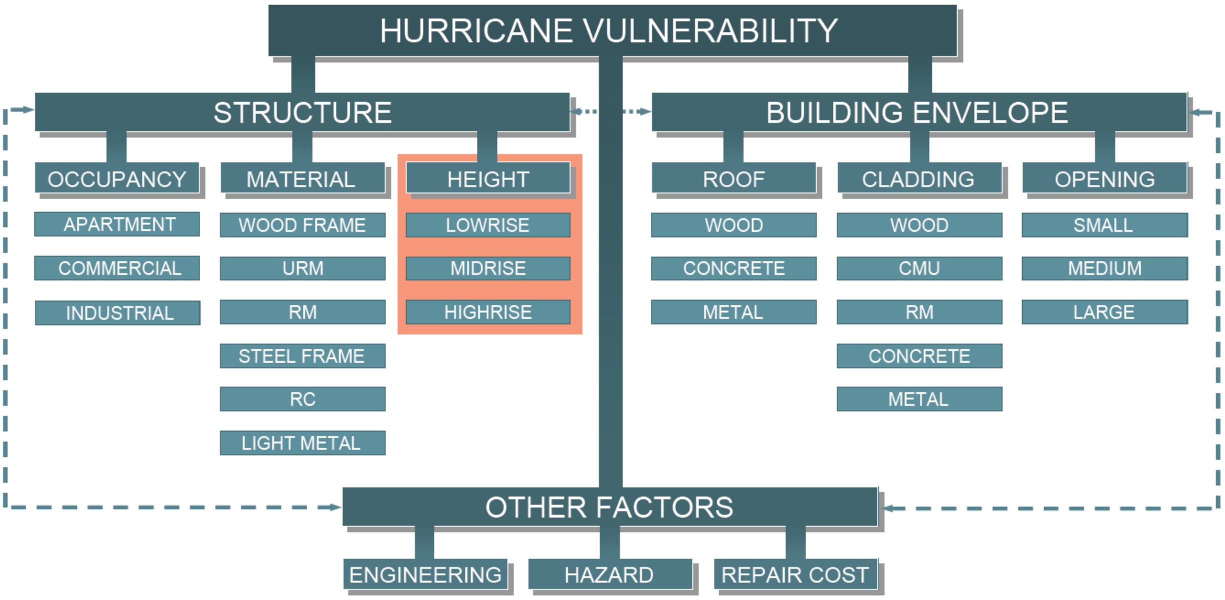


Figure 2:15: AIR Hurricane Vulnerability module

(source:http://www.sbafla.com/method/portals/methodology/Meetings/2009/20090724_AIRCommercialResidential.pdf)

However, for India, AIR developed damage functions based on their occupancy, construction material, and height of buildings only, as there are limitations on the damage database availability for roof type, cladding, and opening. These curves are developed separately for wind and flood. For unknown construction material and or height, the model uses the weighted average approach based on regional distribution. The model has been validated against historical storm data from IMD, International Best Track Archives, and other published sources.

2.3.2.3 CAPRA Vulnerability Curves

CAPRA (Central American Probabilistic Risk Assessment) provides a separate vulnerability module for various hazards. The module provides vulnerability curves for physical vulnerability and human vulnerability. The approach for development is similar to HAZUS-MH. Figure 2:16 provides a typical vulnerability curve for a 2 storey concrete building for physical and social vulnerability for hurricane. Also, the module provides flood-depth damage curves, however, the module does not provide details of the data sets that were used in development of these curves.

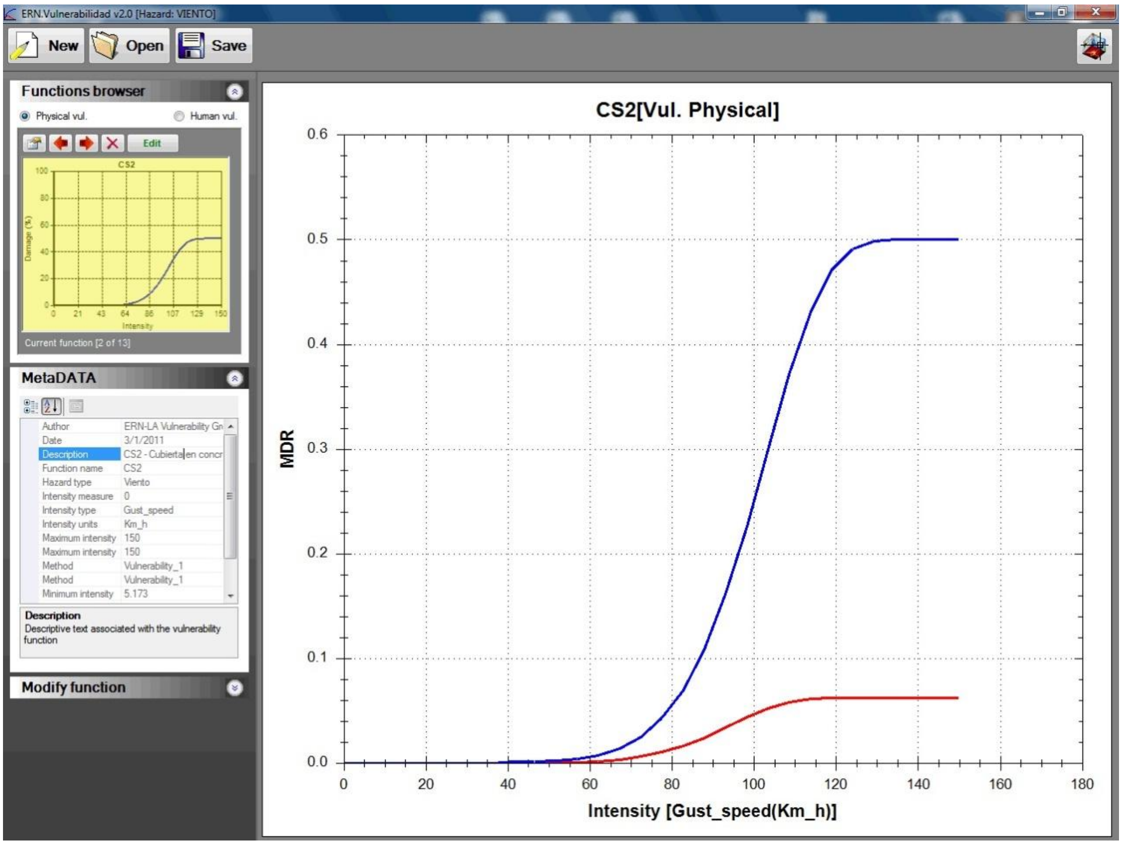


Figure 2:16: CAPRA Vulnerability module

2.3.2.4 RMS Vulnerability Curves

RMS is the World's leading CAT modeling company that has also developed CAT models for both Hurricane and floods for different parts of the world. The development of RMS US Hurricane vulnerability functions is based upon a combination of the historical data, tests, structural calculations, expert opinion, and or site inspections for damage. Any development of the RMS's vulnerability functions is based on structural calculations or expert opinion that is supported by tests, site inspections, or historical data. The development of RMS vulnerability curves are based on engineering principles using the component vulnerability model as well as on analyses of historical building loss data.

The component vulnerability model has an advantage in developing vulnerability functions, especially at higher wind speed ranges where little historical loss data is available, as well as the modeling of vulnerability of various classes of buildings. The component-based building-damage functions are calibrated using historical claims data for each of building, contents, and average living expenses coverage. The calibration process involves a comparison of modeled Mean Damage Ratio (MDR) with that obtained from observed losses.

Recently, in 2009-10, RMS mined and analyzed Hurricane Ike claim data and spent a significant effort on-site to research claims files and interviewed loss adjustors, claims handlers etc. The research revealed many more low wind-speed roof failures than expected from codes and revised its vulnerability curves for residential buildings in RiskLink 11 (2011).

2.3.2.5 US Army Corps of Engineers (USACE) Flood Vulnerability Curves

USACE developed flood depth-damage vulnerability curves for estimating damage to the general building stock using Federal Insurance Administration's (FIA) "credibility weighted" approach and selected curves developed for various districts - Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington. For essential facilities, such as hospitals, schools, and fire stations, the damage is estimated by applying a default depth-damage curve, which is then editable by the user to create a specific function for the facility. Damage is estimated for lifeline systems with a separate set of damage functions that define the potential damage to components of the systems that are either uniquely vulnerable to inundation or are expensive to repair or replace.

A number of prolific USACE District depth damage functions are available for the Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington districts. The New Orleans District has developed expert opinion damage functions (GEC, 1997), for a variety of depth-damage functions including residential and non-residential structures and contents damage for four types of flooding:

1. Hurricane (cyclone) flooding, long duration (one week), salt water
2. Hurricane (cyclone) flooding, short duration (one day), salt water
3. Riverine or rainfall flooding, slow rising and slow receding, freshwater
4. Riverine or rainfall flooding, flash flood, freshwater

In addition, non-residential content damage functions have been provided for a variety of occupancies: The only limitation for these vulnerability functions is that "no basement" has been assumed for all the buildings.

2.3.2.6 FEMA –HAZUS Vulnerability Curves

The physical damage model of FEMA, HAZUS-MH predicts hurricane-induced building damage by comparing loads to resistances. Given the estimates of the loads and resistances associated with the modeled failure mechanisms, the HAZUS-MH approach used to predict building damage, consists of monitoring the wind-speed and direction at 15-minute intervals over the entire duration of the storm. At each time step, wind loads are compared to resistances to predict direct wind damage. The direct wind-induced damage to buildings modeled is directed towards the performance of the roof and other components. Structural wall failures for masonry and wood frame buildings and uplift of whole roof systems due to failure at the roof/wall connections are also modeled. The empirical models based on judgment and experiences are used in some cases where information on the loads and failure mechanisms for some systems are not known *(FEMA 2009)*.

In general, roof failure, wall failure, and roof and wall failures are the important failures for wind loads and for these FEMA has provided a library of large number of damage curves due to wind loads. Typical vulnerability curves for different building materials and their contents are shown in Figure 2:17 and Figure 2:18.

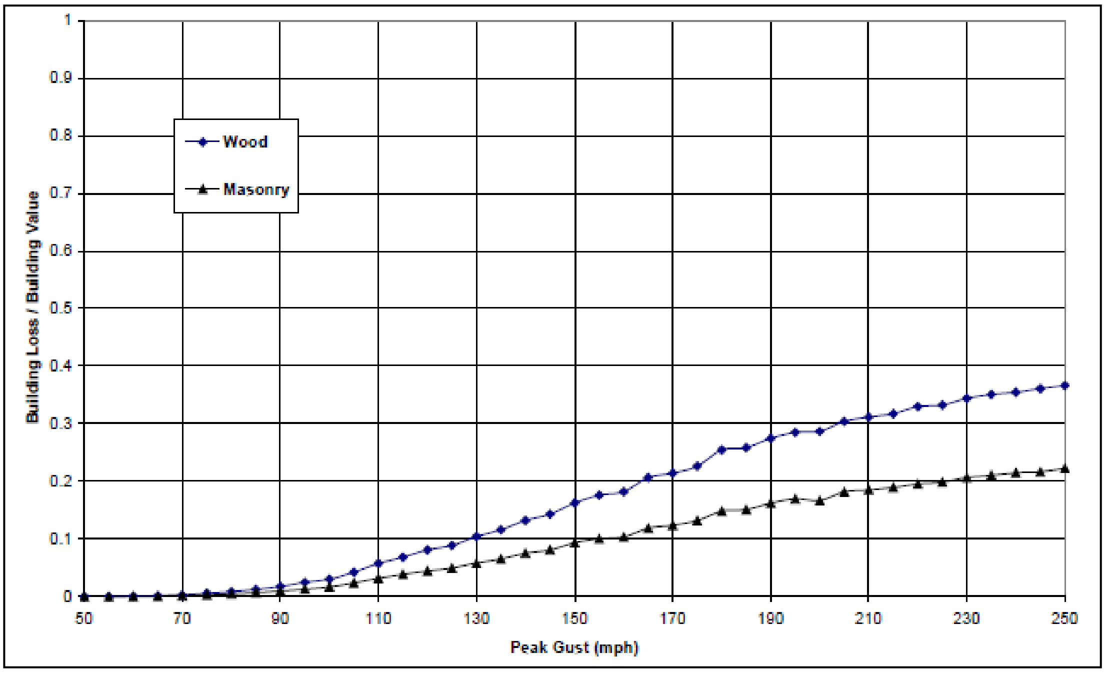


Figure 2:17: Vulnerability curves for different building material types

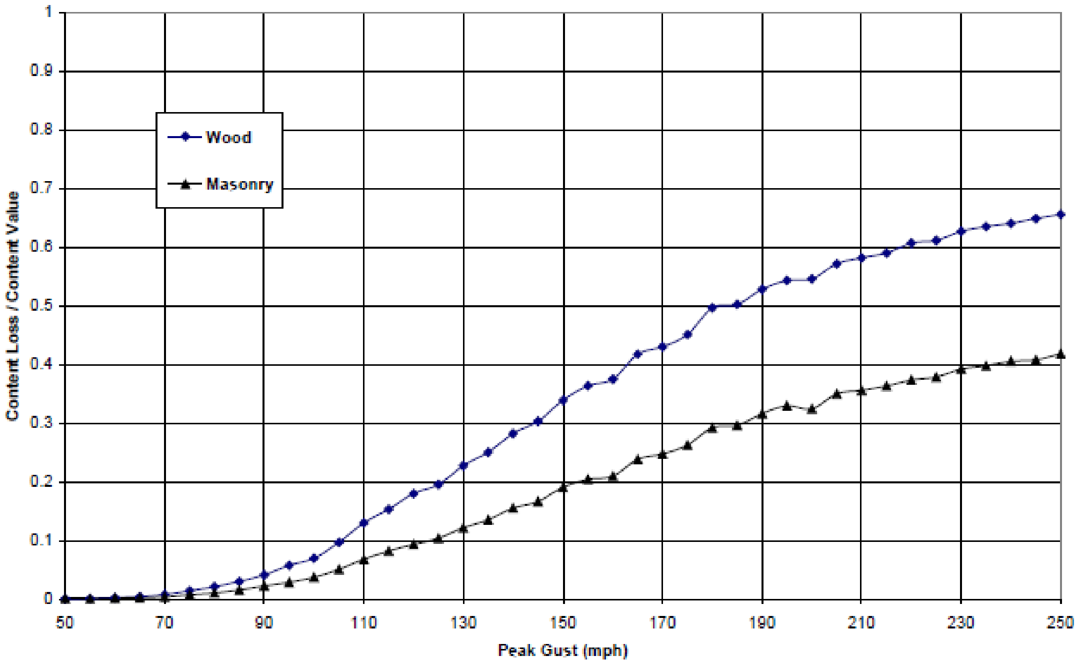


Figure 2:18: Vulnerability curves for Content losses associated with different building types

For water-induced loads, flood–depth damage functions, HAZUS-MH Flood Model has demonstrated the damage and loss capability by developing a large number of curves for use in estimating the damage to various types of buildings and infrastructures in United States.

The HAZUS-MH Flood Model technical manual provides damage function curves for structures, contents, and facilities. Most of these curves have been modified as discussed in the report from the original FIA functions or USACE–Galveston.

2.3.2.7 *Asian Institute of Technology (AIT)*

The Geo-informatics Center at the Asian Institute of Technology (AIT) has developed depth damage functions for adobe, brick, and reinforced concrete structures in Nepal (Hazarika, 2006). The depth-damage functions were developed using post flood damage assessments of 1,514 adobe structures, 3,532 brick structures, and 339 reinforced concrete structures. The damage assessments did not include a separate content damage analysis.

2.3.3 CONCLUSIONS

Based on the review of best practices of various organizations that have developed vulnerability curves, the following points can be summarized (Table 2-3).

- From the review it is evident that damage data from historical events, insurance claims data, engineering studies, and expert judgment are the key inputs for the development of vulnerability functions
- Study of damage from any immediate event provides the best input to calibrate vulnerability functions to any geography. In light of this, it is very important that RMSI team gets approval to send a team for studying the damage due to Phailin cyclone.
- Where there is a lack of data for the development of damage functions, multiple damage functions from various sources representing same structural type could be combined using a weighted average approach.
- RMSI's approach for vulnerability is consistent with the best practices of the organizations in open source, and is detailed in the methodology section 3.2.6.

Table 2-3: Summary of the Risk Assessment models for Vulnerability

Sr. No	Firm	Ownership	Geography	Remark
1	AIR World Wide	Proprietary	North America, Major part of Europe, and some countries in Asia	developed for own purpose
2	EQECAT	Proprietary	USA, Austria and Germany and several other countries	developed for own purpose
3	RMS	Proprietary	North America, Major part of Europe, and some countries in Asia	developed for own purpose
4	FEMA-HAZUS MH	Open Source	USA	Most detailed and are available in public domain
5	World Bank-CAPRA	Open Source	Central American Countries	Available in public domain
6	AIT (flood)	Open Source	Nepal	Available in public domain but available only for floods
7	USACE (flood)	Open Source	USA (Chicago, Galveston, New Orleans, New York, Philadelphia, St. Paul, and Wilmington districts)	Available in public domain

2.3.4 SOCIAL VULNERABILITY

Social vulnerability refers to the socioeconomic and demographic factors that affect the resilience of communities. Studies have shown that in disaster events the socially vulnerable are more likely to be adversely affected, i.e. they are less likely to recover and more likely to die. Effectively addressing social vulnerability decreases both human suffering and economic losses related to providing social services and public assistance after a disaster.

2.3.5 BEST PRACTICES FOR SOCIAL VULNERABILITY

Social vulnerability (SV) within the disaster management context was introduced in the 1970s when researchers recognized that vulnerability also involves socioeconomic factors that affect community resilience (Juntunen 2005). There are three different methods popularly being used for social vulnerability assessment. All these methods have their relevance in the context of the objective of the SV exercise. The three methods are:

1. Social Vulnerability Index
2. Social vulnerability based on casualty modeling
3. Community based vulnerability assessment

2.3.5.1 Social Vulnerability Index

Index based social vulnerability assessment is mainly used to quantify and analyze the distribution of vulnerability groups. GIS technology is effectively used for mapping the spatial distribution. Social indicators are identified and a weighted ranking method is used for developing the index, which is confined to a defined administrative unit. Selection of indicators varies even though most of the practitioners use some of the key demographic indicators including gender, age, disabled people, income, minority community, education, access to information (particularly for cyclone), etc. (Barry E. Flanagan et al 2011, Cutter, S.L and C. Finch. 2008, Cutter et al, 2000). University of South Carolina has contributed substantially in the SV Index development and developed social vulnerability for the whole of US using census data. The SV index developed in US is widely used from local administration for mitigation and planning during natural hazards – particularly hurricane and flood. SV indexing will help in prioritizing mitigation and planning to reduce social impact due to natural hazards that can be predicted ahead of time..

2.3.5.2 Direct Social Loss - Casualty

The HAZUS manual provides detailed methodology for causality and injuries for earthquake and flood hazards. The social vulnerability is an input along with physical vulnerability for risk modeling. For earthquake, detailed models have been developed to assess the life loss, injuries (different levels) specific to time (day or night) and location (resident, business and transit). The flood casualty model considers life loss due to flood and heavy rain due to hurricane/tropical storms based on observation of historical events. Casualties that occur in flood waters, within buildings, and rain-related motor causalities have been considered. All the CAT models developed by AIR, EQ CAT, RMS give less emphasis on social vulnerability. These models emphasize more on the physical vulnerability and loss of physical assets. Risk assessment of these models mainly cater to the insurance industry (physical asset). In MnhPRA social vulnerability was assessed through developing damage functions based on life loss and injuries of historical events.

2.3.5.3 Community Based Vulnerability Assessment

Community based vulnerability assessment is basically used for carrying out vulnerability assessment for small geographic areas. When the geographic area is small, it has limited demographic data and organize it further in lower administrative units which can be used for SOVI analysis. Organizations like the CARE International focuses on the qualitative aspects of addressing the underlying causes of vulnerability at a variety of scales (from national to household/individual) (Dazé, Ambrose, & Ehrhart, 2009); Practical Action's Vulnerability to Resilience (V2R) framework stresses the dynamic and cyclical nature of building resilience to climate change (Pasteur, 2010), which makes numerical measurement difficult. A comprehensive framework for assessing vulnerability to climate change, provided by IUCN, also focuses on obtaining qualitative data from communities and triangulating it with scientific data (although some matrix ranking of vulnerability versus adaptive capacity is included) (Marshall, et al., 2009). The key tools used for this include transect walk with community, PRA exercises with community, focus group discussions, and key informant interviews.

2.3.6 Conclusions

As all the three methods have different applications and the present assignment requires analysis of coastal States and UTs as well as of the hotspot locations, we propose to adopt all the three methods.

- The SOVI will provide the degree and distribution of vulnerable areas along the coastal states and UTs
- The flood casualty model will help integrate social risk into the risk assessment module
- The CBVA will help in mapping the vulnerability at village/panchayat level in the 10 hotspot locations.

2.4 Review of Best Practices of Risk Assessment Software

A computer based solution for natural disaster risk assessment, ranges from desktop to web-based applications for national and international, public or/and private companies. These solutions can range from customized, peril based business solutions to open source solutions. The applicability of these software can be at global, regional or local scales.

The main objective of reviewing the best practices being followed in Risk assessment software development is to identify the standard best practices practiced in risk assessment software worldwide and to implement them within the scope of the present project. Following are the factors considered to identify candidate software for this task:

- Technology/Operating system
- Built in models
- Speed and demand for computing resources
- Supporting software
- Possible technical support
- Study Region

Considering the above factors, the following candidate software have been analyzed in depth to get understand the best practices being followed in these software:

Table 2-4: List of candidate software

S. No.	Software Name	Web based / Desktop
1.	HAZUS-MH	Desktop
2.	Digital Coast	Web based
3.	Pacific Catastrophe Risk Assessment and Financing Initiatives	Web based
4.	CAPRA (Central American Probabilistic Risk Assessment)	Web based
5.	Global Risk Data Platform	Web based

S. No.	Software Name	Web based / Desktop
6.	Des Inventar	Web based
7.	UNDP's Tsunami Resources and Results Tracking System	Web based
8.	Puducherry Decision support system (PDSS) for Natural Disaster Risk Reduction	Desk top

2.4.1 HAZUS-MH

HAZUS-MH is a standardized software that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. Hazus is used for mitigation and recovery as well as preparedness and response. Government planners, GIS specialists, and emergency managers use Hazus to determine losses and the most beneficial mitigation approaches to take to minimize them.

2.4.1.1 HAZUS-MH for Hurricane Winds (Coastal Storms)

A probabilistic hurricane wind-model was used to estimate building damage resulting from 10, 20, 50, 100, 200, 500, and 1,000-year return period storms. Additionally, HAZUS-MH generated an estimate of annualized capital-stock losses due to hurricane winds.

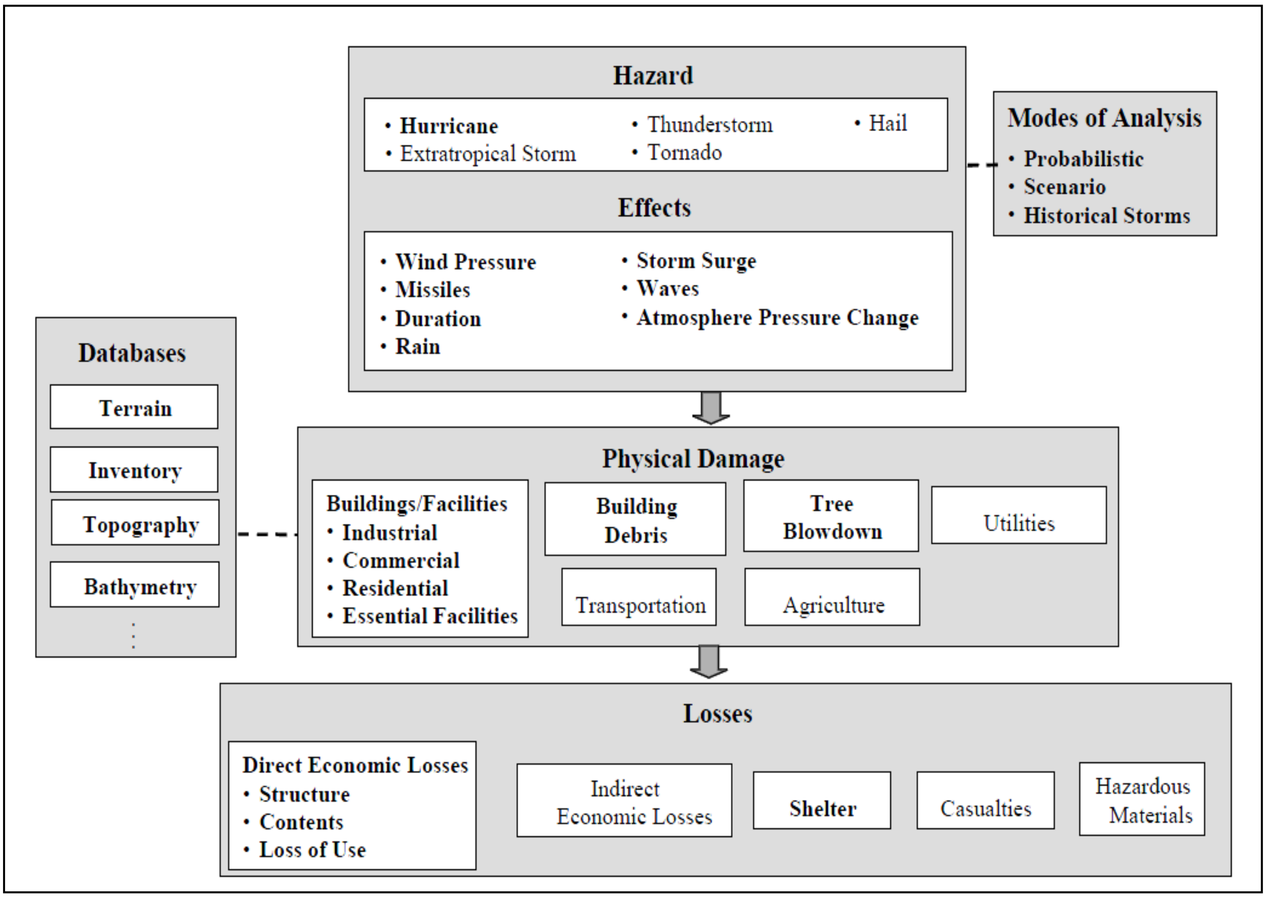


Figure 2:19: Hazus Wind Model Framework

Hazus Wind Model Framework – Elements (Shown in Bold in Figure 2:19) are implemented in the current version of the Hurricane Model.

Summary:

- Desktop programs
- License: Though free but runs on ESRI platform - ArcGIS 9x-10x
- Language: English
- Operating : MS Windows® XP Service Pack 2 or higher
- Language: C,C++
- Technology: Visual C++ 6.0, MFC, COM/DCOM
- Relational database (SQL Server) - Proprietary

2.4.2 Digital Coast

Digital Coast is a partnership and community resource initiated by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center for use by those organizations that manage the nation's coastal resources. The resource, in the form of a website, was developed to address the needs of its users by providing a simplified way to access data relevant to the coast, as well as the tools and methods to turn these data into useful information, increasing user efficiency and effectiveness.

Digital Coast portal provides easily accessible datasets, such as remotely sensed imagery, elevation, land cover and change, benthic habitat, historical shoreline, and other geographic information system (GIS) data developed by the NOAA Coastal Services Center and through government and private-sector partnerships. Access to these data is provided via the Internet, but unlike traditional Web-based data portals, supplementary information about applicable geospatial technology, examples of relevant applications of the data, and opportunities for training are made readily available.

It provides links to various data, tools and additional resources at a single location. The summary of tools and data provided by digital coast is given in the table below:

Figure 2:20: Digital Coast web interface

Figure 2:21: Digital Coast web interface for Historical hurricane tracks (http://www.csc.noaa.gov/hurricanes/#)

Table 2-5: Summary of tools and data provided by Digital Coast

Data Type	Focus Area	Function	Platform	Tool Type
Socioeconomics (13) Hydrography (5) Elevation (22) Imagery (5) Land Cover (16) Ocean Planning (10) Benthic (9)	Climate Adaptation (11) Coastal Conservation (18) Coastal Economy (15) Coastal Hazards (23) Community Resilience (33) Land Use Planning (21) Ocean Planning (20) Water Quality (10)	Change (11) Classification (13) Data Analysis (20) Non spatial Visualization (6) Spatial Visualization (35)	Desktop (21) Web (24)	Data Graphic (4) Handler (9) Model (14) Participatory (6) Viewer (21)

*** Numbers in bracket shows the number of datasets and tools in the related areas.

Summary:

- Various datasets for USA
- Desktop applications (ArcGIS – proprietary, Map Window – Open source) to serve data
- Web viewer to serve data over web

2.4.3 Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI)

PCRAFI is a joint initiative of SOPAC/SPC, World Bank, and the Asian Development Bank with the financial support of the Government of Japan and the Global Facility for Disaster Reduction and Recovery (GFDRR), and technical support from AIR Worldwide, New Zealand GNS Science, Geoscience Australia, Pacific Disaster Center (PDC), OpenGeo and GFDRR Labs.

The Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) aims to provide the Pacific Island Countries (PICs) with disaster risk modeling and assessment tools. It also aims to engage in a dialogue with the PICs on integrated financial solutions for the reduction of their financial vulnerability to natural disasters and to climate change. The initiative is part of the broader agenda on disaster risk management and climate change adaptation in the Pacific region.

The Pacific Disaster Risk Assessment project provides 15 countries with disaster risk assessment tools to help them better understand, model, and assess their exposure to natural disasters. It builds on close collaborations between the Secretariat of the Pacific Community through its Applied Geoscience & Technology Division (SPC/SOPAC), WB and ADB, with technical inputs from GNS Science, Geoscience Australia, and AIR Worldwide.

Figure 2:22: PCRAFI interface

Pacific Risk Information system (PaRIS) is web based and is one of the outcomes of PCRAFI initiative's application built on open source GIS (Geonode) based architecture. PaRIS is one of the largest collections of geospatial information for the Pacific island region. It has been assembled to provide detailed probabilistic risk information for 15 Pacific island countries for a range of decision makers including disaster risk management agencies.

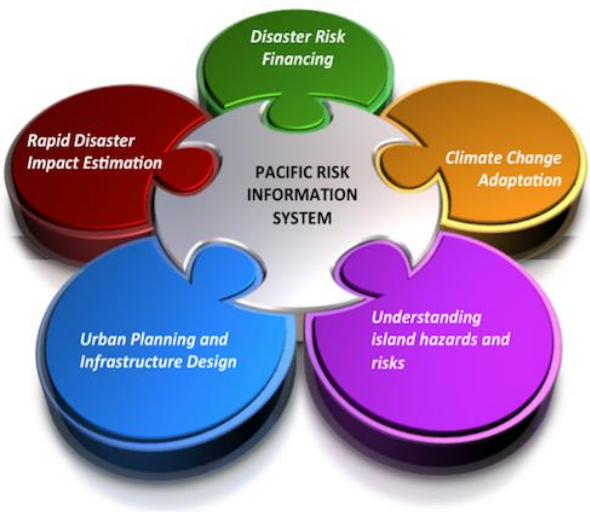


Figure 2:23: Goals of PaRIS - PCRAFI

PCRAFI has assembled, processed, developed, and organized the largest collection of geo-referenced data for hazard modeling in the region:

- Satellite imagery
- Topographic maps
- Bathymetry maps
- Surface geology maps
- Surface soil maps
- Land Cover/Land Use maps
- Geodetic and fault data
- Historical catalogs of tropical cyclones and earthquakes

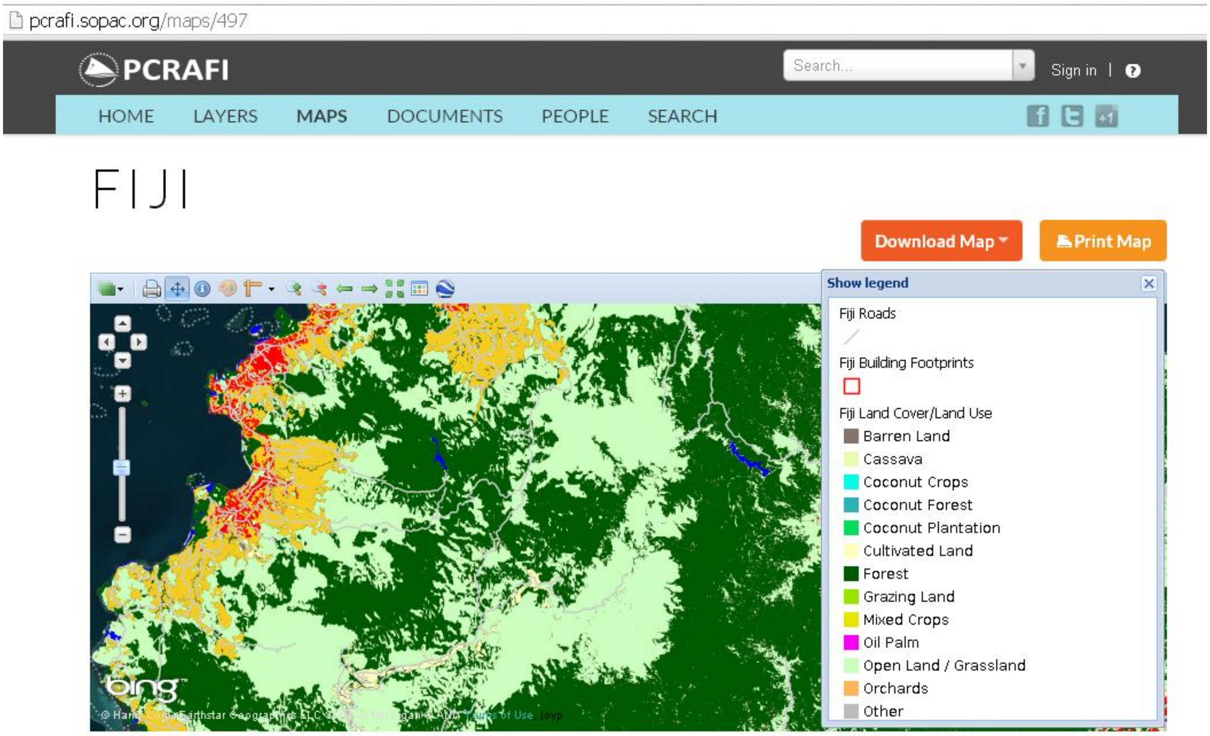


Figure 2:24: Sample data layers in PCRAFI application

The perils covered are tropical cyclones (wind, storm surge and rain) and earthquakes (ground shaking, tsunami). The countries covered are Cook Islands, Fiji, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor Leste, Tonga, Tuvalu, and Vanuatu.

PCRAFI is a part of SOPAC Geonode. The purpose of the SPC Applied Geoscience and Technology Division (SOPAC) is to ensure the earth sciences are utilized fully in order to fulfill the SPC Mission. In the island context, the earth sciences comprise geology, geophysics, oceanography and hydrology.

Summary:

- PaRIS – PCRAFI is developed on Geonode platform. GeoNode is an open service built on open source software.

GeoNode is a web-based application and platform for developing geospatial information systems (GIS) and for deploying spatial data infrastructures (SDI). GeoNode is developed using several open source projects. Some of them are given below:

- GeoExt - The JavaScript toolkit for rich web mapping applications
- GeoServer - Standards based server for geospatial information
- GeoWebCache - Cache engine for Web Mapping Services (WMS) Tiles
- OpenLayers - Pure JavaScript library powering the maps of GeoExt
- pycsw - CSW metadata catalogue server

- PostGIS Spatial Databases

The data in this application is served using open standards endorsed by the Open Geospatial Consortium (OGC); in particular, WMS (Web Map Service) is used for accessing maps, WFS (Web Feature Service) is used for accessing vector data, and WCS (Web Coverage Service) is used for accessing raster data. WMC (Web Map Context Documents) is used for sharing maps.

GeoWebCache provides mapping tiles that are compatible with a number of mapping engines, including Google Maps, Bing Maps and OpenLayers. All the data hosted by GeoNode is also available through GeoWebCache. GeoWebCache improves on WMS by caching data and providing more responsive maps by reducing response time and improving performance of the application.

PostgreSQL/PostGIS is an open source GIS relational database extender for PostgreSQL object-relational database. It adds support for geographic objects allowing location queries to be run in SQL. PostGIS offers many features rarely found in other competing spatial databases such as Oracle Locator/Spatial and SQL Server.

2.4.4 CAPRA (Central American Probabilistic Risk Assessment

CAPRA is an open source platform for risk analysis, which applies probabilistic techniques to hazard and loss assessment. The platform was designed from the start to be modular and extensible. Hazard information is combined with exposure and physical vulnerability data, allowing the user to determine conjoint or cascade risk on an inter-related multi-hazard basis, distinguishing the platform from previous single hazard analyses. The CAPRA suite of software includes hazard mapping, risk assessment and cost-benefit analysis tools to support pro-active risk management. CAPRA can also be used to design risk-financing strategies.

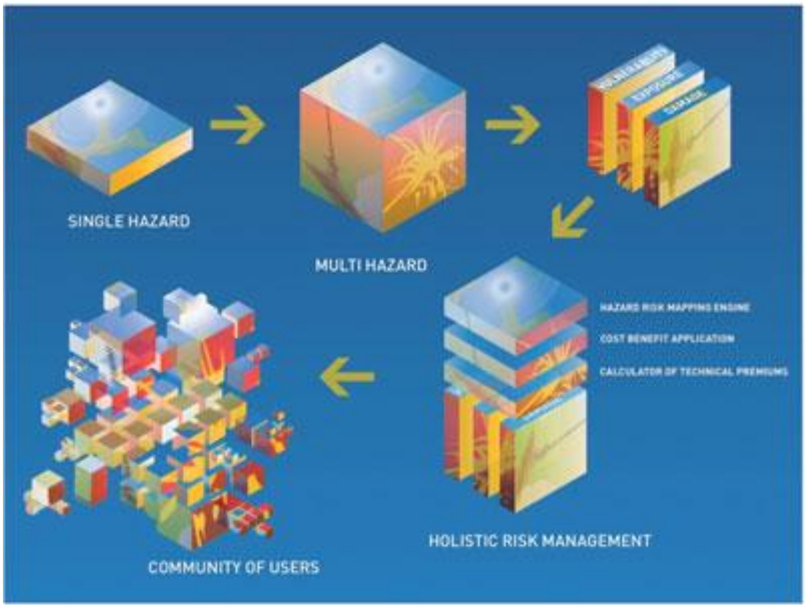


Figure 2:25: CAPRA – Risk Assessment flow

CAPRA has the following series of primary products:

- Compendium of hazard and risk maps – printed atlas
- CAPRA Geonode – Online data and maps
- Hazard and Risk reports
  - Country risk profiles
  - Indicators of risks and risk management

- Software to evaluate risk
  - Hazard models, vulnerability and risk visualization
- Training courses and material
- Series of user friendly materials
  - Hazard assessment report for territorial planning;
  - Cost-benefit application for analysis of retrofitting projects;
  - Calculator of technical premiums for insurance.

Figure 2:26: CAPRA interface

The table below shows a list of CAPRA primary products.

Table 2-6 : List of CAPRA Products

S.No.	Tool name	Platform	Summary	Source URL
1	CAPRA-GIS	Desktop	Geographic information system developed by ERN-AL, which is oriented to probabilistic risk calculation	http://www.ecapra.org/capra-gis
2	CRISIS 2007	Desktop	Seismic and tsunami hazard module. It allows the complete definition of a seismic model for probabilistic hazard assessment, and the calculation of stochastic scenarios for risk evaluation. CRISIS2007 was developed at the Engineering Institute of the National University of Mexico (UNAM), by M. Ordaz, A. Aguilar and J. Arboleda	http://www.ecapra.org/crisis-2007
3	ERN-Floods	Desktop	ERN-Inundación allows the analysis of river flooding, based on a set of stochastic rainfall scenarios calculated with ERN-Huracán (for hurricane rain) or ERN-LluviaNH (for non-hurricane rain).	http://www.ecapra.org/ern-flood
4	ERN-Hurricane	Desktop	ERN-Hurricane is a system of probabilistic modeling of hurricane threat, developed by ERN-AL. The program takes as input the recorded paths of historic hurricanes and hurricane generates stochastic paths that are consistent with the original path. Calculates threat scenarios by high winds, storm surge and heavy rain.	http://www.ecapra.org/ern-hurricane-0
5	ERN-Landslides	Desktop	The module for landslide hazard assessment is currently under revision and is scheduled to be available the fourth quarter of 2013.	http://www.ecapra.org/ern-landslide
6	ERN-Rain	Desktop	The modeling of rainfall not associated with the passing of a hurricane nearby a specific region can be performed using ERN-LluviaNH, developed by ERN-AL.	http://www.ecapra.org/ern-nhrain
7	ERN-Volcano	Desktop	ERN-Volcan is a specialized system in the modeling of volcanic hazard. The program allows to model probabilistically the hazar that a given volcano can generate, in terms of its eruptive history, the magnitude of the eruptions (VEI), and volcanic products can generate.	http://www.ecapra.org/ern-volcano
8	ERN-Vulnerability	Desktop	ERN-Vulnerabilidad is a software developed for the creation and edition of vulnerability curves, for different structural types under the adverse effects of different natural hazards.	http://www.ecapra.org/ern-vulnerability
9	Map Viewer	Desktop	Map Viewer CAPRA-WWJ, is a visualization tool using the NASA® WorldWind Java SDK® engine.	http://www.ecapra.org/mapviewer-capra-wwj

The section below describes the CAPRA- ERN-HURRICANE product, relevant in the present context.

2.4.4.1 ERN-Hurricane

ERN-Hurricane is a system of probabilistic modeling of hurricane threat, developed by ERN-AL. The program takes as input the recorded paths of historic hurricanes and hurricane generates stochastic paths that are consistent with the original path. It also calculates threat scenarios by high winds, storm surge and heavy rain.

A program developed by ERN-AL Consortium for hurricane hazard assessment.

- Version: 1.0.0.0
- Type: Hazard assessment
- License: Apache 2.0
- Language: English and Spanish
- Operating system: MS Windows® XP or higher
- Type: Desktop application
- Language: Visual Basic
- Requirements: .NET Framework 2.0

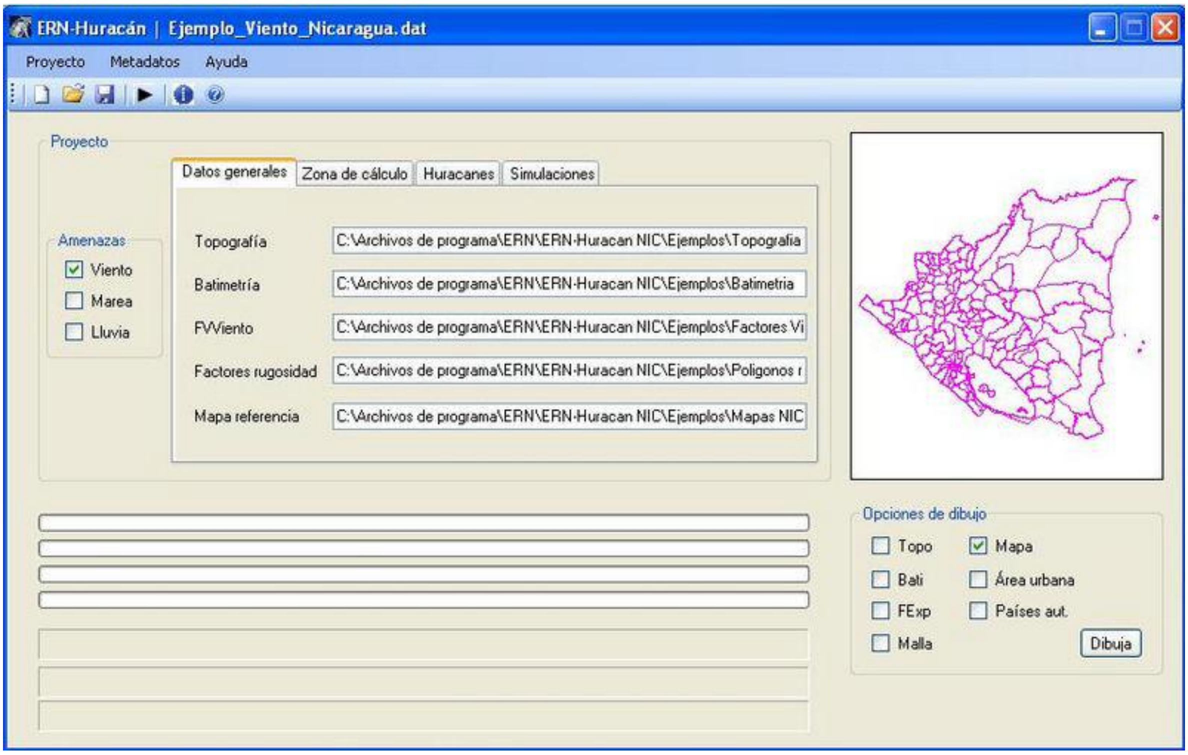


Figure 2:27: ERN-Hurricane system of probabilistic modeling

2.4.4.2 Geonode

GeoNode is being implemented as part of the CAPRA Initiative. Risk assessment projects like CAPRA are very data and analysis intensive, requiring information from a wide variety of sources. This means collaboration. GeoNode can help these initiatives collaboratively manage the input and output data created and collected as part of risk assessments. The results of Phase 1 of the CAPRA project can be found on a GeoNode linked from the www.ecapra.org website. The OpenDRI and CAPRA teams are working together in Nepal and 3 other countries in South Asia to facilitate better management and sharing of risk information.

Summary:

- Desktop applications for various perils using open source technology
- Geonode – open source platform to serve data over the web

2.4.5 Global Risk Data Platform

This application is the new generation of PREVIEW initiated in 1999 by UNEP/GRID-Geneva. The Global Risk Data Platform has now evolved following all standards for Spatial Data Infrastructures (SDI) and providing all the web services in compliance with the Open Geospatial Consortium (OGC).

The data presented here benefited from new developments made for the Global Assessment Report on Disaster Risk Reduction version 2009 and updated for the 2011 and 2013 versions.

The outcomes presented in this application were developed by a large, interdisciplinary group of researchers from around the world, making global disaster risk more visible - a key step towards mobilizing the political and economic commitment needed to reduce it.

Methodologies on hazards modeling were reviewed by a team of 24 independent experts selected by the World Meteorological Organization (WMO) and the United Nations Education and Scientific Cultural Organization (UNESCO).

The Global Risk Data Platform allows the visualization of data on natural hazards, exposure (both human and economical), and risk. Users may perform zooms, pan to a particular area, add different layers of general data including cities, national parks, etc. Different backgrounds can be chosen to highlight different components reflecting vulnerability, such as population distribution, GDP per capita, elevation, land cover. Layers of natural hazards can be added for both events and yearly average for tropical cyclones, droughts, earthquakes, biomass fires, floods, landslides and tsunamis.

The users can visualize, download or use the data live in a GIS software.

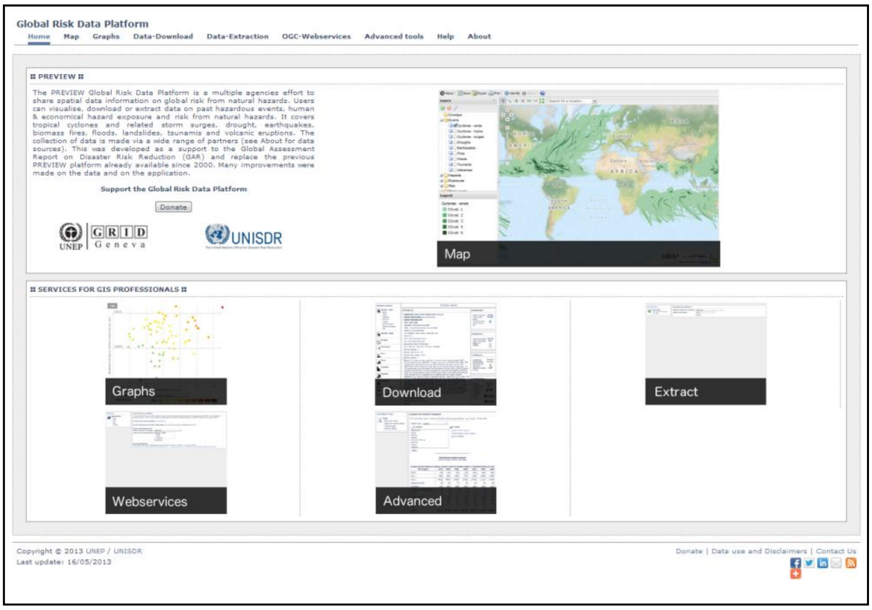


Figure 2:28: Global Risk Data Platform

Summary:

- Geospatial : Open Geosuite (PostgreSQL, PostGIS, GeoServer, Geowebcache, OpenLayers, GeoExt) Server Side Scripting language : PHP
- Reporting: Amcharts

2.4.6 DESINVENTAR

DesInventar is a conceptual and methodological tool for the generation of National Disaster Inventories and the construction of databases of damage, losses and in general the effects of disasters.

The Disaster Information Management System (DesInventar methodology) includes a software product with two main components.

The Administration and Data Entry module is a relational and structural database through which the database is fed by filling in predefined fields (space and temporal data, types of events and causes, sources) and by both direct and indirect effects (deaths, houses, infrastructure, economic sectors).

The Analysis module allows access to the database by queries that may include relations among the diverse variables of effects, types of events, causes, sites, dates, etc. This module allows at the same time to represent those queries with tables, graphics and thematic maps.

Figure 2:29: DesInventar opening page

Summary

- DesInventar on-line is powered by freely available Apache Software Foundation open source products: Apache HTTP server and Apache Tomcat (JSP/Servlet container).
- OS Software used for server - Windows NT, Windows 2000 Server or Windows Server 2003. In the case of Intranet servers, Windows 2000 Professional or Windows XP professional can be considered.
- Following Web Servers and Application Servers can be used:
  - Tomcat 4 or 5
  - IBM Websphere
  - Bea WebLogic
  - Sun ONE application Server
  - Sun Java Web Server
  - Oracle Application Server
- Database Server

  DesInventar has been tested with the following database/indexing systems:
  - Oracle 8i, Oracle 9i, Oracle 10g, Oracle 10express
  - MS Access
  - MS SQL Server 2000 or higher
  - PostgreSQL 7.4 or higher

In theory, DesInventar should run MySQL without any problems, but newer versions have not been tested yet.

2.4.7 EQECAT

The RQE® (Risk Quantification & Engineering) catastrophe risk modeling software platform enables clients to quantify and manage the potential financial impact of natural hazards.

North Atlantic Hurricane Model for US, Caribbean and Bermuda

The North Atlantic Hurricane Model is part of EQECAT's global multi-peril catastrophe modeling platform, RQE® (Risk Quantification & Engineering). The risk model is updated biennially and continues to set standards of scientific rigor in tropical cyclone risk modeling. The model can be used for:

- Risk differentiation and pricing
- Risk aggregation
- Portfolio risk management

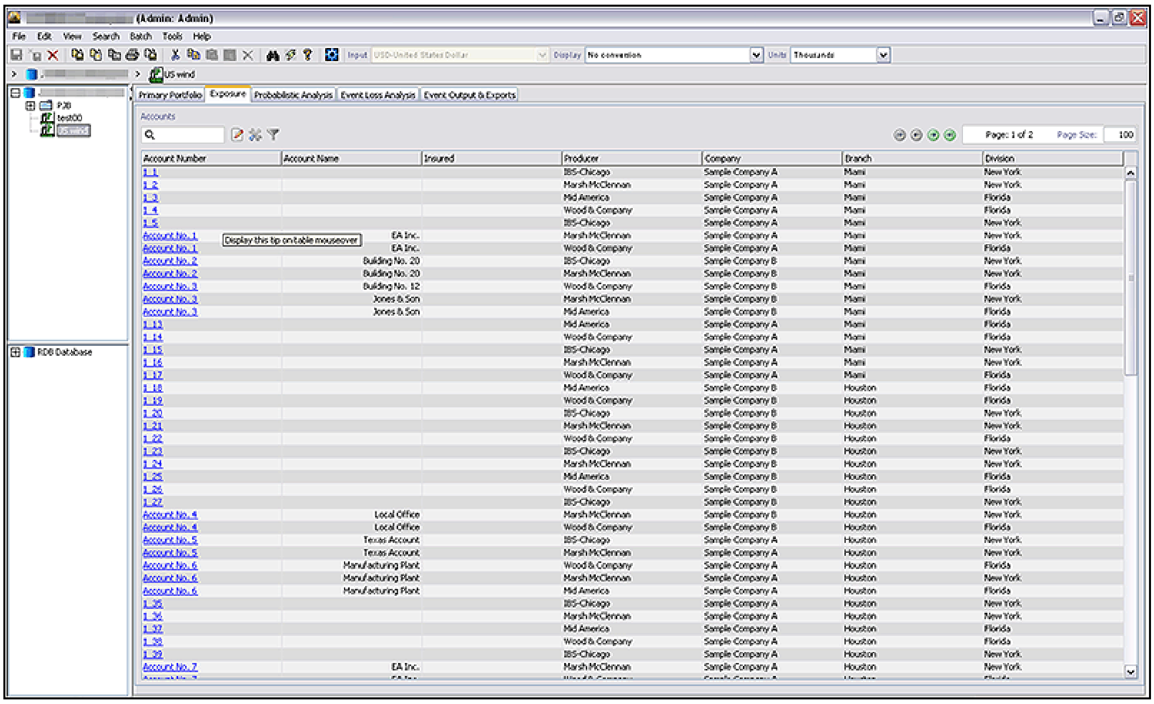


Figure 2:30: RQE (Risk Quantification & Engineering) Import Template Screenshot

Summary:

Results Viewer for RQE software operates on the following Windows operating systems:

<u>Operating System</u>

- Windows 7 x64 Ultimate
- Windows 7 x64 Enterprise Windows 7 x64 Professional
- Windows Server 2003 SP2 64-bit x64 Standard Windows Server 2003 R2 SP2 64-bit x64 Standard
- Windows Server 2008 SP2 x64 Standard, Windows Server 2008 SP2 x64 Standard without Hyper-V
- Windows Server 2008 R2 64-bit x64 Standard

<u>Processor</u>

- Minimum 4 total cores (number of CPU x number of cores per CPU), e.g. single quad-core, two dual-cores

<u>Memory</u>

- 8 GB minimum, 16 GB recommended

<u>3rd Party Software (not provided by EQECAT)</u>

- Microsoft SQL Server 2008 R2 Standard (64-bit) x64 (must be installed on same hardware as Results Viewer) – relational database

<u>Disk Storage</u>

- 1 TB 60 GB required for installation image 400 GB minimum free space for databases (depending upon size of database)

2.4.8 UNDP'S TSUNAMI RESOURCES AND RESULTS TRACKING SYSTEM

The United Nations Development Programme (UNDP) has developed a regional information portal and customized Development Assistance Database (DAD) to help align aid inflows with priority needs. The DAD system is used as a resource for coordination at the regional level. This brings together results and resource allocation data from each country and makes it available at a single site: http://tsunamitracking.org.

By accessing DAD, users can avail of real-time information on who is doing what and where. The portal also provides access to various maps, reports, charts, documents, and other information, which give donors, implementers, governments, and the general public better insight into funding flows and projects' progress. A private sector DAD has also been developed to record private sector flows, particularly those from transnational firms that may not have reported their assistance to the individual government-owned systems in the tsunami-affected countries.

2.4.9 PUDUCHERRY DECISION SUPPORT SYSTEM (PDSS) FOR NATURAL DISASTER RISK REDUCTION

The Puducherry Decision Support System (PDSS) has been built on open source GIS technology and incorporated all the four modules of disaster risk reduction viz. Preparedness, Mitigation, Response and recovery.

PDSS provides maps as well as reports related to the area affected by hazards, loss estimates, and looks for the nearest facilities and suggests early warning dissemination.

It is built on spatial database platform- Qt framework. Qt is a cross platform application framework used for developing GIS based desktop applications. It uses a standard C++ coding and widget toolkit for rapid application development. Qt framework is used to develop various GIS based critical application like Google Earth, Quantam GIS, etc.

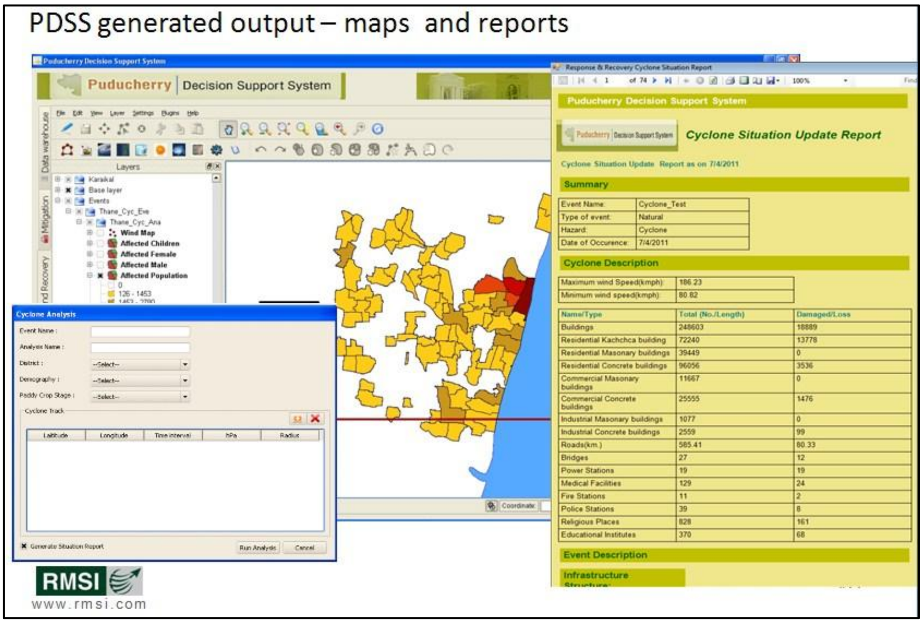


Figure 2:31: PDSS interface

Features:

- Designed and implemented a suitable risk mapping model for Puducherry and Karaikal region
- Maps of risk and vulnerability created with required layers and details
- Availability of consolidated analyzed data on a single platform

- Capacity building on CBDRM model in the Union Territory of Puducherry
- PDSS software is most economical and optimal solution for the client as it has been developed using open source GIS libraries and open source database.
- There is no license fee involved for PDSS hence client can distribute any number of copies of the PDSS to respective department.

Summary:

- Probabilistic modeling using stochastic simulations, Vulnerability and loss analyses, Exposure development,
- PDSS development environment - Open source GIS libraries, PostgreSQL/ Postgis, Qt framework, C/C++ and Microsoft Visual Studio 2008

2.4.10 DIGITAL VULNERABILITY ATLAS FOR SAARC COUNTRIES

The main scope of this project is to create Digital Vulnerability Atlas for selected hazards for four countries namely, Afghanistan, Nepal, Bhutan and Maldives.

The objective of this project is to assist the planners and administrators to be proactive towards disaster management and mitigation. SAARC had envisaged preparing a Digital Vulnerability Atlas of South Asia by integrating the spatial data available from the already existing base maps with the physical, demographic and socio-economic and other data available from various sources.

Summary:

- Web based architecture
- Built on open source technology
    1. Database - Postgre SQL
    2. Mapping server - Geoserver

Table 2-7 : Summary of best practices features in candidate software

S.No.	items	Hazus- MH	Digital Coast	PCRAFI	CAPRA	Global Risk data platform	Des Inventar	EQECAT	Puducherry Decision Support System	Digital Vulnerability Atlas for SAARC Countries
1.	Technology /Operating system	MS Windows XP/ Desktop application	Web based Can run on any popular browser like internet explorer	Web based system built of Geo-node open source technology can run on any popular browser like internet explorer	Desktop Geonode	Web based	Web based	Web based	MS Windows XP/ Desktop application	Web based
2.	Database	SQL Server Relational database Proprietary	Postgres Relational Database Open source	Postgres Relational Database Open source	Postgres Relationa l Database Open source	Postgres Relational Database Open source	MySql Relational Database Open source	NA	Postgres Relational Database Open source	Postgres Relational Database Open source
3.	Built in models	Yes	No	No	No	No	No	Yes	Yes	No
4.	Speed and demand for computing resources	High end system for running analysis	Normal system with internet connection	Normal system with internet connection	High end system for running analysis	Normal system with internet connectio n	Normal system with internet connection	High end system for running analysis	High end system for running analysis	Normal system with internet connection
5.	Supporting software	ESRI ArGIS 9x -10x Licensed	Not required. Data can be downloaded and viewed	Open source GIS Geonode	Open source GIS Geonode		Open source GIS	No	Quantum GIS (Open Source)	PostgreSQL Geoserver, Open layers

S.No.	items	Hazus- MH	Digital Coast	PCRAFI	CAPRA	Global Risk data platform	Des Inventar	EQECAT	Puducherry Decision Support System	Digital Vulnerability Atlas for SAARC Countries
			in any GIS software							
6.	Possible technical support	Available in US only	NA	NA	NA	NA	NA	Yes	Yes	NA
7.	Study Region	USA	USA	Pacific Island Countries (PICs)	Latin American Countries	All the countries across world	Across the world disaster database	USA Europe	Puducherry India	Nepal Bhutan Afghanistan Maldives

2.4.11 CONCLUSION

Based on the review of risk assessment software, it has been found that most of the risk assessment software use highly sophisticated technology. Relational databases such as SQL server and PostgreSQL are used to store data at the backend. In addition, most of these software, except HazusMH and ERN Hurricane, are web based. SQL Server is robust database but it is proprietary software and a licensing fee is associated with this database. In contrast, PostgreSQL is an open source GIS based relational database and stores geometry as one of its attributes. PostgreSQL/PostGIS has been widely used as a backend database in several risk assessment software.

RMSI found that web GIS based software such as CAPRA, PCRAFI and SAARC DVA have been used worldwide for risk assessment practices. Most of these software have been built on open source technology; hence they are cost effective, have wider reach, are simple to use, facilitate cooperative efforts, and help in faster dissemination of information.

CAPRA and PCRAFI are using Geonode platform, which is an open source platform that facilitates the creation, sharing, and collaborative use of geospatial data. It is a complete spatial data infrastructure solution that extends the OpenGeo Architecture with catalog functionality and a sophisticated user experience. It is highly customizable and extendable.

Based on the widespread application of Geonode based web application and as one of the requirements of TOR, it has been decided that a Geonode based risk assessment software will be developed for this project. PostgreSQL/PostGIS will be used as backend database to store geometry as well as tabular data.

3 Approach and Task-wise Methodologies Adopted

3.1 Overall Approach

Our overall approach will be based on the applying the best of international catastrophic risk assessment practices by adapting them to Indian conditions. For this, we will work in close collaboration with various central and state government agencies (Stakeholders), local experts etc., at various stages of the project in order to make the best use of their experiences regarding various aspects of Hazard, Vulnerability and Risk Assessment (HVRA) for cyclones for 13 states and Union Territories. RMSI understands that Project Management Unit (PMU), National Cyclone Risk Mitigation Project (NCRMP) under the National Disaster Management Agency (NDMA) will serve as a liaison between the various stakeholders and government agencies on one side and the RMSI on the other. At the same time, Local experts will be RMSI's partner and will provide technical support for the project.

Overall approach indicating major steps and involvement of various stakeholders is shown in Figure 3:1.

In close coordination with PMU, RMSI team will undertake project initiation for project management and communication activities. The project management will undertake timely progress monitoring against the set targets and communicate the results to the PMU. As a practice, our senior management reviews project progress regularly for such important projects. This will help track any risks/ problems at an early stage and refurbish the work plan to achieve the targets.

RMSI team will contact various research and scientific groups, which are working on the cyclone hazard in the country from research and scientific organizations such as NRSC, INCOIS, IMD, SOI etc. The objective would be to identify past and ongoing studies related to cyclone modeling and HVRA. Such studies shall be reviewed to identify the limitations (if any), suggest the possible recommendations for improvements, and assess their relevance to this HVRA study.

RMSI project team will identify the State contacts and for this project with the help of PMU NCRMP NDMA. The team will prepare a detailed description of each dataset needed for the study. The team will visit the identified stakeholders and discuss with them the data characteristics as per the detailed description. Based on that, the team will develop an understanding of what data and associated attributes would be provided by them and set a timeline for collection. The team shall identify and evaluate the utility of all pre existing data (on hazard, exposure, vulnerability), scientific data, nationally held data, census data, etc. from various sources such as NRSC, SOI, IMD, INCOIS, etc.

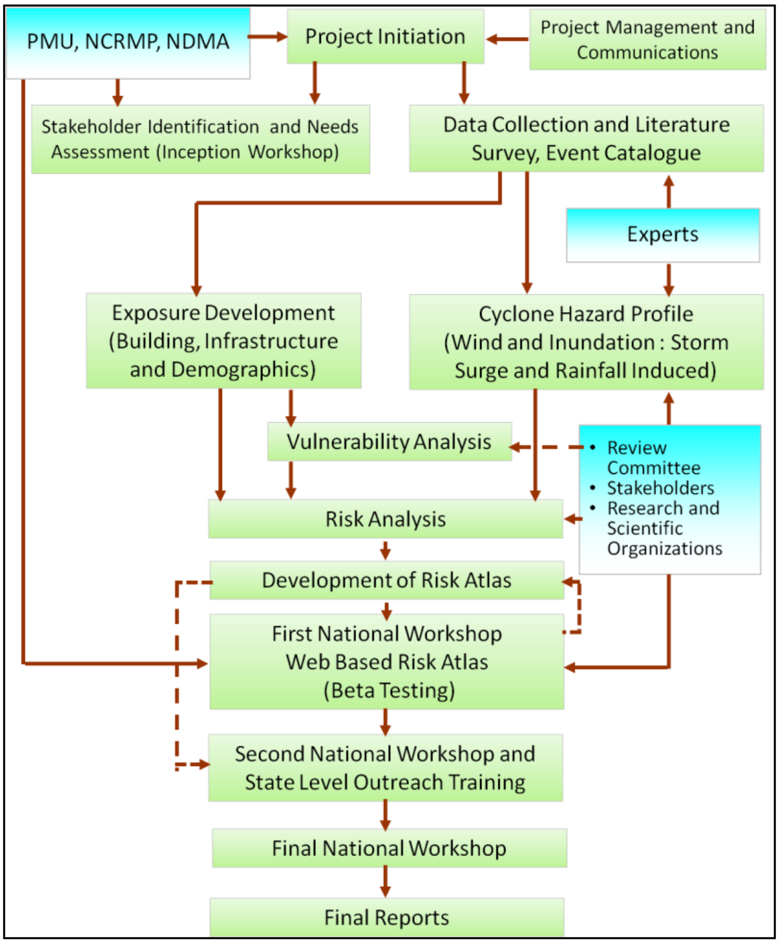


Figure 3:1: Flowchart showing approach and involvement of stakeholders

In the hazard risk profile analysis, the severity and geographical extent of the multi-peril cyclone hazard will be assessed. Team shall establish a scientific and robust methodology for cyclone HVRA based on worked out example. This methodology shall consider the possible interactions amongst various loss mechanisms as shown in Figure 3:2.

Team shall collect and review the information of historical events. The team will focus on identifying the sudden onset hazards based on past hazard information, that have the potential to be major disasters. This will draw upon all existing and accessible data, reports, and collated information, including sources like NDMA, state and central government agencies, IMD, INCOIS, EM-DAT, Dartmouth Flood Observatory, Relief web, UNDP publications and reports, and state level information obtained from state government agencies such as Planning Agencies, Economic Development/Statistics/Revenue.

The methodology for cyclone hazard assessment is given in subsequent sections. This can vary in accordance with the needs of the study and data availability to be assessed immediately after project initiation. RMSI team shall work in close coordination with research and scientific organizations in various stages of hazard assessment. These stages include preparation of historical event catalogue, calibration and validation of models, final results on risk analysis and hazard mapping. RMSI will employ the widely accepted models for this study, which can be updated in future, as and when more detailed or high-resolution data is available. This will also help the respective agencies to replicate the work in future.

During the training session, RMSI will demonstrate how the model development will be done to the key stakeholders who have been identified for taking up cyclone modeling once this study is over. Based on data collection and review and catalogue of historical events, the team shall develop a standard database of input data. Using this database, team shall formulate the various deterministic scenarios for HVRA study.

These scenarios shall consider the various aspects such as spatial and temporal variations in cyclones in Bay of Bengal and Arabian Sea. These scenarios shall be finalized in close coordination with the PMU NCRMP and Project Technical Group. The multi peril cyclone hazard analysis will be conducted for the developed scenarios. The various perils under cyclone hazard shall include winds, inundation due to storm surge and inundation due to cyclone-induced rainfall. Team shall apply state of art and widely accepted models for assessing hazard parameters. The models will be calibrated and validated before applying them in the deterministic scenarios. Finally, the hazard maps will be prepared for the considered scenarios.

Based on the data collected, RMSI team shall develop the exposure data for study area. The main elements of exposure that will be developed are demographics, buildings, infrastructure, critical facilities, utilities, cultural heritage sites, and soil and ecological assets that will involve use of various GIS and remote sensing techniques. The detailed approach for exposure data development is given separately in this report.

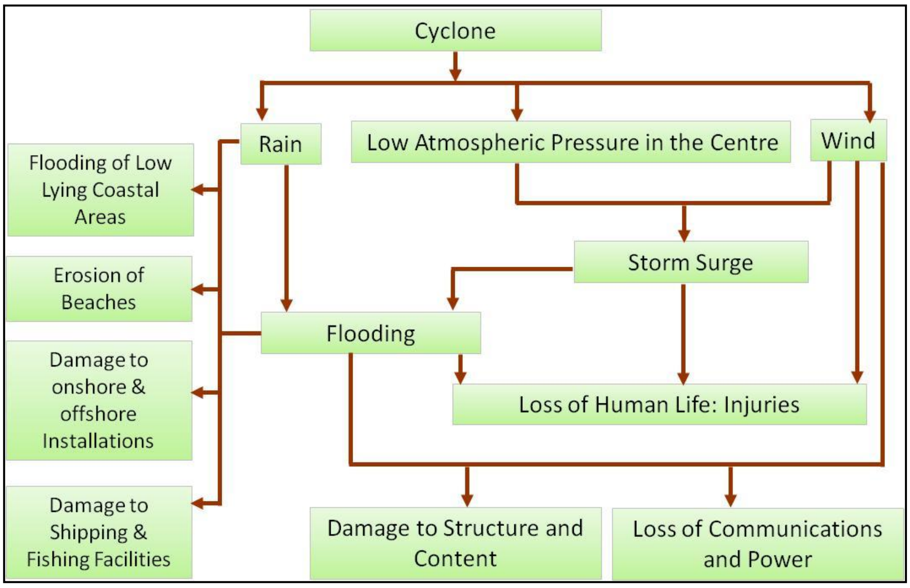


Figure 3:2: Potential impact upon landfall of a tropical cyclone

The vulnerability assessment will involve quantifying the damage susceptibility of each class (physical, social, and economic) with respect to the hazard parameters of each peril. Development of vulnerability functions for the study area will be mainly, but not solely, based on damage data from historical events. An analytical approach complemented by engineering analyses along with expert judgment based on international experience will help in developing vulnerability functions. RMSI team shall work closely with research and scientific organizations to integrate local experiences such as existing building codes, construction practices in general, cultural aspects related to coastal communities, etc. It has been learnt that some of the institutions have worked on the building codes and structural vulnerability aspects. In addition, for specific coastal areas, discussions with key authorities and engineers' associations will be undertaken to understand and document the use of building codes, technical standards for utilities and other infrastructure elements to develop a better understanding of vulnerability. This association will help in deriving more country-specific vulnerability functions.

RMSI shall apply its local and global experience of catastrophe risk assessment in establishing the methodology for risk assessment. The risk assessment shall consider the hazard, vulnerability, and exposure and spatial resolution. Teams will perform the risk assessment at the highest resolution such as habitation/village or Panchayat, which can easily be scaled to mandal, taluka, district, and state levels. Risk Analysis will be carried out in two broad categories: Direct Economic Loss and Social Impact. Direct economic loss will be calculated for every deterministic scenario and for all types of exposures at risk like residential, commercial, industrial buildings, essential facilities, infrastructure and others. Social impact is the quantification of susceptibility of population to mortality and injuries, and needs like shelter, food, rescue/evacuation etc. in the event of a disaster. Finally, risk metrics will be derived as described in the risk assessment section of this proposal. These risk metrics will be estimated for all categories of assets including demography or population. Using risk metrics, vulnerable hotspots will be identified and mapped.

Using the outcomes of study and various data, a Web-GIS based dynamic Composite Risk Atlas will be developed based on Geonode technology. This shall include the various data sets such as remote sensing images, DEM, hazard, exposure, vulnerability and hot spot risk maps. The composite risk atlas shall provide a framework for specific decision support needs (evacuation planning, shelter needs, etc).

The above approach will be first applied to the two Category-I states selected at the time of inception. Once the Risk Assessment and Risk Atlas are finalized for the selected states, the whole process will be replicated for the other states under the study.

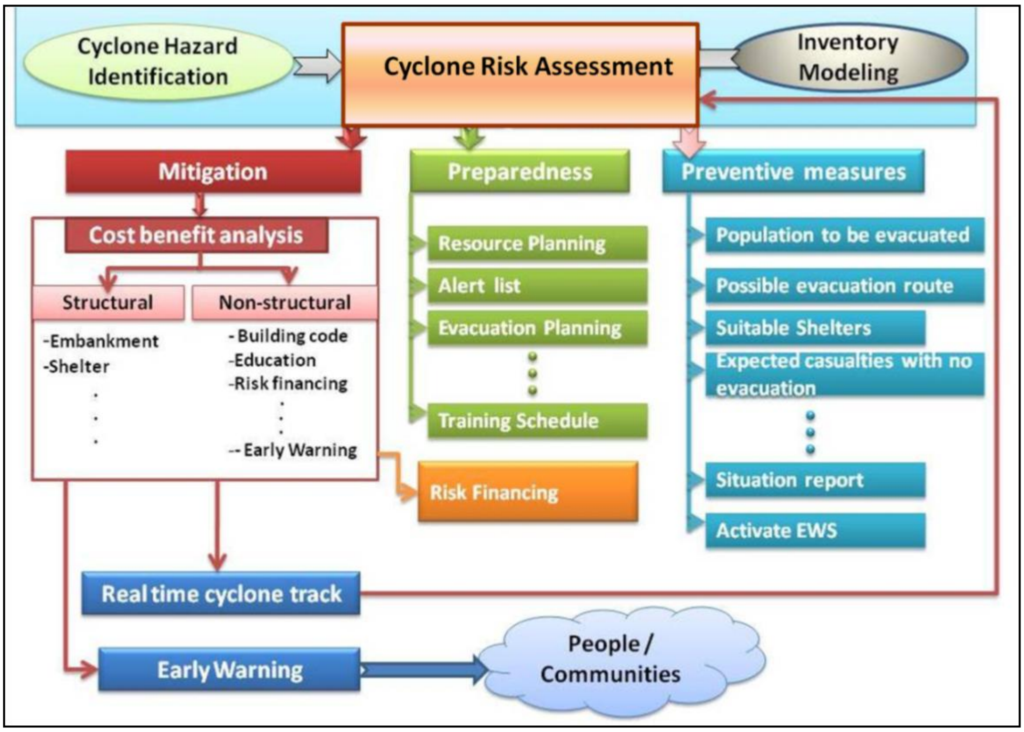


Figure 3:3: Decision Support Framework for Cyclone Risk

The above scenario based HVRA outcomes will be used for identification of hotspot areas and then identification of interventions that reduce vulnerability of structures as well as communities. The hotspot identification will first identify most vulnerable districts and then the most vulnerable Panchayats within identified districts. The interventions will be suggested at the Panchayat level. The figure above shows how outputs of risk assessment can be used for mitigation, preparedness, and response planning. For all identified hotspots, the focus will be on reduction of structural vulnerability through zonation, retrofitting and landuse planning, and population vulnerability through better evacuation planning, contingency planning, shelter planning, etc.

The complete process above will be documented as a Practitioners' Guide to assist in all activities of disaster risk assessment, mitigation, preparedness, response and recovery.

Final outcomes of study will be disseminated through workshops involving PMU NCRMP NDMA, research and scientific organizations, and all the stakeholders. The workshops will be conducted in three parts. First national workshop will include the beta testing of composite risk atlas to get feedback. Second national workshop will be held after addressing the feedback on the beta version of the composite risk atlas. This will be a demonstration to a wider audience. Immediately after the second workshop, state level outreach training shall be conducted. This will provide the state level stakeholders a comprehensive training on the use of the risk atlas for future operations. Final national level workshop will be conducted as a part of the closure and handing over of the Atlas to the state and national users. Based on the feedback and subsequent modifications, the final report will be submitted.

3.2 Task-wise Methodologies

3.2.1 Data Requirements and Availability

Historical track data – Tropical cyclone track data for the North Indian Ocean (the Bay of Bengal and the Arabian Sea) for the period from 1877 to 2011 have been compiled by the Indian Meteorological Department (IMD). This data will also be supplemented with best track data from JTWC and IBTracs (NOAA). The other available sources like Unisys Hurricane Database (2012), SMRC (1998) and several research publications will also be considered in preparing a master database of cyclonic tracks and its intensity information for all the13 States/UTs along the coast of India.

Coastlines - The coastline for India is available from digital world map of National Geophysical Data Center (NGDC http://www.ngdc.noaa.gov/mgg/coast/). RMSI will also approach Indian Government agencies like NRSC and NHO for this dataset. If the data is obtained from the Indian organizations, we will use that data; otherwise the data available with NGDC will be used.

Bathymetry – Various Indian organizations like INCOIS, NHO, NIO, etc. have bathymetric data for the Indian coast. Bathymetric data of Indian coast is also available with the National Geophysical Data Center (NGDC) – NOAA Satellite and Information Service. RMSI team will contact INCOIS and other organizations involved in coastal zone management to collect Bathymetric data that is better than what is available with NGDC.

Surface roughness – Roughness is the characterization of wind resistance/frictional effects of the actual surface relief (buildings, forest canopy, etc.) of the land cover. Surface roughness will be mapped using landuse/land cover data obtained from remote sensing satellite imagery.

Topography – An accurate representation of land topography is needed to compute storm surge, wind field and inland inundation. RMSI will reach out to Survey of India, NRSC, INCOIS and other agencies working with satellite data and also state departments involved with flood management to check for the availability of better resolution DEM i.e. better than SRTM (Shuttle Radar Topography Mission). If a DEM better than SRTM is not available then only SRTM shall be used. In case a better quality DEM is available for certain areas, RMSI will create a DEM by merging various DEM grids on a variable resolution grid that captures all levels of resolution in a single grid.

In addition to these datasets, RMSI will also try to collect the following datasets.

1. GIS and Land Use data

- Detailed survey data – any survey data related to elevation available with state agencies, telecom operators, etc., any data related to buildings, population behavior, etc.
- Land use and Soil data – RMSI has LULC data at 25 meter resolution. RMSI will reach out to NRSC, INCOIS and other agencies for identifying any additional higher resolution data for any areas and will be merged them onto a variable resolution grid to obtain a seamless single grid.
- River network with hydraulic parameters – RMSI has a river network dataset. The team will reach out to agencies involved in flood management for additional datasets and may combine them to create a detailed river network.

2. Rainfall and Flow Data

- Daily/hourly rainfall is available with IMD for about 30 years and discharge data for stations in the study area for long term period will also be requested from various central and state government agencies responsible for maintaining flow gauge stations
- Stage or tidal level data to model tidal impact – Average values for this data are available in the public domain. RMSI team will reach out to INCOIS, NRSC and state coastal management agencies for historical data related to this.
- Flood extent and depth information – There is not much data available on this in the public domain. The state flood management agencies, IMD, CWC, etc. will be approached to explore what kind of data are available with these organizations.

3. Exposure, Demographic, and Economic Data includes

- Buildings and infrastructure
- Critical and high-risk facilities, such as administrative headquarters, police stations, fire stations, hospitals, schools, existing cyclone/flood shelters, etc.
- Low vulnerable structures (for potential shelters/vertical evacuation
- Utility networks such as water, electricity, and telecommunication
- Cultural heritage sites
- Ecological assets such as mangroves and coastal plantations
- Demographic data such as population at different administrative levels with respect to gender, age, disabled
- Economic data such as livelihoods classifications, occupational patterns, BPL, GDP/district, livestock numbers, replacement costs

RMSI team will reach out to state departments responsible for these exposure elements, NRSC for any exposure data extracted from satellite imagery.

3.2.1.1 Data Review and Quality Standard

Standards provide a common method to acquire, manage, and display information. They are necessary to maintain an open system concept and an extensible application. In this regard, PostGRES/POSTGIS shall be used as the spatial database. Having said that, RMSI would discuss this with the PMU and, based on that discussion, take the final decision on the standards to be followed.

As listed in the section on data requirements and availability, RMSI team will further identify and review the availability and utility of existent hazard, exposure, and vulnerability data sources available with various national and state/UT governmental institutes. The team's effort would be to get the highest possible resolution data for all these aspects given the constraints of data availability and time to getting access to the data. The data obtained from various sources will be brought into a single seamless variable resolution grid. The grid will be used as the base standard for all datasets and efforts will be made that this grid remains consistent across various data layers.

In addition, data collected from various ministries and the field, will be run through the quality checking process and will be used for data processing. RMSI will take care of following points during data processing.

- Resolution: A clear understanding will be arrived at with the client about the resolution at which each data set will be processed.
- Projection System: The projection system for final data set will be decided in consensus with the PMU
- Positional Accuracy: Prior to data processing, the reference data for geo-referencing will be finalized. Each dataset will be geo-referenced with respect to finalized referenced data only.
- Naming Convention: Naming convention of all files will be standardized to maintain consistency in the names of all the files.
- Creation of Unique IDs: RMSI will maintain a unique id for each data set, which will help analyze the data at any stage with respect to the initial one.
- Standard Unit in all Dataset: Unit for each entity will be decided and will remain consistent in the entire dataset.
- Essential Fields: RMSI will maintain a few common fields in all the datasets, which help to link them as primary/foreign keys in a relational database.
- Logical Checks: RMSI will apply various logical checks on the data to verify the quality of the data.

3.2.2 METHODOLOGY FOR CYCLONE AND STORM SURGE HAZARDS

North Indian Ocean is one of the most prominent hot spots of cyclogenesis in the world. Statistics show that about 15% of the global tropical cyclones form over the Bay of Bengal and the Arabian Sea, and on an average, 5 to 6 storms form in this region every year, out of which 2 to 3 may be severe. The massive destruction and loss of human life associated with tropical cyclones can be attributed mainly to the sudden inundation and flooding of the coastal areas produced by storm surges. The India Meteorological Department (IMD) categorizes cyclonic storms based on their intensity, which is normally measured from the sustained maximum winds in the cyclone field.

The overall approach for hazard assessment is shown in Figure 3:4 below.

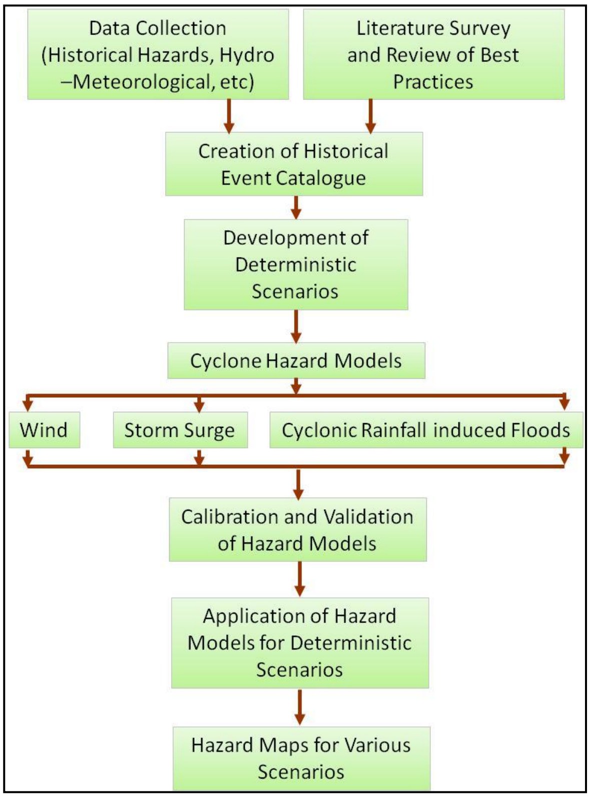


Figure 3:4: Flowchart showing approach for Hazard Assessment

As far as historical cyclone tracks database is concerned, a variety of databases with more than a century of records for the Indian region are available with RMSI. Initially, available cyclone tracks and their intensity information along with the surge reports would be collected for the study area from IMD's atlases, SMRC (1998), IBtracs (NOAA), and from several research publications. The publication SMRC (1998) contains historical records dating back to a few centuries of cyclones, which formed over the North Indian Ocean and made landfall over Indian coasts.

The IMD's Storm Track Atlas (1891-2007) provides tracks of movement and intensity. All the databases will be reconciled to make a uniform master database for cyclone and surge events for the selected area. From the generated master database, frequencies and locations of landfall will be determined for each stretch of the 13 identified coastal states and union territories.

From the generated database, the maximum pressure deficit (ΔP) will be tabulated for each cyclone episode, and using this as input, a suitable statistical analysis will be performed to calculate maximum value of ΔP for key return periods. Climate change and other man-made changes add a further degree of uncertainty beyond assessed projections of the model.

The hazard modeling will be performed using two models:

1. ADCIRC
2. RMSI Cyclone Storm Surge Model

ADCIRC will be used as the primary model and it would be fully delivered to NDMA. The RMSI model will be used as a secondary model for validation purposes.

For the historical tracks, surface winds associated with a tropical cyclone will be derived from a RMSI proprietary dynamic storm model (Jelesnianski and Taylor, 1973). The only meteorological inputs required for the model are the positions of the cyclone, pressure drop and radii of maximum winds at any fixed interval of time. The main component of the storm model is a trajectory model and a wind speed profile approximation scheme. The trajectory model represents a balance among pressure gradient, centrifugal, Coriolis, and surface frictional forces for a stationary storm. A variable pressure deficit, forward speed, and radius of maximum winds are used to compute the wind fields at model grid points. The storm strength is reduced after the cyclone crosses the coast. The above process will be repeated for each time step along the track and the maximum wind will be computed at each location throughout the life of the storm. Figure 3:5 shows sample wind speed maps generated using the model.

Using the historical tracks wind field and associated parameters, dynamical simulation of storm surges will be carried out by making use of the location specific model. The maximum surge height computed with the model will be calibrated/validated against the all observed data. The tidal amplitudes and an assumed wind wave setup will be linearly added to the maximum surge amplitudes, to determine the maximum possible sea level inundation associated with the tropical cyclone at each coastal grid point (spaced at 5-10 km along the coast) of the numerical model. Finally, scenarios of storm surge flooding due to probable maximum surge amplitude will be prepared for all the return periods used in the statistical analysis for the selected districts to identify the flood-prone extent delineation. Figure 6 and Figure 7 show sample storm surge contour and flood extent maps from RMSI model. The figures blow shows the cyclone wind field and storm surge maps generated using ADCIRC model.

The outcomes from this task will be used in the location specific vulnerability and risk associated with cyclonic winds and storm surge flooding. Losses will include physical damage due to wind and surge flooding. The output of the study would be provided for spatial description of coastal inundation involving various GIS themes for village/habitat information system. Assessment of cyclone risk and vulnerability at village/habitat level would be useful to evolve sustainable local level development action plans for preparedness and mitigation.

The analysis will be based on the historical catalogue of tropical cyclones. The catalogue compilation process will involve sourcing, cleaning, and filling the gaps by informed judgment. It is extremely important to assess the wind field and associated surges in almost real time, through a combination of various types of observations and numerical models.

3.2.2.1 Methodology for Deterministic Scenario Generation

Initially, systematic collection of cyclonic data will be carried out from various sources, which have been mentioned in the earlier section.

All the databases will be reconciled to make a uniform master database for cyclone and surge events for the selected area.

From the generated database, frequencies of landfall and locations of landfall will be determined for each stretch of the coast. This comprehensive database will show land falling cyclonic events on the coast during 1877-2012.

A catalogue based on the analyses of the annual frequency of cyclonic disturbances, depressions, cyclonic storms and severe cyclonic storms formed in the Bay of Bengal and the Arabian Sea will be made. Using this historical data, a general trend of the cyclones hitting a particular coast will be determined. The complete coastline will be partitioned into sections on the basis of similar frequencies. This is because the same return period events on east and west coast are very different. For example, a 5 year return period cyclone around Orissa is different from the same return period cyclone in Arabian Sea.

For every such section, based on this catalogue, return periods for various cyclone events (moderate and severe) can be determined by sorting the data based on maximum pressure deficit (ΔP) using a suitable statistical analysis (Gumbel distribution). A maximum value of ΔP will be calculated for return periods of 5, 10, 25, 50, 100 and 500 years.

A significant increasing or decreasing trend of land falling cyclones will be made during the last 2-3 decades along selected coastal stretches. An increasing trend in the frequency of cyclonic disturbances is found in the case of depression in the Arabian Sea as a whole having fluctuations of about 2-6 years (SMRC, 1998). Keeping this in view, the short period of predominant fluctuation with a periodicity of 2-6 years will not be left out. For example, a cyclone of intensity 100 kmph has a return period of 2 years in Andhra but a cyclone of the same intensity in Gujarat may not have the same return period.

For districts having no definite trend or with less stormy activity, return periods for tropical cyclone will be derived by extrapolating from nearby datasets. Such approaches may contain considerable uncertainties.

3.2.2.2 Determination of tidal amplitudes at each grid point of the numerical model for the selected district

After identifying locations along coastal district, RMSI plans to calculate hourly tidal values at each location for 30 years using WXTide32 software. Based on surge data for a particular coastal district, one has to look at a particular month in which the maximum surge is occurring. Accordingly, tidal data for that particular month is considered and the maximum daily water levels will be computed for the 30-year period. Fifty per cent exceedence value for each station will be calculated for final tidal amplitude. At the end, tidal amplitude will be interpolated at each model grid point. Indian Tide Tables will also be considered here.

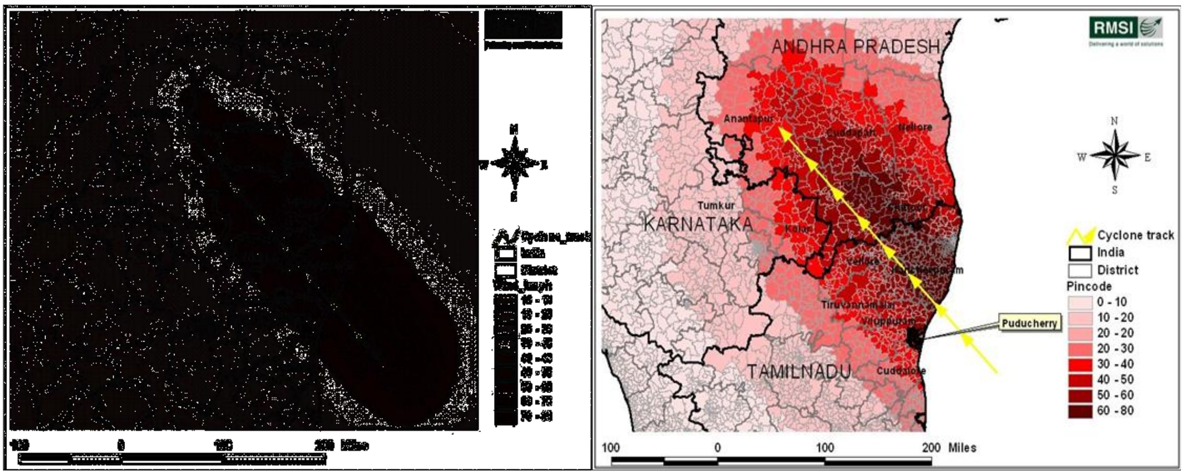


Figure 3:5: Sample of wind field map at district level (left) and at Pin Code level (Right)

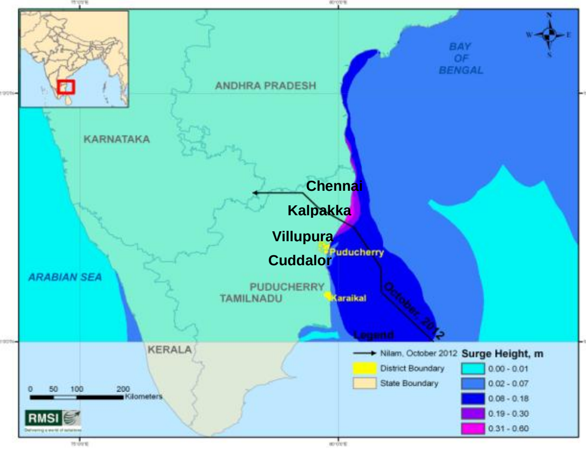


Figure 3:6: Sample of computed peak surge contours (m)

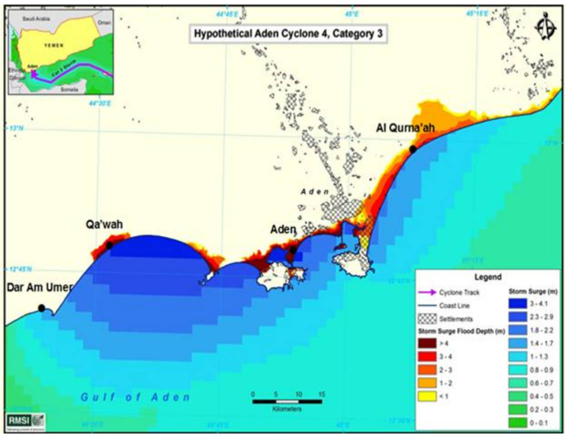


Figure 3:7: Sample output of flood water extent and depth (m)

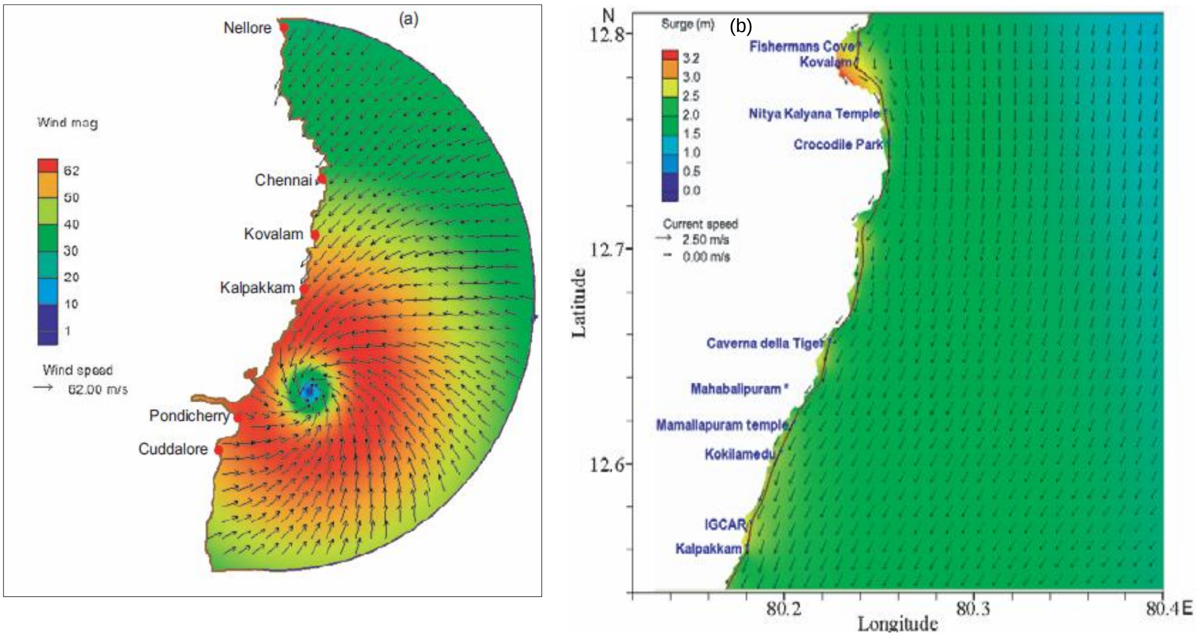


Figure 3:8: (a) Computed wind field (b) Computed storm surges along with associated currents and inundation

3.2.2.3 Computation of Total Water Levels along the Coastal Stretch

The probable total water level (maximum storm surge values) is defined to be the sum of storm surge amplitude with 100-year return period, tidal amplitudes and wave setup. The tides augment the storm surges, and the resulting water levels may be enhanced significantly if they are in tune with each other. Wave set-up is the increase in water level caused by wave action at the shoreline. This is dependent on the magnitude of the wave heights and the local bathymetry near the shoreline. Very recently, some case studies of storm surges associated with typhoons in the East China Sea using a coupled storm surge–wave model by Yin et al. (2009) have reported that the net impact considering all physical mechanisms for setup was a maximum of about 0.5 to 0.6 m.

The probable maximum storm surge (deterministic events) values based on key return periods (2, 5, 10, 25, 50 and 100) will be estimated for all the selected 13 coastal States/UTs of India.

3.2.2.4 Derivation of Inundation Extent Maps

Flood extent maps will be prepared by applying CCHE 2D – Coast Package by integrating model output (maximum probable surge amplitude) with GIS elevation data to produce maps with varying flood depths depicted in different colors. The corresponding flood extent maps will be generated for all the key return period (2, 5, 10, 25, 50 and 100) for further use in loss assessment and risk modeling. The CCHE 2D – Coast Package, along with the latest GIS technologies, would be used to demarcate the areas that are prone to floods and to estimate the flood depth in the inundated areas with the help of high resolution Digital Elevation Da These flooded areas will be overlaid on the various physical, social and economic exposures. Vulnerabilities of villages, housing, hospitals, population, agricultural areas, business, community livelihoods, rural infrastructure etc. will be determined from the derived flood extents. The CCHE 2D-Coast is a processes-based integrated two dimensional model, which is capable of simulating coastal processes in different coasts with complex shorelines such as irregular wave deformation from offshore to onshore, nearshore currents induced by radiation stresses, wave set-up, wave set-down, sediment transport, and seabed morphological changes.

This methodology will be used to identify the critical "hotspot" high vulnerability coastal zones in the 13 coastal states/UTs of India. Assessment of cyclone risk and vulnerability at village/habitat level would be useful to evolve sustainable local level development action plans for preparedness and mitigation.

3.2.2.5 Calibration and Validation of models

The calibration and validation process is intended to ensure that the model parameters are well set to reflect the physical nature of each river basin. A good fit in this case indicates a robust simulation, which can be used with reasonable confidence. A poor fit, on the other hand, indicates low confidence. Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized.

An independent sample of events will be used to calibrate and validate the cyclone model in terms of pressure drop, which plays a fundamental role over the wind speed for the episode, and surge height and extent of inundation in the coastal areas, an important factor owing to the high flow velocities. Model's performance will be tested by calculating relative error of (%EV).

The performance of the model components (wind speed, surge height and flood depth) simulations will be checked by means of the relative error of observed components, expressed as percentage (%ERR):

$$\%ERR = \frac{(Vs - Vo)}{Vo} * 100$$

where Vo and Vs are the observed and simulated surge height (wind speed, flood depth), respectively. Therefore, %EV > 0 and %EV < 0 would indicate an over- and underestimation of the heights by the model, respectively.

3.2.2.6 Quality assessment of the data and integration of Bathymetry/topography data

The severity of the storm surge at any location of interest is a consequence not only of the strength of the storm but also of the complex interaction of the storm's track, pressure and wind fields with the bathymetry (water depth offshore) near the coast. Fine interval quality data on elevation and bathymetry as required by the model are not readily available for the Indian coastline. Hence, data on land topography of the areas adjacent to the coastline and the bathymetry of the nearshore areas, which are of critical importance for accurate prediction by the model will be used.

The 'raw' data obtained from different agencies often contain missing and erroneous values. There can be discontinuities due to non-climatic factors such as station relocations, changes in the surroundings, etc.

Data cleaning will be performed by a series of quality control (QC) checks to identify missing values and to flag suspected values. Two types of data validation will be carried out: replacement of erroneous values and missing values. For interpolating a missing value, either data from a number of stations surrounding a target station (spatial interpolation) or interpolation between observations over time (temporal interpolation) will be used. For enhancing the data, the potential dates of discontinuity due to changes in the station location will be identified from the station history.

The projection and datum of bathymetry/topography data obtained from various data sources can be different and need corrections before they can be merged and used in the storm surge model. In addition, the resolution of data is dependent on the source and geographical location. A sample of merged bathymetry/topography collected from various sources is depicted in Figure 3:9.

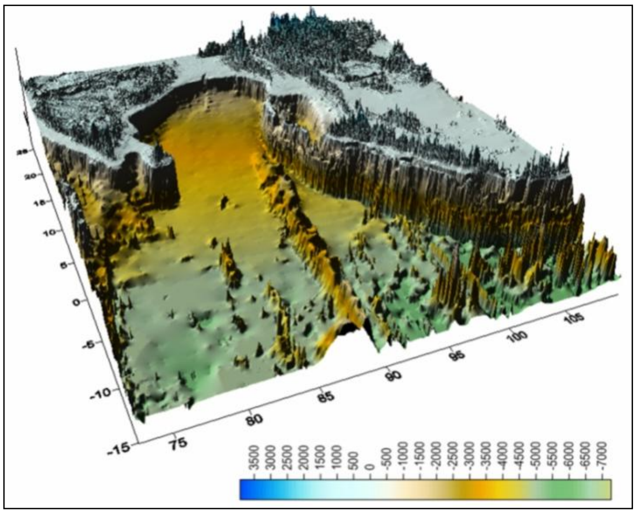


Figure 3:9: Sample of digital elevation model using resolution (1 min) data

3.2.3 CYCLONE INDUCED RAINFALL FLOOD MODELING

The coastal districts of India have experienced severe flooding in the past not only due to storm surges originating in the Bay of Bengal and the Arabian Sea, but also flooding from the rivers as well as from heavy precipitation associated with tropical cyclones and monsoon depressions. The methodology proposed for hazard assessment of cyclone induced rainfall flood modeling is presented in brief in the subsequent sections.

The objective of this task is to assess the flood hazard associated with rainfall generated by cyclones for the study area (area up to 10 m elevation with reference to mean sea level along the coastline). A review of historical flooding will be undertaken to define the worst and most widespread flood events and to understand the nature of flooding (fluvial, coastal, monsoon influenced, cyclones or depressions influenced). The most important part of flood hazard identification and assessment is the flood-prone area (extent) delineation; and assess its intensity and magnitude. Flood-prone areas are those areas subject to inundation with regular frequency. The determination of a flood prone area requires considerable collation of historical data, accurate digital elevation data, rainfall and discharge data and a number of cross-sections located throughout the study area. The outcomes from this task shall be used in the vulnerability and risk associated with flooding.

3.2.3.1 River Basins in the Study Area

It is understood that the area for study is an area up to 10 m elevation with reference to mean sea level along the Indian coastline. So the maps for floods due to cyclone induced rainfall need to be developed for the study area. In order, capture the impact of the upstream conditions of the river basin, hydrological unit (river basin) approach shall be followed in this study (Figure 3:10). A study shall be divided into two parts: 1) states for prototype, and 2) other states. The prototype states include Odisha and Andhra Pradesh. The major river basin in the prototype part include Subarnrekha, Brahmani Baitarani, Mahandi, Godavari, Krishna and Pennar. Major rivers in the other states include west flowing rivers, Narmada, Tapi, Mahi and Sabarmati.

Figure 3:10: River basins in the study area

3.2.3.2 Overview

Flood hazard will be assessed for major river systems across the study area to estimate the potential inundation from cyclone induced rainfall floods. A deterministic approach will be used to combine the information on (1) the scenarios of flooding, (2) the spatial extent of floods for different severity levels, and (3) the consequences of these floods (e.g. inundated area, and flood depth). Flood hazard modeling methodology is presented in the flowchart below (Figure 3:11).

Based on the data availability, an appropriate approach shall be adopted. In case of flow/discharge data availability, the flood hazard shall be determined using the hydraulic model approach as given in the steps below. These steps include: i) disaggregation of flow/discharge due to impact of cyclone, ii) simulation of deterministic events, iii) two dimensional inundation model (hydraulic modeling), iv) calibration and validation of flood extents, v) derivation of flood extent maps.

In case of unavailability of flow/discharge data, a more detailed approach shall be adopted, in which rainfall data shall be used to estimate the flow/discharge. The steps to be adopted in this scenario include: i) disaggregation of cyclone induced rainfall, ii) simulation of deterministic events, iii) establishment of rainfall runoff relationship (hydrological modeling), iv) two dimensional inundation model (hydraulic modeling), iv) calibration of validation of flood extents, v) derivation of flood extent maps. Details of the above-mentioned tasks are given below.

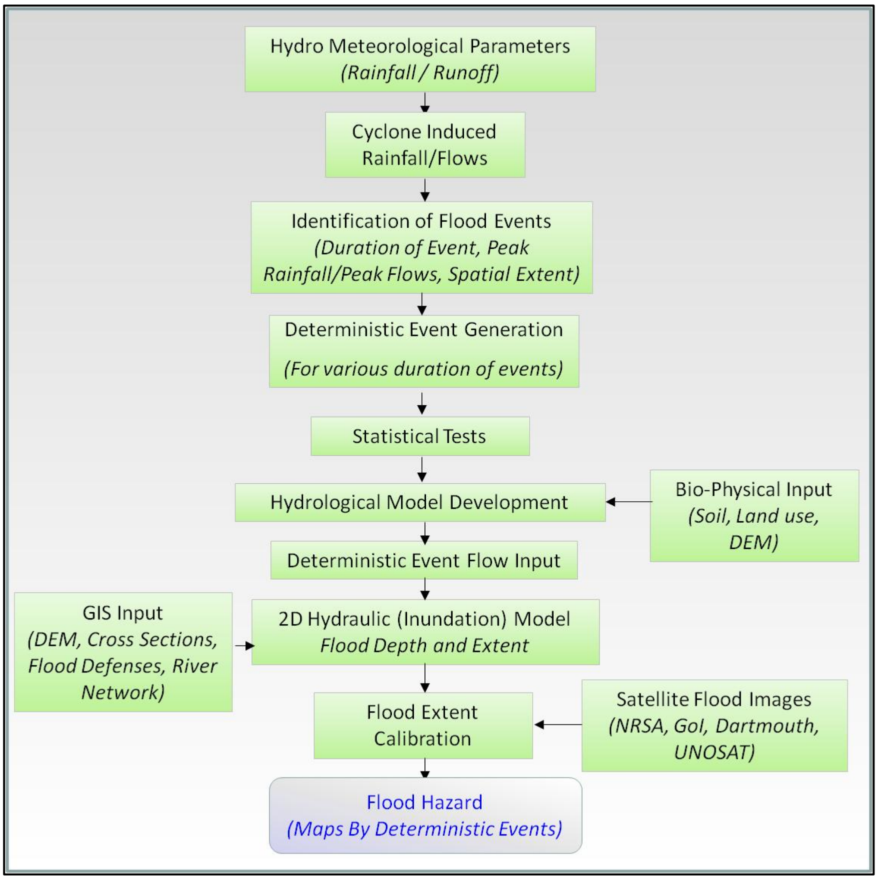


Figure 3:11: Cyclone generated flood hazard modeling framework

3.2.3.3 Extraction of Cyclone Generated Rainfall/Flows

The main factors that control the weather and climate of a region are geographical and atmospheric conditions. These include latitude, mountain ranges, land and water distribution, altitude, wind, air mass, ocean currents, depressions and cyclonic storms. India has wide range of weather and climatic regimes from arid to humid arising due to influences of the above-mentioned factors. Over 80% of the rainfall occurs during the monsoon or rainy season when flooding normally occurs.

During pre monsoon (May and to some extent until mid June) and post monsoon periods (October, November and December), cyclonic storms of severe intensity develop in the

Bay of Bengal and Arabian Sea[1]. In general, 5-6 cyclones are generated in the Indian Ocean, out of which 2-3 are more dangerous (category 3 and above). These cyclones bring the considerable amount of rainfall with them, thus causing flooding. Heavy and prolonged rains due to cyclones may cause river floods and submergence of low-lying areas by rain, causing loss of life and property.

Cyclone generated rainfall/flows shall be extracted by using historical cyclone and rainfall/flow information. The historical rainfall/flow discharge data will be studied and analyzed along with the history of cyclones in the region to demarcate rainfall/flows generated from the cyclones. Historical cyclone information shall be adopted from IMD's (India Meteorological Department) Cyclone eAtlas. This atlas gives information about the tracks of Cyclones and Depressions over North Indian Ocean for period 1891-2012 (http://www.rmcchennaieatlas.tn.nic.in/ViewByParam.aspx). Rainfall data shall be adopted from IMD's high resolution gridded rainfall data. This data is available for the period 1901-2009 at 1-Degree grid resolution.

A review of historical cyclonic events will be undertaken from various sources. From this review, synoptic situations of major cyclones, meteorological causes of heavy rainfall, and the general climatology of an area of interest will be assessed. By using historical cyclone information, dates of cyclones greater than category 3 shall be extracted, which made landfall. This shall help compile a catalogue of cyclones affecting various parts of India.

The rainfall/flow data corresponding to dates of cyclones shall be derived from available flow/rainfall information. The rainfall/flow data shall be extracted three days prior and three days after the date of landfall of the cyclones for entire peninsular India. This shall help compile the catalogue of cyclone-generated rainfall/flows for characterization of floods. In case of availability of flow/discharge data, flow/discharge information shall be used. In the absence of flow data, rainfall data shall be used and subsequently flows will be estimated. Using the catalogue of cyclone-generated rainfall/flows, deterministic events shall be developed by using the approach described in the next sub section.

3.2.3.4 Simulation of Deterministic Events

Deterministic events shall be developed based on the catalogue of cyclone-induced rainfall/flows. In case of availability of flow data, flows at important gauge stations (upstream of the study area) will be estimated for key return periods (2, 5, 10, 25, 50 and 100 years) from this analysis. The estimated return period flows will be given as an input to the hydraulic model (details of the model are given below) for flood plain delineation.

In absence of the flow data, a rainfall-based approach shall be used. A catalogue of cyclone-induced rainfall shall be used to develop the deterministic events.

The rainfall for various river basins will be estimated for key return periods (2, 5, 10, 25, 50 and 100 years) from this analysis. The estimated return period rainfall will be given as an input to the hydrological model (details of the model are given below) to estimate the flows. The estimated flows shall be given as input to the hydraulic model for flood plain delineation.

In both the approaches (rainfall or flow), the key return period values of respective variables shall be estimated using multi-variate extreme value distribution analysis. The Multi-variate extreme value distributions are popularly used to model the rainfall/flows. The advantage of this approach is the consideration of dependence structure among the stations, which will not be the case, when the individual stations are analyzed. Generalized Extreme value distribution has been found to be the best marginal

[1] Rakhecha P. R., and Singh, V. P. Applied Hydrometeorology, Springer and Capital Publishing Company, Delhi, India.

distribution for peak rainfall/flows of various durations. The steps followed in the deterministic event generation are presented below.

- Information is generally collected from the hydro-meteorological monitoring agencies.
- Screening and compilation is done for common sets of the data sets for certain years of records in the form of peak rainfall/flows for durations.
- Data is tested for homogeneity and consistency.
- Parameter estimation is carried out for different durations for multivariate extreme value distribution
- Statistical modeling is carried out with multivariate extreme value distribution
- Study of diagnostic plots
- Application and interpretation of statistical tests
- Comparison of historical and deterministic rainfall/flows among the stations

3.2.3.5 Hydrological Model Development

A hydrological model establishes the flow behavior of the watershed or basin by converting the rainfall into runoff. They often represent the spatial variability of the atmosphere and land surface characteristics that control the rainfall-runoff process. In usual hydrologic practices, hydrological models are regularly applied worldwide. Catastrophe risk modeling studies in urban and regional areas subject to flooding are beginning to use hydrologic models. Hydrologic simulations for flood flows rely on precipitation data and geospatial information to provide critical flood information for decision-making and operations. The hydrological model, prior to being employed into flood risk studies, needs to developed, calibrated and validated for the study area. The team proposes to use the open source hydrological model HEC-HMS. The USACE's Hydrologic Engineering Center (HEC) developed the Hydrologic Modeling System (HMS) model. This model is widely used for hydrologic modeling and is publicly available from the USACE. The HEC-HMS model is a generalized modeling system capable of representing many different watersheds. HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is applicable across a wide range of geographic areas for addressing a variety of project goals. Applications include large river basin water supply and flood hydrology, as well as supporting small urban or natural watershed runoff modeling.

To apply the model for a specific purpose and location, a model of the watershed is constructed by dividing the hydrologic cycle into manageable pieces, by constructing boundaries around the watershed of interest, and establishing appropriate geographic and other parameters in the model. The model provides a completely integrated work environment, including a database, data entry utilities, computation engine, and reporting tools, with a graphical user interface. Additional information on the model is available at: http://www.hec.usace.army.mil/software/hec-hms/.

The core elements of the HEC-HMS model are the basin model, meteorological model, control specifications, and time-series data manager. To develop the model for a particular use and location, the following steps are generally implemented.

- Basin Delineation (using HEC–GeoHMS)
- Creation of Basin Model (including all elements such as sub-basins, channels and reservoirs)
- Estimation of Physical Loss, Routing and Transformation Parameters (for each sub-basin element)
- Addition of Time-Series Data (for various meteorological parameters)
- Setting Control Specifications (for running the model)
- Calibration and Validation
- Interpretation of Flows at Critical Locations

HEC-HMS allows the user to select from a number of methods to represent catchment characteristics for Rainfall Loss and Infiltration, Rainfall-Runoff Transformation, Stream Flow Routing, Base flow Methods and input of meteorological data. The flowchart in Figure 3:12 explains the step-by-step approach to be adopted for hydrological modeling.

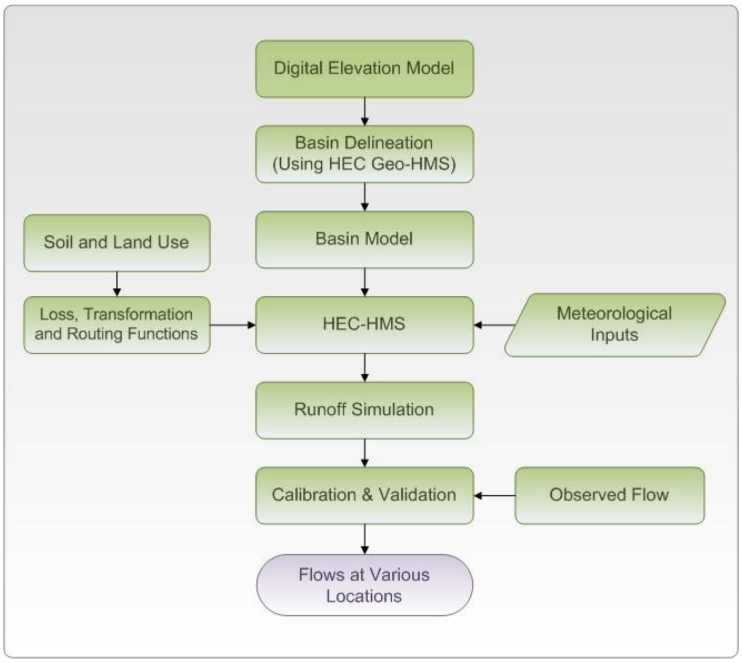


Figure 3:12: Flowchart for hydrological modeling

3.2.3.6 Two Dimensional (2- D) Inundation Model Development

The main purpose of the hydraulic modeling is to route the flows from one location to another, while estimating the water surface elevations and profiles for various scenarios. Generally, the flows or water surface elevations observed at a particular location are given as inputs to the model along with the channel characteristics such as cross-section, slope and roughness. Alternatively, flows estimated in the hydrologic modeling provide input to the hydraulic modeling. Detailed hydraulic modeling requires an inventory of drainage conveyance structures, surveyed cross-sections of streams and rivers, and topographic mapping of flood plain areas. In addition, site and aerial photographs, historical high water marks from past events, and anecdotal flood observations all serve to guide a detailed hydraulic model development.

A numerical 2D hydraulic model developed by the University of Mississippi - The National Center for Computational Hydroscience and Engineering (CCHE2D) is proposed to be used for prediction and understanding of the floodplain inundation process. CCHE2D model is a two-dimensional depth-averaged, unsteady, flow and sediment model. The resulting set of equations is solved implicitly using the control volume approach and efficient element method. The numerical technique employed ensures an oscillation-free and stable solution. An integrated package of CCHE2D simulates the river flows, non-uniform sediment transport, morphologic processes, coastal processes, and pollutant transport and water quality. These processes are solved with the depth averaged Navier-Strokes equations, transport equations, sediment sorting equation, bed load and bed deformation equations.

Mesh generation is an important process in discretizing the area of interest into smaller units of regular geometric shape. The CCHE package has a separate mesh generation facility. The mesh generator is operated with a powerful GUI designed for applications of free surface flow simulation. Figure 3:13 shows the methodology to be adopted for hydraulic modeling. The broader outline of the process can be given as follows.

- Generation or acquisition of Digital Elevation Model (DEM) for the area of interest
- Conversion of the DEM into XYZ file for mesh generation
- Specification of Boundary Conditions
- Parameter setting for inlet and outlet boundary conditions
- Simulation for flows
- Result Visualization and Interpretation

Mesh Generation is the first step towards the application of CCHE 2D for the area of interest. The (Digital Elevation Model) DEM file can be imported to CCHE-Mesh from various compatible formats such as Topography database (*.mesh_xyz), ASCII (*.asc) and Shape files (*.shp). To generate the mesh boundaries and sub-boundaries, first the number of nodes in i & j direction are defined (based on fineness of mesh required). Finally, a mesh generator gives the geometric (geo) used for input to the CCHE 2D model. The simulation can be started after setting of parameters like initial flow conditions, flow parameters and inlet/ outlet boundary conditions. The initial flow conditions include initial bed level (obtained from geo file), initial water surface, bed roughness, bed erodibility, and maximum silt deposition thickness. The set of flow parameters include simulation parameters like simulation time, time step, turbulence model, flow type (steady, unsteady or quasi steady), bed roughness defined as manning's n, roughness height, Wind, and advanced parameters such as Coriolis force coefficient, Gravity, von Karman constant and fluid kinematic viscosity. Inlet boundary conditions can be given in the form of total/ maximum discharge or discharge hydrograph at upstream section and outlet boundary can be open boundary condition, rating curve, or stage hydrograph. The typical output from the model can be evaluated for water surface elevation, flood water depth, and velocity.

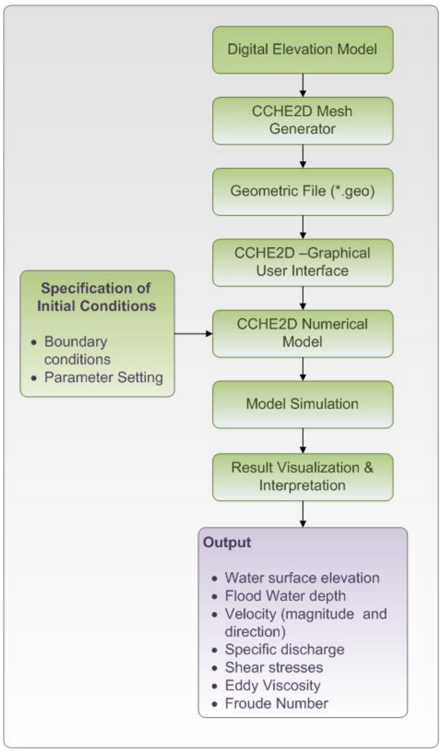


Figure 3:13: Flowchart for two dimensional hydraulic modeling

3.2.3.7 Derivation of Flood Extent Maps

Based on the 2, 5, 10, 25, 50 and 100 year return period flow values estimated by the simulation, the RMSI Team will determine the boundaries of the above stated return period flood plains by using two dimensional hydraulic modeling. Flood extent maps will be prepared by integrating model results with GIS data to produce a map with varying flood depths depicted in different colors. The corresponding flood extent maps will be generated for all return periods for each type of flood for further use in loss assessment and risk modeling. A sample of a flood extent map for a coastal area is shown in Figure 3:14.

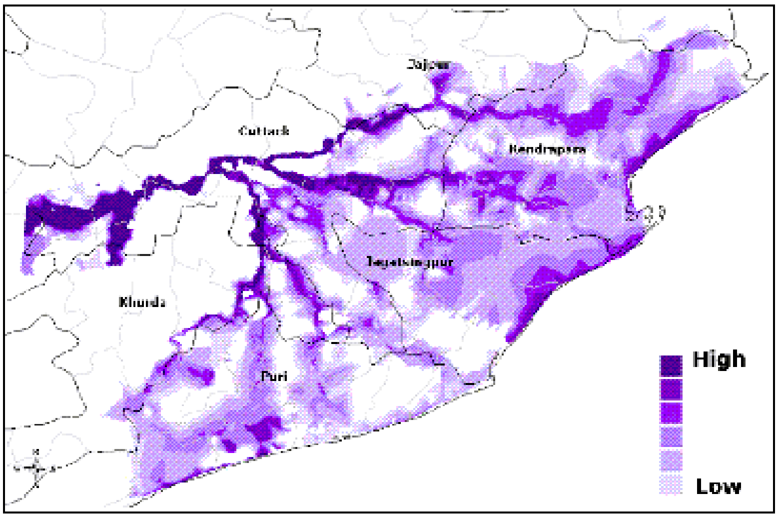


Figure 3:14: Sample flood extent map for coastal area

3.2.3.8 Input Data Requirements

For in depth assessment of the nature and extent of floods by application of widely accepted methodology, the followings are data required:

- GIS and Land Use data
- Digital elevation model (DEM) / Detailed survey data
- Land use and Soil data
- River network
- Hydraulic parameters of river (roughness and other channel property)
- Rainfall and Flow Data
- Daily/hourly rainfall and discharge data for number of stations and for long term period
- Stage or tidal level data to model tidal impact
- Flood extent and depth information

3.2.4 EXPOSURE DATA DEVELOPMENT

Exposure is a critical component of any risk model. The main elements of exposure that will be developed are demographics, buildings, infrastructure, agriculture, soil strata and ecological assets. Figure 3:15 shows the broad categories of exposure elements that will be considered in the present study.

The overall process of developing the exposure database is illustrated in Figure 3:16. RMSI will adopt a "bottom-up" approach in which different types of buildings and infrastructure elements will be classified into different categories, estimating their count under each category, combining building counts with per unit built-up floor area in case of buildings or other infrastructure characteristics, and applying per unit costing information relevant to the category. The output of exposure will be calculated from the total monetary value by asset category.

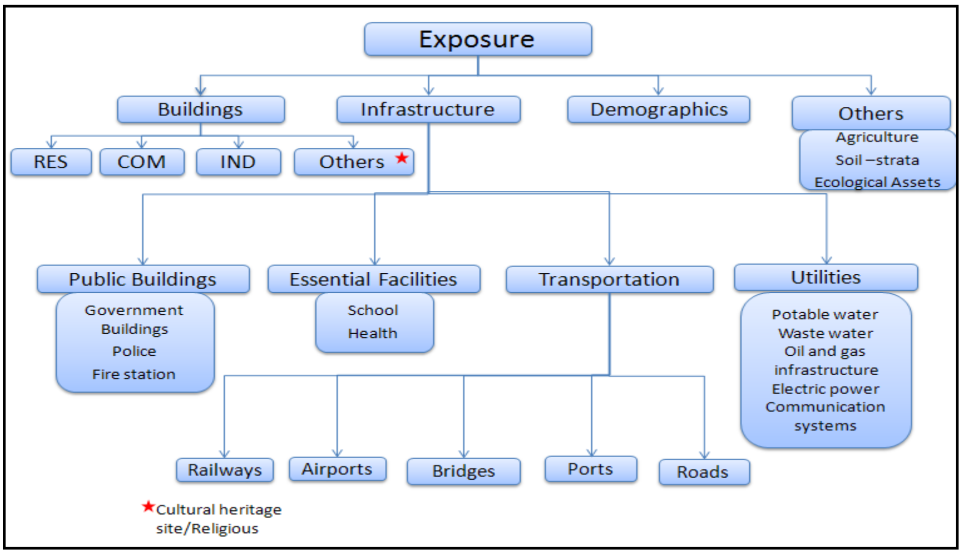


Figure 3:15: Broad categories of exposure elements that will be considered in the study

Figure 3:16: Exposure data development methodology

3.2.4.1 Data Collection

Data collection is very important in the exposure development process as the quality of the exposure developed is very much dependent on the kind of exposure information that can be collected. Data collection would be done in close coordination with Project Management Unit (PMU), NCRMP. The details of data required, data sources, and alternate data sources is summarized and provided in Table 3-1.

Table 3-1: Details of data requirement for various exposure elements

Sl. No.	Data	Data source(s)	Alternate	Preferred vintage and data format	Last option
1.	Administrative Boundary Map – State, district, taluk, block, mandal, village	Survey of India/ Census of India	RMSI in-house data or commercial data to be procured by NDMA	Vintage – 2011 Format – GIS format with attribute unit names	In case data is not available from data sources as per the schedule, RMSI will use alternate sources mentioned
2.	Census Data (State, district, taluk, block, village level and demographic information including population, gender, age, etc)	Census of India	Census 2001	Vintage – 2011 Format – xls	RMSI will apply state level growth rate on 2001 census data for arriving at 2011 figures
3.	Census Housing Data	Census of India	Census 2001	Vintage – 2011 Format – xls	RMSI will apply state level growth rate on 2001 census data for arriving at 2011 figures
4.	Coastal plantations and coastal ecological assets	National Centre for Sustainable Coastal Management/ SICOM-MoEF (Society of Integrated Coastal Management)	State Coastal Zone Management Authority	Vintage – 2011 Format – GIS format with attributes type (mangrove/plantation, etc)	RMSI will extract from LU/LC map within 10 m contour
5.	State level economic growth rates	Planning Commission or States and UTs agencies, Department of Statistics	Internet sources (Economic and statistical reports, national and state levels) and country reports of World Bank/ADB	Vintage – 1991, 2001, 2011	RMSI will use state level data available on internet
6.	Transportation (roads, rails, bridges, ports, airports)	CPWD or PWD/ NHAI/Railways/Port Authority/AAI/ Statistical Department/CRRI	Respective departments of States and UTs or commercial data to be procured by NDMA	Vintage – 2011 Format – GIS format along with unit replacement cost	In case GIS data is not available, RMSI in-house GIS data on roads and railways will be used

Sl. No.	Data	Data source(s)	Alternate	Preferred vintage and data format	Last option
7.	Utilities (water, electric, communication, oil and natural gas)	PHED/State electricity organizations/telecommunication dept./Ministry of Oil and Petroleum	Statistical Department or commercial data to be procured by NDMA	Vintage – 2011 or 12 Format – GIS format along with unit replacement cost	In case GIS data is not available, village level aggregate data (tabular data) will be derived using state level indicators. Alternatively, if data is available for few states, that will be used for assessing for other state using GDP/population.
8.	Critical facilities (hospitals, police stations, schools, fire stations)	Economic and Statistical departments	Various State departments - Health Dept/Education /Police/Fire Dept/Statistical Department (both National and State) or commercial data to be procured by NDMA	Vintage – 2011 Format – GIS format	In case GIS data is not available, village level aggregate data (tabular data) will be derived using state level indicators. Alternatively, if data is available for few states, that will be used for assessing for other state using GDP/population.
9.	Industrial and commercial buildings	Ministry of Commerce & Industry (Heavy/ Small/Medium)	Department of Industries (State), Department of Commerce, Department of Statistics and various national reports	Vintage – 2011 Format – GIS format with attribute – unit price of buildings, content value, types of industries	In case GIS data with attribute is not available, multiplier of unit cost will be derived separately for different industrial and commercial buildings. For content value, multiplier of building value will be used. Satellite data will be used for locating industrial and commercial agglomerations.
10.	Others (religious and heritage structures)	SOI	State/UT Statistical department	Vintage – 2011 Format – GIS format	In case data is not available, NDMA will procure this from private data providers
11.	Land Use Land Cover (LULC) maps	NRSA,	State Remote Sensing Centers	Vintage – 2011 Format –GIS format (NUIS	In case data is not available within the timeline, in-house medium resolution data will be

Sl. No.	Data	Data source(s)	Alternate	Preferred vintage and data format	Last option
				standard)	used (cities 5 m and rest 25 m)
12.	Agriculture data	Ministry of Agriculture or Planning Commission	State Agriculture Departments	Vintage – 2001 - 2011 Format –xls format for key crops at village level	In case this data at village level is not available, aggregate data at district level available in public domain will be used
13.	Soil strata map	National Bureau of Soil Survey and Land Use Planning	FAO global data available in public domain	Vintage – recent Format - GIS	-
14.	High Resolution Digital Elevation Model	Survey of India (Contours)	NRSA/ State Remote Sensing Centers (30 meter resolution data)	Vintage – recent Format –GIS raster Resolution – 1 m	SRTM 90 m which is available in public domain will be used
15.	Satellite Images	NRSA	-	Mandatory requirement as per ToR.	NDMA will procure this data for the project
16.	Building cluster data	NRSA	State Remote Sensing Centers	Vintage – 2011 Format –GIS	If this data is not available, it will be extracted from land use land cover provided (cities 5 m and rest 25 m). Only for 10 hotspot areas, it will be created from CARTOSAT data
17.	Replacement cost of all exposure elements	CPWDs and PWD, CRRI, NHAI, NBA, HUDCO,	Private builders and infrastructure developers, World Housing Encyclopedia reports, www.eeri.org	Unit replacement cost, capacity, construction material	In case replacement cost is not available, proxy values will be taken from the nearby states/UTs

Note: Base year for all analysis considered here as 2011 taking into account that key data available (census) are for 2011.

Based on discussion with PMU (NCRMP), RMSI will identify the contact persons of the departments/organizations and request PMU to write to these organizations. RMSI team will prepare a detailed description of each dataset needed for the study and share it with the state contact point in advance. The project team will coordinate with the state nodal officers and visit each state. During the visits, officer RMSI will conduct stakeholder meetings with the support of the state nodal officers. The objective of the stakeholder meeting is to appraise the stakeholders about the project, the data required from each organization, the importance of high quality data, and final outcome of the study. The team will discuss the data characteristics as per the detailed description and how this will be used for the study with the stakeholders. Based on the discussions, the team will finalize what data and associated attributes can be collected from various agencies within the timeline set. RMSI will also demonstrate similar applications to the stakeholders during the meeting, which will provide an idea on the Web GIS atlas that will be developed as part of this study.

The data available and collected from each state will be document and provided in the Inventory and Data Review report, which is the second deliverable of the project.

3.2.4.2 Data Processing

The data collection process will be followed by data processing. RMSI will do the initial analysis of collected data and prepare a list of input data having information about the vintage, source, resolution, and attribute details. RMSI will share the list with PMU (NCRMP) to ensure common understanding regarding data availability. After initial analysis, data will be processed to bring them in usable formats, which will be followed by running quality assurance steps on the data. There will be separate quality checks for aggregate and site-specific data. RMSI will take care of the following points during data processing

- Resolution: A clear understanding will be arrived at with the client about the resolution at which each data set will be processed. For example, aggregate data can be analyzed at state/district/mandal/taluka/village/habitation levels depending upon data availability and requirement.
- Projection System: The projection system for final data set will be decided in consensus with PMU (NCRMP)
- Positional Accuracy: Prior to the data processing, the reference data for geo-positioning will be finalized. Each data set will be geo-referenced with respect to finalized referenced data only.
- Naming Convention: Naming convention of all files will be the same to maintain consistency in the names of all the files.
- Creation of Unique Id: RMSI will maintain a unique id for each data set, which will help to analyze the data at any stage with respect to the initial one.
- Standard Unit in all Dataset: Units for each entity will be decided to have consistency in the entire data set.
- Essential Fields: RMSI will maintain a few common fields in all the data sets, which help to link them.
- Logical Checks: RMSI will apply some logical checks on the data to verify the consistency in the data.
- Metadata: RMSI will create metadata considering the various data limitations and the assumptions RMSI makes while processing the data. All the information stored in Metadata will help the client to understand the data more clearly.

3.2.4.3 Gap Analysis

The processed data will then be analyzed for gaps. In an ideal condition, when the processed data has no gaps, it can be directly used to estimate the exposure value by multiplying total area/length/count with unit replacement cost.

Normally, it is seen that once the data is processed, gaps are identified primarily in the areas of:

Missing Location Information: For risk assessment, it is necessary to understand where a particular exposure element is located within the area of interest. It is not necessary that for every exposure element, RMSI should get a Latitude and Longitude that pin points its location, but at least there should be an associated district or municipality. GPS based field survey for collecting coordinate information of exposure elements is not envisaged as part of the scope of work. However, best efforts will be put to collect coordinate information of key exposure elements using geo referenced maps or Google images.

Missing structure or classification information: It is often seen that there is no concrete information about the structural configuration or use of an exposure element. This information is very critical to model the vulnerability of the exposure element against a specific hazard. Therefore, when detailed data related to structural types is not available, the exposure team may have to resort to sample field surveys, interaction with builders or infrastructure developers, and analyzing the available literature on the subject. This will help in understanding the regional characteristics of building typology specific to different regions. This information will be used for physical vulnerability analysis. The details of carrying out a building survey are further elaborated below under the Sample Survey section.

Missing replacement costs: Since the risk has to be assessed in monetary terms, it is very important to know the replacement cost for every exposure element. RMSI will devise a three pronged approach in which three levels of data sources will be used to collect the replacement cost. Primarily, the team will consult with government agencies (including PWD and other civil departments in the municipal governments) to gather the replacement costs. This will be further validated in consultation with private builders/infrastructure developers, sample field survey along with literature review and internet resources. The literature surveys include historical event damage reports (government reports), technical papers, review of web sites like the World Bank, UN, CIA fact sheets, etc.

In cases where replacement costs for particular exposure elements are not available for a state, the replacement costs available for the neighboring state will be applied taking into consideration the state GDP.

No data available/obtained: It is also often observed that there is no organized data available for a specific exposure type or it is not shared for reasons of security. In case of non-availability of data related to any exposure elements, secondary data will be used to estimate proxy values and thus fill the gaps. If no data is available, RMSI will create representative data that is required for analysis. In such cases, an internet survey will be done. There are various internet sites, which provide national level information about the country. If these sources also have sparse records, then data available for other states with similar building types and construction practices will be applied.

The data outputs, after undertaking these processes to bridge the gaps, serve as inputs to the relevant steps (count estimation, area/length estimation, unit cost estimation) from which the final total exposure value in the area of interest will be calculated.

3.2.4.4 Sample Field Survey

In order to bridge the various gaps in data on local construction practices (construction materials, structural types, and architecture) for residential, commercial, industrial categories, as well as for religious buildings and infrastructural elements such as bridges, power lines, irrigation systems, and airports, the RMSI team will conduct field surveys to understand structural and vulnerability characteristics of these exposure elements.

The field survey will be carefully designed and administered by experts from mapping and engineering domains. Multiple teams will visit different states for information collection. The field survey will be carried out using a structured questionnaire in which various parameters related to the structural characteristics of various building categories will be captured. The information will be captured through interaction with the building occupants and through observations.

Before the start of actual field survey, the team will pre-test the questionnaire in 1-2 locations. Based on the experience, necessary modifications will be made in the questionnaire before starting the actual survey. The survey team will collect the data and will enter the data on a daily basis in a pre defined database having a customized data entry interface. The interface will have quality control capabilities to avoid illogical entries. For example, if the structure is a permanent structure there will be a control to disallow entry of thatch or tiles as roof material. The data entered will be shared with the quality team and will be examined on a daily basis. The data quality team at RMSI will conduct daily telephonic/online meetings with the survey teams of each state to discuss the progress and quality issues of the data. In case the quality team observes any issues in the data collected, these will be discussed and rectified before the team returns from the survey location. Common data issues/errors observed during the survey will be documented along with the corrective actions. This will be shared with all the state survey teams and the quality team will appraise the particular task of each state to ensure that other teams are not making similar errors. In addition, teams will also collect geo-tagged photographs of all surveyed buildings and infrastructure, which will be used during the analysis.

Representative samples will be selected for all the building categories in order to understand the variations in the construction practices within the area of interest.

Stratified random sampling method will be used to select the sample. The sample size of each type of household based on the structure type, namely, permanent, semi-permanent, serviceable, non-serviceable, and unclassifiable, has been calculated at 99% confidence level and the margin error of 3.5 according to the following formula (Krejcie, et al 1970, Xu, Gang 1999). Total number of households of all coastal districts in the study area has been considered from Census 2011.

Formula:

$$n = \frac{X^2 * N * P * (1-P)}{(ME^2 * (N-1)) + (X^2 * P * (1-P))}$$

Where:

n = required sample size

X2= Chi-square for the desired confidence level at 1 degree of freedom

N= population size

P= population proportion (.50 for this table)

ME= desired margin of error (expressed as a proportion)

Sample size for each structure type has been calculated using the above formula. The relationship between sample size and total population is illustrated in Figure 3:17. It should be noted that as the population increases, the sample size increases at a diminishing rate and remains relatively constant at slightly more than 380 cases.

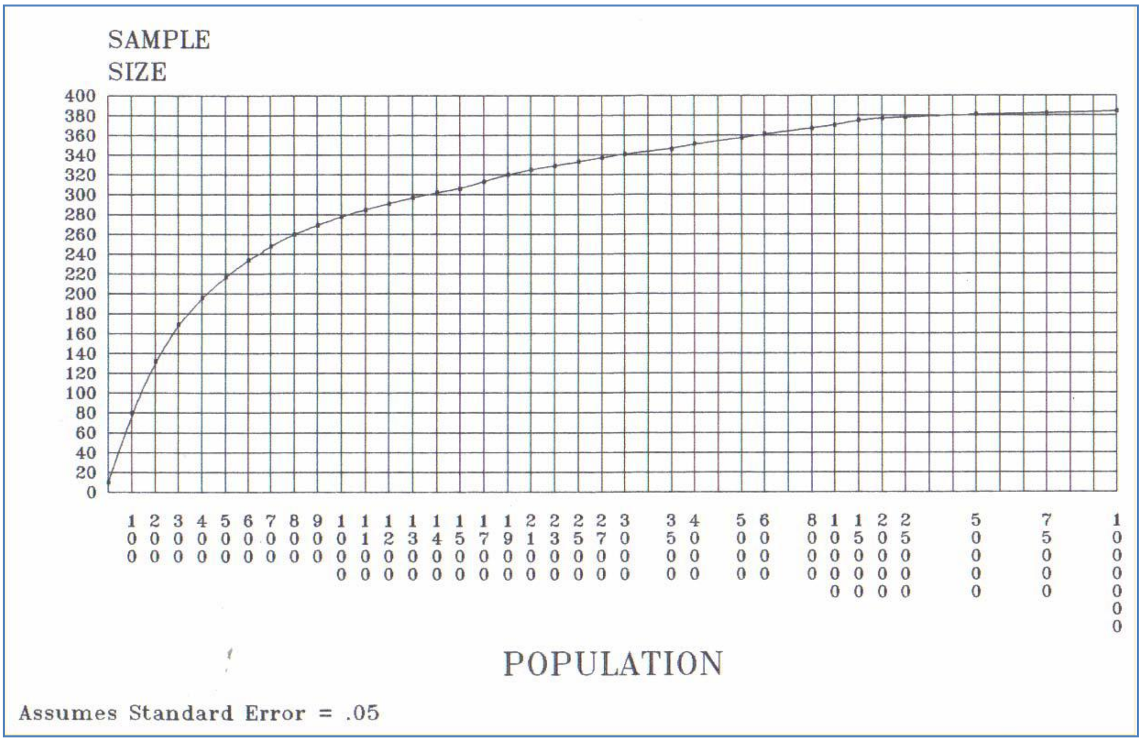


Figure 3:17: Relationship between sample size and total population

To select the district to be surveyed, household types for each district falling under the area of interest have been considered. In addition, the proneness of these districts to cyclone as per IMD has also been considered.

Using Analytical Hierarchy Process (AHP), weights for type of structure and proneness to cyclone have been defined. Higher weights have been given to temporary structures and more cyclone prone districts.

A matrix has been derived by multiplying the weights of types of structures and proneness to cyclone determined by AHP. Using this matrix, the number of households have been derived in each district by structural type and vulnerability to cyclone. In the next step, the number of households in each district has been normalized by the sample size derived by using the above mentioned formula for each structure type.

To finalize the district to be surveyed, the detailed structure of the households by predominant materials of roof and wall from census 2011 have been considered. The census provides 90 combinations based on the predominant materials of roof and wall. These combinations have been further grouped into 19 combinations based on the vulnerability of these combinations to cyclones as shown in Table 3-2.

Table 3-2: Combination of household types based on the predominant roof and wall materials

Combination	Roof Type	Wall Type
Comb_1P	Grass/ Thatch/ Bamboo/ Wood/Mud etc.	Burnt brick/Stone packed with mortar
Comb_2P	Grass/ Thatch/ Bamboo/ Wood/Mud etc.	Mud/unburnt brick & Stone not packed with mortar
Comb_3P	Grass/ Thatch/ Bamboo/ Wood/Mud etc.	Wood
Comb_4P	Grass/ Thatch/ Bamboo/ Wood/Mud etc.	Burnt brick/Stone packed with mortar

Combination	Roof Type	Wall Type
Comb_5P	Plastic / Polythene	Grass/thatch/bamboo etc.
Comb_6P	Handmade Tiles & Machine made Tiles	Grass/thatch/bamboo etc.
Comb_7P	Handmade Tiles & Machine made Tiles	Mud/unburnt brick & Stone not packed with mortar
Comb_8P	Handmade Tiles & Machine made Tiles	Burnt brick & Stone packed with mortar & Concrete
Comb_9P	Machine made Tiles	Wood
Comb_10P	Burnt Brick & Stone/Slate	Mud/unburnt brick & Stone not packed with mortar
Comb_11P	Burnt Brick & Stone/Slate	Burnt brick & Stone packed with mortar
Comb_12P	G.I./Metal / Asbestos sheets	Grass/thatch/bamboo etc.
Comb_13P	G.I./Metal / Asbestos sheets	Mud/unburnt brick & Stone not packed with mortar
Comb_14P	G.I./Metal / Asbestos sheets	Wood
Comb_15P	G.I./Metal / Asbestos sheets	G.I./metal/asbestos sheets
Comb_16P	G.I./Metal / Asbestos sheets	Burnt brick & Stone packed with mortar & Concrete
Comb_17P	Concrete	Mud/unburnt brick & Stone not packed with mortar
Comb_18P	Concrete	Burnt brick & Stone packed with mortar Concrete
Comb_19P	Any other	Any other

To select the district to be surveyed, all those districts that had all the roof and wall material combinations were selected. Out of these selections, all those districts were selected which were highly vulnerable to cyclones. Based on this, total sample size came to around 2,287 distributed across eight districts as shown in the Table 3-3.

Table 3-3: Number of buildings to be surveyed

State Name	District Name	Category of proneness based on IMD	Permanent	Semi-permanent	Serviceable	Non-Serviceable	Unclassifiable	Total Sample
Gujarat	Junagadh	Vulnerable	14	5	0	1	3	23
Andhra Pradesh	Srikakulam	Highly Vulnerable	40	15	56	27	17	154
	East Godavari	Highly Vulnerable	80	48	57	118	76	379
	Guntur	Highly Vulnerable	75	39	39	121	120	394
West Bengal	South Twenty Four Parganas	Highly Vulnerable	68	148	138	155	54	564
	Purba Medinipur	Highly Vulnerable	35	138	63	86	38	360
Tamilnadu	Kancheepuram	Highly Vulnerable	60	28	48	34	50	221
Orissa	Ganjam	Highly Vulnerable	41	18	62	51	20	193

3.2.4.5 Exposure data development

Exposure categories can be organized into 'aggregate' or 'site specific' to analyze the impact of hazards. Aggregate data are those where area and replacement costs of exposure elements will be summed at district/municipality levels while the site-specific data will be represented by a separate location (Longitude, Latitude) on the earth's surface with a separate replacement cost. A general rule for categorizing the data as aggregated or site specific is based on the level at which the location information is available.

For regional hazards like earthquake, risk assessment can be done with data aggregated at district or municipality level but for hazards like flood, which are location specific, estimating risk based on aggregated data is not the best solution. This is because when exposure is aggregated at any level, the assumption is that it is equally distributed across the entire aggregation unit like a district; whereas in reality that is not the case. Many times, it is observed that the whole exposure is only in one part of the district and the rest is devoid of it.

To resolve this, RMSI will use building agglomeration data either extracted from landuse/landcover maps received from NRSA or the State Remote Sensing Agencies. These cluster data will help to distribute the aggregate data over the built-up area within a district or municipality. Only sample ground verification will be conducted on the building agglomeration data thus generated to mention the quality of the data in the report.

3.2.4.6 Social and Economic Data

The Census data 2011 will be used as the main source of social and economic data. The census data (2011) for the country is available at the district level. The census data provides population distribution by age, gender, education, and occupation. It also gives the number of households in different building types. Details about basic amenities such as kitchen, electricity, and access to potable water and sewerage are also available. Using the decadal population growth rate of the state, the population data will be projected to year 2013. Similarly, the district-level 2011 household information providing the details of number of households within each district will also be projected to 2013. Finally, all the data will be compiled for the development of the demographic exposure database. The team will put their best possible efforts to collect the village level data (2011) either from the Census department or state governments. In case village level data is not available, statistical methods based on population and built up ratio will be used for scaling down the district level data to village level.

3.2.4.7 Residential, Commercial, Industrial and other Building Exposure

Residential building data as provided in the Census is limited only to building counts based on their broad categories. As a result, the classification, and quantification of exposure data pertaining to residential buildings will become a challenging and complex process mainly because of the absence of location information and replacement costs of each of the identified typologies. The building location information will be compiled by creating a building agglomeration dataset as described in section 3.2.4.8. Table 3-4 below shows the major structural types into which all residential buildings are classified as per the Census of India.

Table 3-4: Major structural types of buildings

S. No.	Building Types Based on Material and Structure
1	Mud
2	Stone
3	Block/Brick
4	Wood
5	Metal, Asbestos sheet

S. No.	Building Types Based on Material and Structure
6	Concrete
7	Others

At this point, it is not known if the commercial and industrial data providing business location information is available. If this data is available, then RMSI will use it for commercial exposure development.

Religious and cultural heritage sites will come under the 'Others' category of buildings. For religious places, capacity in terms of number of people that can be accommodated would be very useful. These attributes will also help disaster managers for planning the shelter locations at the time of disasters. Cultural heritage bears a unique or exceptional testimony to a cultural tradition and data for these categories of buildings are generally available with the tourism departments of the state and the center.

Secondary sources of commercial and industrial data will also be considered and will include sources such as telecom directories; chamber of commerce databases; data with local and regional government authorities; data with utility agencies (electrical connections); business taxation and/or internal revenue agencies; provident funds etc.. A valuable resource could be created with a small number of data variables such as business name, geo-coded physical location of head office and branches or depots, number of employees as well as an indicator of the usual location of employees (such as head office, branch, depot or field).

3.2.4.8 Building Agglomeration Data

The data received from various governmental and non-governmental agencies are generally in tabular format. The data lacks the spatial distribution of population and the building agglomerations within the district. In building agglomeration data, buildings are clustered based on the occupancy type and height. For hazards that are mostly localized in nature, it becomes pertinent to know the spatial distribution of building exposure within the district. In order to fulfill the above-mentioned requirement, building agglomeration data derived from satellite images will be used at variable resolution.

As mentioned in the Figure 3:16 we will try to get building agglomeration data from NRSA or State Remote Sensing Agencies. In case this is not available as per the timeline, RMSI will use its in-house land use data to extract the building agglomerations. The data is available at 5 m resolution for major cities and at 25 m resolution for the remaining areas.

3.2.4.9 Exposure data development for 10 hotspots

The methodology for identification of 10 hotspots is provided in detail in the Risk Assessment section.

Building agglomeration mapping of the 10 hotspots will be carried out using CARTOSAT data having 2.5 m resolution. The building agglomerations data will be captured and will be classified into residential, commercial, and industrial clusters. CARTOSAT images will be classified into residential, commercial, and industrial classes by using image processing software. The classifications will be done based on the tone, texture, shape, size, pattern, and associations between buildings. For example, residential strips generally have a uniform size and spacing between structures with linear driveways and lawn areas. Commercial strips are more likely to have buildings of different sizes with non-uniform spacing between them. They are also characterized by the larger driveways and parking areas associated with them. Commercial areas are often abutted by residential, agricultural, or other contrasting uses that help in defining them. Similarly, industrial areas are generally situated at some distance from urban centers. The identified building agglomerations will be validated using the Census 2011 data and will be further improved using Google Earth satellite imagery.

RMSI team will conduct a sample survey for ground verification of the building agglomeration data developed before embarking on further analysis. The sample survey will help in refining the cluster classes further into commercial and residential, which cannot be captured through image interpretation. These building clusters will be used for distributing the aggregate socio economic data over these polygons based on the area ratio for calculating the affected exposure for site-specific hazards.

3.2.4.10 Agriculture

Crop statistics will be collected from Department of Agriculture data to assess the agricultural exposure. The key attributes would be area and tonnage of production for several years, which will be used for calculating average production for calculating loss.

3.2.4.11 Soil Strata

Soil strata map of 1:50,000 scale available with National Bureau of Soil Survey and Land Use Planning will be used for extracting the soil strata map of the study.

3.2.4.12 Ecological Assets

Mangroves/other plantations are critical coastal assets from a coastal zone management perspective. They play a vital role in reducing the impact of storm surge further landward. The data for mangroves/other coastal plantations will be collected from concerned national or state agencies. In case this is not available, it will be extracted from the landuse/landcover map that will be collected from NRSA or State Remote Sensing Agencies.

3.2.4.13 Critical Facilities

Schools, hospitals, police stations, and fire station buildings will be included under critical facilities. These facilities play a critical role in mitigation and recovery operations during and after disasters. For all the critical facilities, RMSI will collect information from various agencies/State departments on aspects such as location, construction type, year of construction, cost of construction, number of stories. For schools, RMSI would also try to capture number of rooms, floors, students, availability of open areas and toilet facilities, and contact numbers. Similarly, for hospitals, additional attributes that would be useful for emergency planners include number of beds, number of patients and staff, contact numbers of hospitals, cost of equipment and availability of medicines.

3.2.4.14 Utilities

Utilities include electric power, oil and gas pipelines, potable and waste water systems, and communication systems. The data will be collected from various national and state agencies. In case GIS data is not available, village level aggregate data (tabular data) will be derived using some state level indicators. Alternatively, if data is available for a few states, it will be used for assessing similar data for other state using GDP/population ratio.

3.2.4.15 Transportation

Transportation data will be collected from various national and state agencies. Information will be collected for attributes that provide information on use, type of construction, classification, and replacement cost. In case GIS data is not available, in-house GIS data on road and rail will be used. Alternatively, village level aggregate data (tabular data) will be derived using state level indicators.

3.2.5 Spatial Exposure Database

Based on all the above exercises, a spatial exposure database will be created. This database will be used for risk assessment. The exposure data in GIS format will be delivered along with a report as part of the fifth deliverable.

3.2.5.1 Data Dependencies

- Building exposure data (residential/commercial/industrial) will be developed at cluster level, which is called building agglomeration data. In building agglomeration data, buildings are clustered based on the occupancy type and number of floors. For identification of hotspot areas, building clusters of variable resolution will be used. RMSI will use building agglomeration data either extracted from landuse/landcover map received from NRSA or State Remote Sensing Agencies. These clusters data will help to distribute the aggregate data over the built-up area within a district or municipality. In case data is not received from NRSA or State Remote Sensing Agencies, RMSI will use in-house data for this. RMSI has LU/LC data of 5 m resolution for major cities and 25 m resolution for rest of the region.
- For 10 hot spot areas, building cluster data will be developed from CARTOSAT at 2.5 m resolution for detailed analysis.
- Use of land use data (agricultural, open space, industrial areas etc.) as per NUIS standards will depend on the availability of the datasets from various agencies. In absence of this data, RMSI will use in-house available data
- In absence of site-specific data for infrastructure, aggregate level data will be developed using various secondary sources.
- In case of non availability/missing structural information of particular exposure elements, inputs from builders/infrastructure developers, expert opinion and the available literature on the subject will be used
- In cases where replacement costs cannot be obtained from stakeholder agencies, the team will conduct literature surveys to extract the approximate values of various exposure elements.
- In case of non-availability of data related to any exposure elements, secondary data will be used to estimate proxy values at aggregate level to fill the gaps.
- The data received from various departments usually have different formats. There may be inconsistencies in the spellings of various administrative units (villages/talukas/mandals/districts). In such cases, Census (2011) data will be used as the reference. Sometimes, there may be issues in the boundaries of the administrative units. In such situations, data received from the concerned state/UT will be given higher priority than data available with the Survey of India.
- Sometimes data cannot be obtained from the concerned department because of data security policies or some other concerns. In such situations, assistance of NDMA will be required to get the data
- Vintage of the various exposure elements will depend upon the availability of data from various agencies.
- Sometimes data is not available at village level. In such cases taluka/district level data will be extrapolated to village level.

3.2.6 VULNERABILITY ANALYSIS

Modeling vulnerability of a system to natural hazards involves establishing a relationship between the potential damageability of critical exposure elements and different levels of local hazard intensity for the peril of interest. Physical vulnerability refers to the degree to which an asset would undergo damage or be destroyed in a hazardous environment caused by catastrophic events. Social vulnerability refers to the incapability of people, organizations, and societies to endure adverse impacts from disasters to which they are exposed. Vulnerability assessment will involve quantifying the damage susceptibility of each asset class with respect to hazard parameters of each peril.

Damage susceptibility associated with a given level of hazard is measured in terms of a mean damage ratio (MDR) defined as the expected proportion of the monetary value of repair needed to bring back the facility to pre-event condition, over the replacement value of the facility, as a consequence of the hazard. The curve that relates the MDR to the hazard is called a vulnerability function. Vulnerability functions shall be developed for various assets for different perils, using analytical/synthetic and statistical methods complemented with expert engineering or heuristic judgment based on local and/or international experiences.

3.2.6.1 Physical Vulnerability Assessment

Development of physical and social vulnerability functions for all the 13 States/UTs will be mainly, but not solely, based on damage data from historical events. An analytical approach complemented by engineering analyses along with expert judgment based on national/international experience will help in developing vulnerability functions with sound reasoning and these two approaches will also fill the gaps in the available damage data for various historical events. Figure 3:18 presents a flow chart indicating the interface between different components of vulnerability development. Proposed methodology for developing the vulnerability functions uses the three different approaches i.e., damage statistics of the past events, analytical/synthetic and or engineering studies and international experience. The following tasks constitute the methodology:

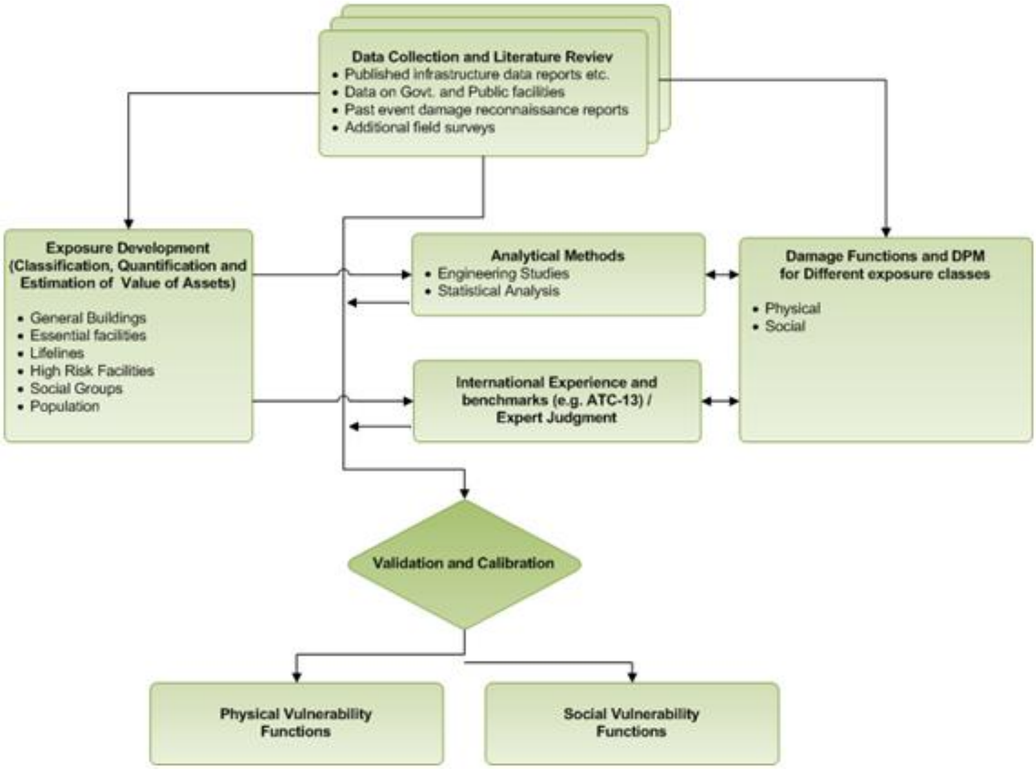


Figure 3:18: Vulnerability Functions Development Methodology

3.2.6.2 Data Collection and Literature Survey

Locality-specific damage data in terms of quantity and extent of damage shall be collected for historical events wherever available. This data, in general, is collected in a variety of text and descriptive formats. They will be digitized by way of engineering interpretation of damage states and repair strategies.

Building stock in the region is to be reviewed and categorized into meaningful classes of typical buildings. Note that the classification, in general, can be different for different hazards. As a result a super set of all classifications may be made and used.

Building (and other coverage types such as Contents, and Time Element)-specific data shall be collected with emphasis on vulnerability parameters such as material of construction, gravity and lateral resisting systems, age (to include practice and code enforcement), roof-material, height (in form of number of stories), shape (in matters of cross-section), design characteristics (both architectural and structural), maintenance levels (including upgrades to codes), reconstruction and retrofitting/mitigation measures, wherever possible.

Special emphasis will be given for collection of mortality rates, hospitalization by gender, age, physical condition, treatment, need for hospitalization, etc. during historical events. In addition to this, efforts will be made to capture historical disaster information about number of people looking for shelter by age, gender, income, and duration, etc. Efforts will also be made to understand the infrastructure in all the cyclone prone districts of the 13 States/UTs.

Literature survey shall be undertaken to extract and compile useful information on buildings, contents, time element (including additional living expenses, business interruption, and down time) infrastructure and social damage and vulnerability in the region. This shall include resources such as technical papers, historical event damage reports, building code provisions (and degree of its enforcement), studies on social impact of disasters, gender behaviors and needs, etc. Note that, data will also be adopted into the study for regions with similar infrastructure and building performance, if available, for purpose of enhancing the statistical convergence.

Information on damage mechanisms and behavior of different coverage classes in the region during past historical events; construction and design practices; code provisions and compliance levels; maintenance levels and regional trends, if any, shall be collected.

3.2.6.2.1 Relevance of Data Collection and Literature Survey

Building occupancy, such as residential, commercial, educational, governmental, or industrial, could be a factor when determining degree of damage to buildings and contents, incurred by cyclone and associated hazards. Note that building code provisions differ based on occupancy type to account for different loadings and performances.

Building material type, such as masonry or concrete, light or heavy (flat or sloping) roof material, is a factor when determining either the damageability, repair, or type of debris, which will be generated after the hazardous event.

Building structural characteristics such as gravity and lateral resisting systems, height or number of levels, cross-sectional configuration, etc., also are a factor when determining how much damage a building will sustain during a hazardous event, as well as the repair strategies.

All the above information will be captured as part of data collection and literature review to understand the treatment given to these subjects in prior studies. These will be supported by surveys. All surveys conducted will be based on statistical approaches that not necessarily cover each and every block in the study area, but will use samples of different regions in the study area.

Social vulnerability is partly an outcome of aspects of social setup that influence or shape the susceptibility of various factions of the society to disasters and drive their ability to respond. It is, however, crucial that social vulnerability is not considered as a function of exposure to hazards alone, but also the sensitivity and resilience of the society to prepare, respond and recover from disasters. Therefore, it is the combination of the two factors (direct and indirect) that drives the MDR for social vulnerability.

Vulnerability functions for buildings, critical facilities, and infrastructure will be developed using the above approach to estimate the vulnerability due to cyclone and associated hazards. The above approach will also be used for estimating the social vulnerabilities. This approach is very similar to the ones used in various open source models like HAZUS, CAPRA and GEM. The developed vulnerability functions would be compared with corresponding functions in the above open source models to improve the performance of the developed vulnerability function.

Agricultural vulnerability to crops due to cyclone and associated hazards involves developing a relationship between crop production and hazard parameters or wind speed, rainfall, locality, intensity, frequency and duration.

3.2.6.3 Social Vulnerability Assessment

Indicator identification and social survey: Social vulnerability is partly an outcome of aspects of social setup that influence or shape the susceptibility of various factions of the society to disasters and drive their ability to respond. It is, however, crucial that social vulnerability is not considered as a function of exposure to hazards alone, but also the sensitivity and resilience of the society to prepare, respond and recover from disasters. So it is the combination of the mentioned two factors that drives the MDR for social vulnerability.

Social vulnerability is a culmination of economic, demographic, and housing characteristics that influence a community's resilience to environmental hazards. The major components of vulnerability are well being, livelihood resilience, skills awareness, social security and social awareness. RMSI would employ a two-pronged approach to assess the social vulnerability of the different communities across the study area:

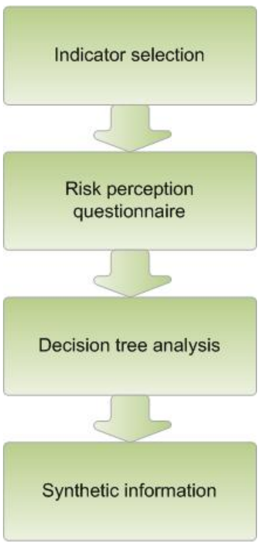
SoVI (Social Vulnerability Index): A scientific approach using the secondary data available with the various administrative units and departments of the Government.

Community Assessment sample survey: Analysis of primary data collected through sample surveys conducted at different levels.

Social Vulnerability Index (SoVI): In an effort to scientifically assess social vulnerability under the Hazard Vulnerability and Risk assessment (HVRA) exercise, RMSI intends to use the Social Vulnerability Index (SoVI) to quantify the social vulnerability in a comparative metric that will facilitate the examination of the differences in social vulnerability among the different geographical units. This index will provide information of vulnerability distinction of the communities in different parts of the study area, thus making it easier to intervene with appropriate mitigation and prevention activities. SoVI would prove valuable to the lower administration units and state administration in planning and decision-making as it would graphically illustrate the geographic variations in social vulnerability by reflecting the uneven capacity of preparedness and response. This will also indicate the differential ability of recovery across the geographical units.

The proposed steps under SoVI are:

1. The secondary data available with the departments related to gender, ethnicity, class/income group etc will be used to derive the input variables to calculate and generate the vulnerability index.
2. The variables will be normalized as either percentages, per capita values or density functions
3. Accuracy of the data sets will be verified using descriptive statistics
4. Z score standardization will be used to standardize the input variables
5. Principal component analysis (PCA) will be performed with the appropriate component selection to reduce the tendency for a variable to load highly on more than one factor
6. Parameters will be set to extract the factors and then examine those to determine the broad influence on social vulnerability
7. The scores will be calculated for the vulnerability components applying the positive and negative cardinality as per requirement.
8. The SoVI scores will be mapped using objective classification illustrating areas of high, medium and low social vulnerability.



Community Assessment Sampling Survey: RMSI would involve a four step methodology to measure the vulnerability of individuals within households. The individuals will be selected using appropriate sampling techniques. Samples will be selected in high, medium and low hazard zones to get a real representation for the study area.

In order to select a representative sample, three main criteria can be chosen:

- Administrative units
- Hazard proneness
- Demography

Indicator Selection: This would involve Literature Review, Development of selection Criteria and selection of Vulnerability Indicators

Risk perception questionnaire: The development of the questionnaire would be based on asking participants to rank the vulnerability of ten hypothetical individuals, where vulnerability is defined as 'a person's ability to recover', to various natural hazard impacts.

Decision Tree Analysis: Decision trees are a schematic way of representing alternative sequential decisions and the possible outcomes from these decisions. The analysis begins by placing all the data, in this case the results from the risk perception questionnaire, into a decision tree analysis program and ends with the establishment of high vulnerability classes.

Synthetic Information: This step in the methodology provides the opportunity to apply decision tree rules to a spatial area in order to analyze the vulnerability of individuals within a household in a real community.

The four step methodology outlined is intended to be integrated into a broader risk assessment. It is also hope that the methodology is an example of a useful quantitative vulnerability assessment that can be used to manage some of the social issues, such as the vulnerability of an individual within a household, relevant to impacts from a hazard.

3.2.7 Risk Assessment

Risk Analysis can be categorized into two broad categories: Economic Loss and Social Impact.

3.2.7.1 Economic Loss

Economic Loss has two main components; i) Direct loss which happens due to the direct impact of the hazard on structures and crops, and ii) Indirect loss which is the consequential impact of the hazard.

3.2.7.1.1 Direct Loss

Risk is the uncertainty of future losses and loss is the decrease in asset value due to damage, typically quantified as the replacement or repair cost. Loss estimation is the last step in risk analysis.

Direct Loss is a function of the damage ratio derived in the vulnerability module translated into currency loss by multiplying the damage ratio by the value at risk.

L = MDR(j,h) * Value_At_Risk(j) Equation 1

where:

MDR(j,h) = Mean Damage Ration for a exposure type 'j' at a specific hazard intensity 'h'

Value_At_Risk(j) = Replacement cost of the exposure type 'j'

For crop loss, the direct losses can be computed using the MDR and crop production in terms of economic value or crop yield, acreage and current year prices.

As discussed in the hazard section for cyclone and associated hazards, a large set of scenario events will be created. Direct loss will be calculated for every scenario event and for all types of exposure at risk like residential, commercial, industrial buildings, essential facilities, infrastructure, and agriculture. This will be done for each asset class at each location where the treatment of location differs from cyclone and associated hazards and asset class to asset class. Losses will then be aggregated at administration level of resolutions (district/municipality/ward) as required.

L(i, j) = MDR(j,i,h) * Value_At_Risk(j) Equation 2

where:

MDR(j,i,h) = Mean Damage Ration for exposure type 'j' at a hazard intensity 'h' for event i

Value_At_Risk(j) = Replacement cost of the exposure type 'j'

Based on the above approach, losses will be computed for all the exposure elements. As discussed in the exposure section, various exposure elements have been categorized into two broad categories:

Aggregated Exposure – where the area and replacement cost of buildings representing the exposure type are summed at commune level.

Site Specific Exposure – where every asset in the exposure category is represented by a separate location (Longitude, Latitude) on surface of earth with replacement cost.

The following sub sections describe, how the above described approach will be applied for these broad exposure categories.

Aggregated Exposure

The losses will be estimated at the built up area clusters for various exposure types based on the area overlap of the cluster with the hazard grid. The losses will be estimated only on the area of the built up cluster that is impacted.

Site specific exposure

Site-specific exposure will be further divided into two types – point location type exposures like Airports, Ports, Electric Power Stations, Bridges, Railway Stations, etc., and polyline type exposures like roads, railway lines, electric transmission lines, pipelines, etc. For point locations losses will be estimated at the point. In case of polyline type exposure elements, loss will be estimated at every node of the polyline and then summed up to estimate the total loss for that element.

3.2.7.1.2 Indirect Losses

Indirect losses of disasters are losses resulting from the consequences of physical destruction. Indirect losses are incurred as a result of interruption of business in the codependent sectors (sectors that are dependent on agriculture, etc.), relocation of population and resources brought about by disasters. Often the largest loss following a natural disaster is business interruption. Business interruption is not only important for immediate financial reasons but also for more intangible considerations as ongoing stakeholder confidence, reputation, brand value, etc. The methodology discussed here calculates Business Interruption as a function of damage to buildings and infrastructures. The following time dependent losses will be calculated: Relocation expenses, Loss of proprietor's income, and Loss of rental income.

To calculate these it will be important to capture the building recovery time and loss of function. Recovery time is a function of availability of resources and labor to carry out repairs. The Time Element vulnerability function will help in the estimation of these. Effort will also be made to account for various types of variations by identifying the key resources required for recovery and trying to find some values for them based on historical information coupled with expert judgment and inputs from open source models alike HAZUS, CAPRA, etc. Separate relations will be established between damage and repair and replacement costs, annual gross sales, contents value, relocation costs, rental costs and income by sector as all of these get impacted to a different extent for the same amount of damage. This will be done based on the study of the behavior of various sectors during historical disasters caused by cyclone and associated hazards, coupled with expert judgment and inputs from open source models alike HAZUS, CAPRA, etc.

For infrastructural elements, restoration curves will be developed based on an approach similar to the development of vulnerability curves described above. When infrastructural damage is applied to the repair and replacement cost and associated restoration curves, an estimate of the loss to the infrastructure and the elapsed time for their restoration is obtained. These restoration curves will be compared to the corresponding curves for similar structures used in open source models like HAZUS.

3.2.7.2 Social Impacts

Social impact is the quantification of susceptibility of population to mortality and injuries, and needs like shelter, evacuation, contingency planning etc. in the event of a disaster.

Casualty: The module will combine the output from the building damage module with building inventory, and social vulnerability estimates to quantify casualty status. The output of the casualty model will contain estimates of four classes by general occupancy and time of the event. The casualty severities will range from "Severity 1: First aid level injuries not requiring hospitalization" to "Severity 4: Instantaneous death or mortal injury." The methodology will estimate the impact of the disaster on indoor and outdoor population separately.

Need assessment of cyclone shelters and their siting: Quantification and prioritization of the locations of a cyclone shelter should be on the basis of the purpose it is intended to serve. The basic purpose of cyclone shelters are to provide safe shelter to the vulnerable population of society during cyclones who would have had otherwise least coping capacity to face disaster, such as the poor without having cyclone resistant pucca houses, the destitute, disabled, the children, the senior citizens and other dependents. Further, multi-purpose utilization of cyclone shelters to keep them operational during normalcy is also another important concern while identifying the proper locations.

The Gap Analysis/ assessing the need for number of Cyclone Shelters required in the area can be arrived at in the following manner.

Total No. of Villages = V, Total Population in the area = A

Total Population living in safe houses: B. For places where the Storm Surge heights are low one-storied houses can be considered safe. However, in areas where the Storm Surge Level is above the normal plinth height, single storied houses cannot be considered suitable as safe houses and then the people residing in two-storied houses may be considered safe.

Therefore, Total Vulnerable Population = C= A - B

Assuming 2 sq. ft. /per person of usable carpet area during emergencies (as per NDMA guidelines), Total Usable Carpet Area required for sheltering the Total Vulnerable Population

D = C X 2 = 2C sft.

> Usable Carpet Area in the available alternate public/ community buildings like schools, community buildings, temples, mosques, churches, etc. in the area and near vicinity = E sft.

Total Usable Carpet area of existing and functional/ operational cyclone shelters = F sft.

Total Usable Carpet area of cyclone shelters under repairable condition = G sft.

Total Usable Carpet area of cyclone shelters proposed under any other similar projects = H sft.

Therefore, Total Usable Carpet area available to provide shelter to the vulnerable population during cyclone = I sft.

Hence, through Gap Analysis, it is found that the balance Usable Carpet Area required = J [= C – I] sft.

Thus, if 'J' sft. of usable carpet area is developed in safe shelter/s, the entire balance population can be sheltered.

Identifying locations of Cyclone Shelter in an Area

The locations of Cyclone Shelters may be prioritized on the basis of vulnerable population, areas exposed to the risk of tidal surge and chronic flood inundation, all weather connectivity and potential high grounds in chronic inundation areas etc.. Further, the potential locations worked through mapping analysis may be corroborated with on-site reconnaissance survey report.

In case the area chosen is substantially big, on a map of the area, the line of 10 km from the coastline can be delineated. Now, over the map, a grid of 5 square km may be overlaid for fixing the location of Cyclone Shelters. This 5 square grid will ensure that the maximum travel distance on an average will be 1.5 km from the remotest village/ habitat to any Cyclone Shelter.

Based on the locations of the existing and proposed Cyclone Shelters/ Multi-purpose Cyclone Shelters, additional locations can be proposed.

The next step is to verify on field the actual locations proposed and arrive at precise land locations of the site (with GPS details), lands which are on elevated grounds and owned by government/ community without any litigation, lands where there are vegetation like shelter-belt plantations/ mangroves in near vicinity (which offer cyclone-resilience by reducing wind speeds) and where construction works will not have a derogatory environmental and social impact (for which environmental and social screening is to be conducted).

Finally, the 1.5 km maximum travel distance needs to be also verified to check whether the travel distance is uninterrupted by natural barriers like forest/ vegetation, mounds, creeks, etc.

Evacuation planning: Rescue and Evacuation requirements are driven by the number of people who are looking for shelter. A map showing the existing all weather connectivity (any type of roads), existing and proposed cyclone shelters, hospitals and rural connectivity projects under other national and state schemes will be overlaid on a map showing geomorphology and flood inundation areas to pin point the stretches of potential roads that could be designated as safe exit routes or for vehicular accessibility to existing or proposed cyclone shelters.

However, for evacuation across 13 states, conditions are different/varying across states. For example developed states along the western coast along with TN and AP, there is almost blacktop/concrete road access to the coastal villages and settlements. However, the scenarios with respect to proper road access to the absolutely coastal villages./settlement in Odisha and WB are miserable. In Odisha, PMGSY works along with support from this WB supported NCRMP and is targeted towards increasing road access. However, to have proper connectivity to all the settlements along the coast in this state is herculean and requires immense investment. In West Bengal, of the three coastal districts, the coasts of N&S 24 Parganas have the Sunderban archipelago towards the Bay of Bengal, apart from a few road bridges connecting these islands, the access is through creeks in the delta. Therefore, evacuation plans in this area are to be designed differently.

Guidelines for Contingency Planning - The HVRA conducted will help in reviewing the community-based contingency planning. The preparedness plan which constitutes of delineating escape routes on maps would be revisited now, based on scientific modeling and analysis of time taken to move to safe places. The community in a particular large village may be now be divided into households that would move to different cyclone shelters based on the capacity defined and not haphazardly. Similarly, the content in training of the different task-forces on Shelter Management, Water and Sanitation, etc., can be modified based on the precise HVRA conducted. Modeling and simulations would also help to understand the maximum tidal surge levels and the effects of it at micro level in the village/ settlements and accordingly, the evacuation of not only people but livestock can be re-designed.

3.2.8 HOTSPOT IDENTIFICATION AND VULNERABILITY ANALYSIS

Following steps will be involved in hotspot identification:

- Using the risk analysis conducted using various deterministic scenarios Identify the districts, which are most prone to cyclone risk among all the coastal districts across the 13 states in the country. The physical, social and economic losses will provide the necessary inputs for this selection.
- From among the identified districts, which are at most risk to cyclones, identify the 10 panchayats/villages at most risk. The panchayat/village in a rural area and a Ward in an urban area would best serve as a unit for hot-spot communities for the following reasons:
  - Panchayat/ village/ Ward level maps and information related to vulnerabilities and capacities are available in the census and at district and sub-district (block/ taluka / mandal) levels. For example, information like number of pucca houses existing and number of IAY (Indira Awaas Yojana) houses allotted in each financial year, information relating to panchayat-level capacity building programs conducted, funds allocated for developmental or disaster mitigation work, etc.
  - Secondly, cyclone shelters and other built infrastructure/ nodal facilities along with road work connectivity are generally planned at panchayat/village level/ cluster of panchayat/village level.
  - Finally, since the panchayat/ village / Ward (in urban area) is the last tier for administrative decisions and fund allocation, the strategies spelled out after conducting HVRA can get more practically implemented and intertwined with on-going developmental works.
- Next perform the physical, social and economic vulnerability analysis for these panchayats/ villages. Most of the inputs for these would be available through the exposure data and vulnerability functions. Additional inputs will also be used like presence of safe shelter in the vicinity, presence of all weather roads connecting the villages to the shelters, presence of transport, height of saline embankments, etc.
- Along with the Hazard and Vulnerability assessment, there is a need to assess the existing capacity of these panchayats/villages and the inherent/ developed coping mechanisms within the inhabitants. The assessment of the capacity can be done by reviewing the Panchayat Disaster Management Plan, whether the same is in place and is being revised periodically. More importantly, it is necessary to assess the understanding level among the panchayat officials regarding the Panchayat Disaster Management Plan and trainings offered, whether DRR related capacity building programs have been conducted for the panchayat officials, whether the existing warning dissemination arrangements are in place or not, etc., whether the local communities/ NGOs/ CBOs have participated in preparation and revising the community contingency plans, whether trainings/ refresher trainings have been conducted for the task forces at the panchayat/ village levels, whether mock-drills are being conducted periodically, whether trainings for local masons have been conducted relating to cyclone-resilient construction practices, etc.

3.2.9 WEB-GIS BASED COMPOSITE RISK ATLAS

The primary objective of developing this Web-GIS based Composite Risk Atlas is to provide a mechanism for:

1. Data sharing – this will ensure that up-to-date information about buildings, infrastructure, critical facilities, population and demographics are available at a centralized place to facilitate disaster risk reduction efforts in the study area.
2. Sharing outcomes of the study – this will ensure that individuals, researchers, planners, disaster management specialists, first responders, professional engineers, school authorities etc., have access to the different types of vulnerabilities due to cyclone and cyclone related hazards so that they could use that information in their respective work areas.
3. Provide a platform for deterministic risk assessment that could be later extended for dynamic probabilistic risk analysis.
4. Assistance in disaster planning, preparedness, response and recovery – this is the dynamic aspect of the application that will allow the users to see the impact of imminent or just occurred disasters on various assets of the study area thereby helping in response activities. The application will also provide ground truthing abilities to support recovery operations, followed by inputs for improving planning and preparedness.
5. Bring all the agencies involved in disaster management under one common platform so that data and information sharing is made easy.
6. Contains all the maps related to Hazard, Exposure, Vulnerability, hotspots and realistic disaster scenario maps for training and decision support where users can create different scenarios and choose hazard levels.
7. Administrator should be able to create partitioning sub system for different states and perform processing on that partition for planning and mitigation.
8. Option for users to share the data and maps with other users.
9. System will be scalable and compatible for Phase II modeling and dynamic decision making.
10. User will be able to find the shortest route for evacuation using the application.

3.2.9.1 System Requirements Specification (SRS) Preparation

The system requirement specification (SRS) describes in detail the functionality to be implemented in the application. It covers the business needs of the client and stakeholders to identify the business problem and propose the solution. In a nutshell, it contains the collection of data, functional and behavior requirement of the software application to be developed. SRS is the first and important milestone of the software development life cycle.

- Use case scenarios
- Map publishing and Viewing:
- There are two types of users in the "Composite Risk Atlas".
  - Administrator
  - Normal users or Guest

Administrator has a privilege to upload the GIS data, modify the styles and publish the layers to the website. He can also change the configurations to ensure the smooth running of the "Composite Risk Atlas".

Normal users and administrator can view the layers (maps) in the "Composite Risk Atlas". They can perform all the GIS functionality as given below.

- Pan
- Zoom in
- Zoom out
- Previous view and next view
- Attribute Info tool
- Measure distance
- Measure area for Polygon and Circle

- map search

Following is the list of layers that will be visible to users:

1. Remote sensing imagery as the standard base data layer
2. Building infrastructure layers including roads, bridges, railway lines, ports, inland water transport and embankments
3. Critical infrastructure
4. Location of shelter and vertical evacuation
5. Critical and high risk facility including administrative head quarters, police stations, hospitals, schools, existing cyclone/flood shelter, major and hazardous industry facility, power plant and sensitive installation.
6. Utilities including water pipelines, electrify pipelines and telecommunication
7. Land use land cover
8. Soil type
9. Ecological data
10. "Hotspot" risk maps
11. Social data including total population by village/block/district, density of population, population by gender, children, aged and disabled.
12. Listing of social capital organization
13. Economic data based on livelihood, occupational patterns (per census classification), people below poverty lines, livestock, GDP by district (if possible) and replacement values.

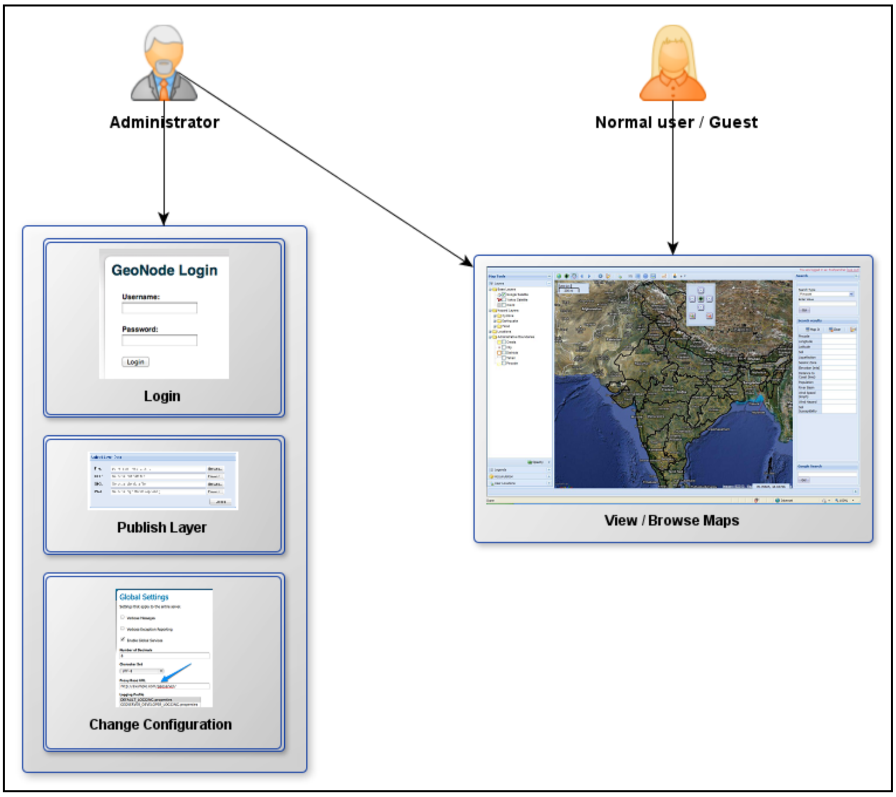


Figure 3:19 Map publishing and Viewing

3.2.9.1.1 Sharing map and data

Users can generate reports, which contain both the data and maps. These reports can be exported to PDF, Excel and MS Word format for further sharing and processing.

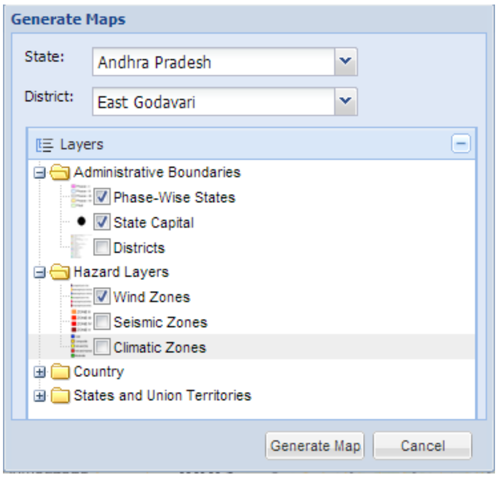


Figure 3:20 Generate Map

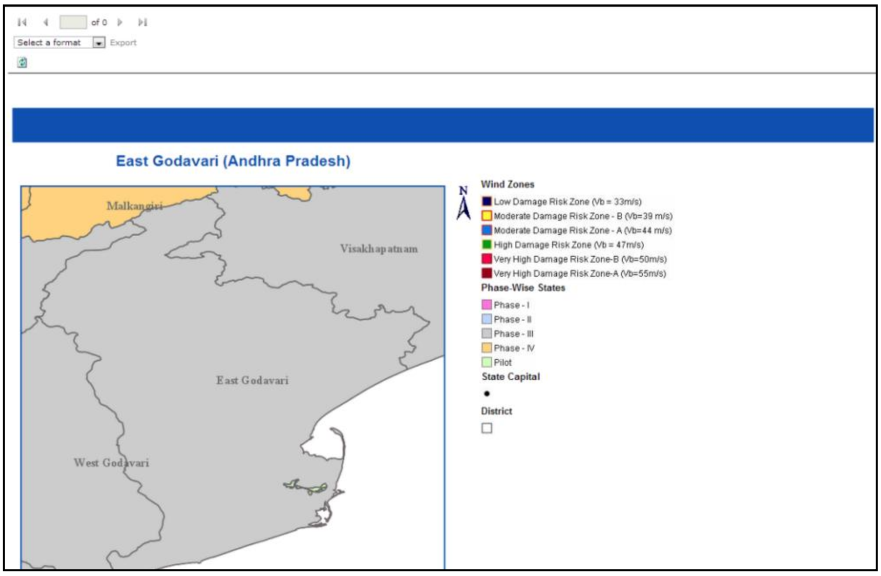


Figure 3:21: Report

3.2.9.2 Review of Geonode Platform and Framework Overview

Geonode is an open source platform for managing and publishing the geospatial data on the web. The Geonode is user friendly and users can easily modify geonode and share interactive maps over the web.

Figure 3:22 Satellite Imagery

Following are the functionality, which makes Geonode a suitable framework for this project:

- Geonode supports both the vector and raster data including ESRI Shapefiles, satellite imagery and Geotiff format
- It supports all popular base layers including Open street maps, Google satellite and Bing.
- It reprojects all the layers to web Mercator projection for better display
- It can be installed on Linux, Windows or OSX
- Geonode's look and feel can be customized based on user requirements.
- Geonode is highly secure. For example, Guest users may only be allowed to view maps. But the Administrator can give permissions to registered or specific users to edit specific layers or to manage specific layers.
- Geonode internally uses the Geoserver for map rendering. Geoserver can pick the maps from the database server called postgreSQL. The user can take regular back up of the data in postgreSQL and recover it in case of accidental loss of data. The user can also implement replication on postgreSQL server, which in turn can be used for load balancing.
- The Geonode supports social networks. The maps can be shared using Facebook, Twitter and Google +.
- All the layers in Geonode can be cached so that layers are rendered faster to the user.

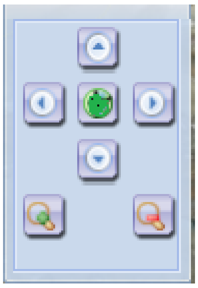
3.2.9.3 Description of proposed functionality

The web based "Composite Risk Atlas" will be developed by customizing the Geonode framework to suit the requirements of the client and stakeholders. The administrator can publish both the raster and vector data into the Atlas.

Following are functionality supported by "Composite Risk Atlas":

- Administrator will be able to publish and share the data
- Administrator will be able to give permissions to registered users or any other users to edit particular layers
- The administrator will be able to cache the layers for better performance
- Updating facility from NDMA/ SDMAs/ DDMAs will be provided so that the Atlas doesn't remain static

User will be able to use all mapping functionalities as given below:



- Pan
- Zoom in
- Zoom out
- Previous view and next view
- Attribute Info tool
- Measure distance
- Measure area for Polygon and Circle
- map search
- Adding/deleting and modifying the shelter locations

Following are the list of layers that will be visible to the users:

- Remote sensing imagery as the standard base data layer
- Building infrastructure layers including roads, bridges, railway lines, ports, inland water transport and embankments
- Critical infrastructure including hazardous material storage structure and power plant.
- Location of shelter and vertical evacuation

- Critical and high risk facility including administrative head quarters, police stations, hospitals, schools, existing cyclone/flood shelter, major and hazardous industry facility, power plant and sensitive installation.
- Utilities including water pipelines, electrify pipelines and telecommunication
- Land use land cover
- Soil type
- Ecological data
- Social data including total population by village/block/district, density of population, population by gender, children, aged and disabled.
- Listing of social capital organization
- Economic data based on livelihood, occupational patterns (per census classification), people below poverty lines, livestock, GDP by district (if possible) and replacement values.

3.2.9.4 Proposed system design and architecture

Following are the functional and system architecture of the “Composite Risk Atlas”.

Functional Architecture

The “Composite Risk Atlas” will be a web GIS based application developed by customizing the open source Geonode application. It will also use Ajax based JavaScript libraries called Open layers and GeoExt to give the additional functionality to the users. Geonode will internally connect to Geoserver and Geowebcache to render the map on the “Composite Risk Atlas”. The map data will be stored along with its attribute inside the PostgreSql server and inside the folder on the server. Geoserver will connect to the PostgreSql server to fetch the map data and return the map to the user.

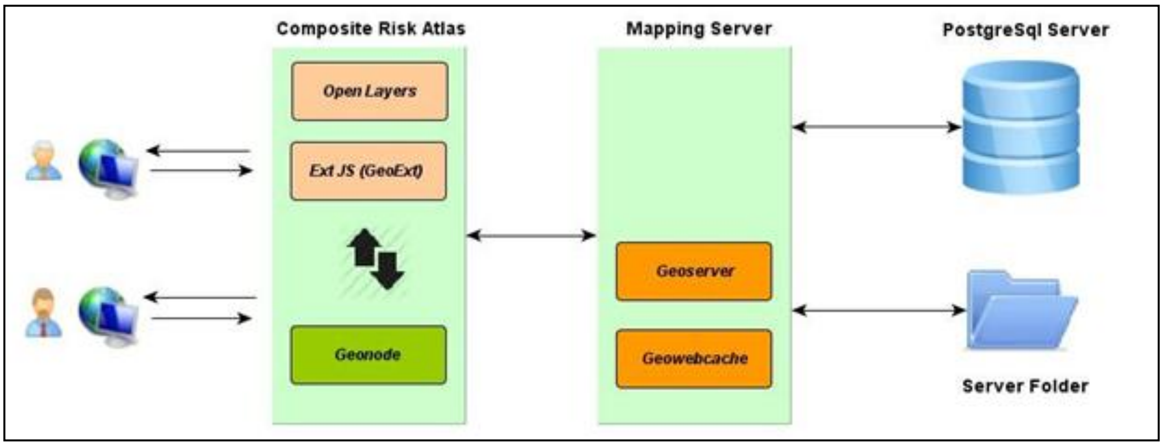


Figure 3:23 Functional Architecture

System Architecture

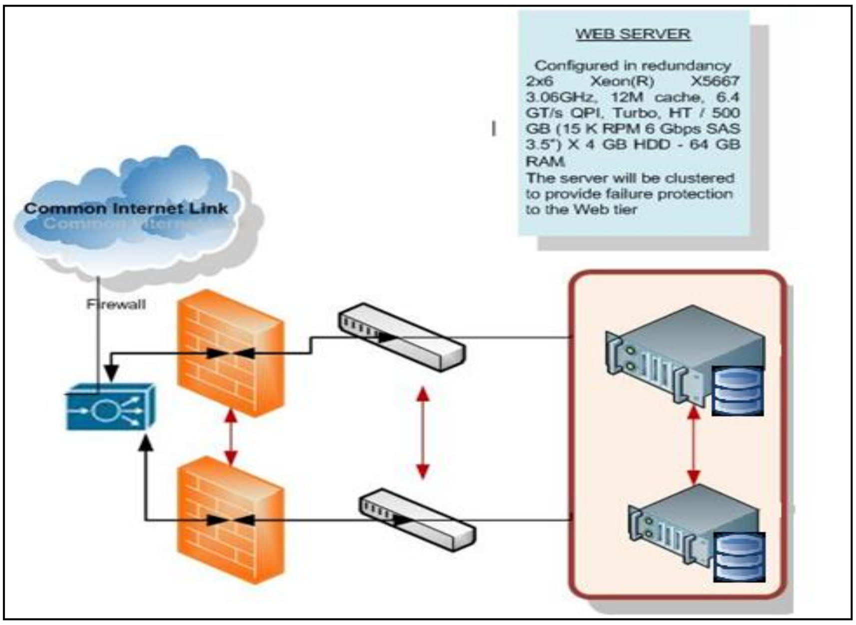


Figure 3:24 System Architecture

The system architecture consists of two redundant web servers clustered to provide failure protection, along with a firewall. Geonode will be installed on both these servers. Data from the PostgreSQL will be replicated on both these servers.

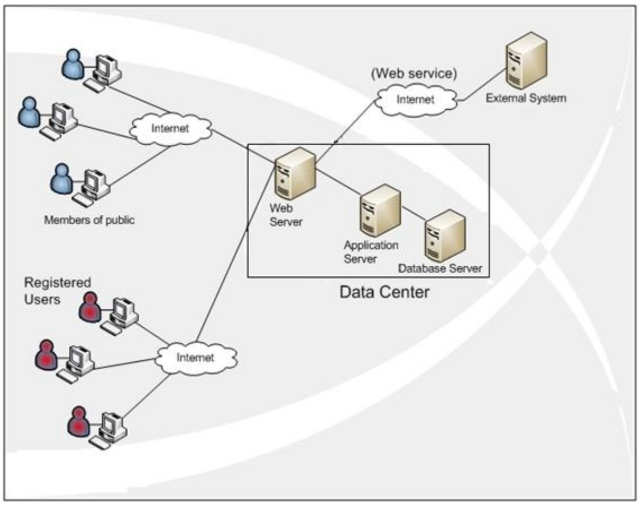


Figure 3:25: Network Architecture

To maintain high availability of the application, a clustering mode solution is proposed. This will help in providing 24x7 availability of the Atlas.

High Availability

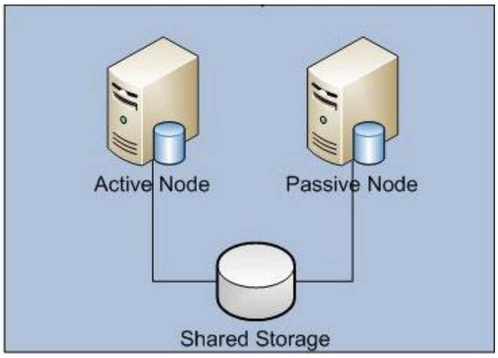


Figure 3:26 Redundant Server

The application architecture is a centralized and web-based application with high-availability architecture with mirrored servers at each of the tiers. Following are the steps taken to ensure high availability of the system. Load balancing will be done at each tier

The application architecture provides load balancing in situations of peak load to maintain the service levels of the Atlas.

Database Server and Web Server are configured and connected via Network Load Balancer for high availability.

High Scalability

The application architecture is scalable to meet growing future usage in terms of transactional volumes and number of users.

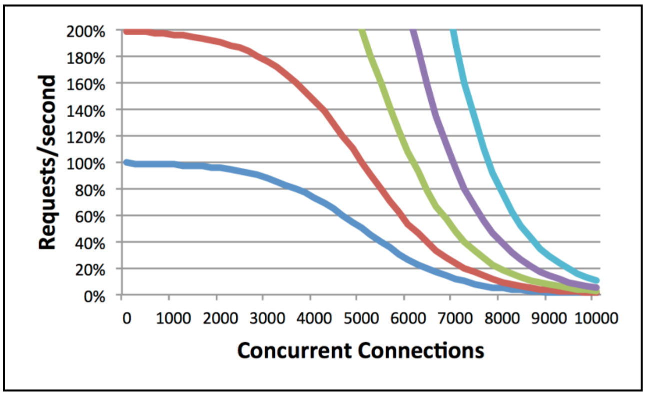


Figure 3:27 Load on the web server

Interoperability

The application supports spatial data interoperability and multiple browsers (IE, Chrome, Safari & Mozilla Firefox).

Integration with existing systems

Due to the flexible and scalable architecture of the Atlas, it is easy to integrate any existing system with it.

3.2.9.5 Benefits of RMSI's proposed solution

The reasons that give RMSI's solution an edge are shown below and described thereafter:

- No vendor lock-in – RMSI's solution is based on open standards and will use Geonode. Open standards will ensure that their multiple implementations are available from different vendors and they can be replaced with each other, thus giving business the freedom of switching vendors.

- No platform lock-in – RMSI's solution will run on Geonode platform that gives business a range of choices in hardware platforms and operating systems for deploying the portal. Geonode can be deployed on Linux, Windows and OSX.
- Secure – RMSI's solution will use industry standards, government-grade encryption technologies including advanced algorithms such as DES, MD5 and RSA and a fine-grained access-control security model making the portal fully secure.
- Fast – RMSI's solution will employ various techniques (like full-page caching for static content) to deliver increased web performance. All the layers of the "Custom Risk Atlas" will be cached for better performance.
- Scalable – RMSI's solution will be capable of multitier, limitless clustering, enabling it to meet any user load requirements of the present and the future.

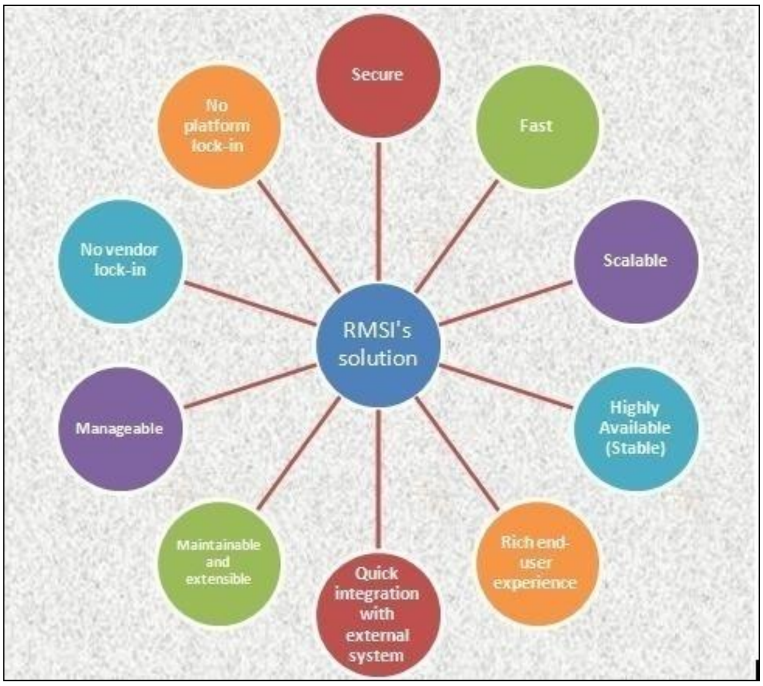


Figure 3:28 Benefits

- Highly Available (Stable) – RMSI's solution supports hardware and software load balancing, HTTP failover and session replication making it possible to maintain zero down time for portal.
- Rich end-user experience – RMSI's solution employs Web 2.0 technologies to deliver to the end-user a participative experience using the interactivity of Rich Internet Applications (RIA).
- Quick integration with external system – RMSI's solution uses Service Oriented Architecture (SOA) allowing quick integration with external applications and services.
- Maintainable and extensible – RMSI's solution employs sound design principles (like 'separation of concerns', 'programming to interface', 'encapsulation', 'loose coupling', etc.) making it easier to change and augment the system as and when required.
- Manageable – RMSI's solution allows for easy monitoring of the system to ensure continued health of the system and the ability to improve its services only by changing the system configuration and not the system itself.

3.2.9.6 Technical user guide and decision making guidance documents

Documentation and training are key components of this project to ensure project sustainability. The team will develop a comprehensive training and capacity building plan for knowledge transfer, which is explained in the subsequent section. In addition to the handouts and materials provided during the workshops and training sessions, user manual and decision makers guidelines documentation would be key deliverables of this assignment.

Technical user guide: This would be a comprehensive user manual, which explains all the functionalities of the risk atlas with screen shots of the applications demonstrating the task and output. The fundamental principle RMSI will follow while developing the manual would be to ensure that the demonstration and text are self-explanatory and a person with basic understanding of GIS and DRR can perform the required thematic map preparation and analysis. The user guide will have a separate section on data inventory in the system along with details of source, attribute information, vintage. RMSI assumes that the user will have a basic understanding on concepts of GIS and computer operations and this will be excluded from the manual.

Taking into consideration the key objectives of this application, there will be a separate section to explain, with illustrations on building various scenario maps, specific use cases in terms of damage and loss potentials. In addition to this, it will have the capability of carrying out economic evaluation of damages, which is essential for developing appropriate mitigation measures.

This manual will also have tutorials, which explain step-by-step tasks to be carried out for some of the key analysis and thematic map preparation.

In addition, the manual will have a separate section on Modeling cyclones and associated flooding, physical and social vulnerability assessment, hotspot identification, shelter planning, evacuation planning, habitat planning, and population relocation.

Decision making guidelines: This document will have fundamentals explained in brief that are used for decision making specific to DRR and cyclone risk mitigation. Based on these fundamentals, the document will also explain steps and guidelines for prescribing long term and short term state specific mitigation measures required for vulnerable groups. While prescribing this, RMSI will also take into consideration the existing National and State specific rules and regulations of development and conservations.

Some of the key guidelines envisaged to be included in the decision making guidance document include processes and steps to be carried out for need analysis for construction of safe shelters, gap analysis for mangroves, coastal protection structures, economic evaluation of asset in defined area etc. This will be explained with required charts and exercises.

3.2.10 DOCUMENTATION AND TRAINING

RMSI will design an inclusive training program to ensure knowledge transfer, capacity building and project sustainability. During the inception phase of the assignment, RMSI with the help of NDMA will map the key stakeholders, understand their requirements, capacity and accordingly develop a detailed training and capacity-building plan. The training and capacity-building plan will include content, schedule and plans of action for implementation and this will be finalized in consultation with NDMA.

Our proposition for capacity building is to involve identified stakeholders from all the 13 States/UTs in the key project activities including data collection, quality review, analysis and testing of the Risk Atlas in addition to actual state level training. The stakeholders for these activities will be carefully identified who have a basic background on DRR and who in future can carry out the operational activities in the state. Middle level officers will be ideal for this. This approach will ensure ownership among stakeholders in addition to capacity building and knowledge transfer.

The training and capacity building activities will be carried out in a phased manner and at different levels. This will include three national level workshops and seven state level outreach activities. The details of the proposed workshops and outreach activities are provided below.

3.2.11 National Level Workshops

The objective of the national level workshop is to test the beta version of the risk atlas and subsequently take the project findings and the risk atlas application to a wider audience. RMSI proposes 3 national workshops of 2 day duration for this.

Testing beta version of risk atlas: Once the beta version of the risk atlas is ready, RMSI in coordination with NDMA will conduct a national level workshop to present the functionalities and capabilities of the risk atlas. The attendees of the workshop mostly will be policy makers and selected representatives from 13 States/UTs, NDMA and the World Bank. The team will demonstrate the functionalities and the base data available in the system and its application. Development of realistic disaster scenario maps and assessment of vulnerability and risk assessment specific use cases based on some of the damaging past events will be demonstrated. As the stakeholders will have on-ground experience in dealing with these past events, the specific use cases of these events will be used for bench marking and verifying the capability and authenticity of the system. The team will explain the data layers involved in the analysis and their limitations, if any, for building the scenarios. The opinions and suggestion of the stakeholder will be document and will be considered during the finalization of the risk atlas.

Demonstration of risk atlas: The second national workshop will be conducted in coordination with NDMA after RMSI addresses the suggestions and recommendations of the stakeholders. Now the application will be ready to be demonstrated to a wider audience accommodating the requirements and expectations of the stakeholders and users. The same stakeholders invited for the first national workshop will be invited for this workshop and the risk atlas will be presented again to ensure that all the comments and suggestions are addressed satisfactorily before opening to a wider audience.

Final national level workshop: The national level workshop will be conducted as part of the closure session and handing over of the system to the State and National users. A larger audience including senior and middle level officers, policy makers both at state and national levels from all 13 States/UTs, other stakeholders like INCOIS, NDMA, the World Bank, other funding and DRR organizations working in these states, lead NGOs, etc. will be invited. The team will explain the study in details and further present the risk atlas capabilities. On the second day of the workshop, RMSI suggests to form smaller groups in which users will have hands on activities in working on the risk atlas. RMSI team will actively support the groups in exploring and understanding the application's capabilities.

The agenda for all the three workshops will be designed carefully in consultation with NDMA. Key principle for developing the agenda would be to ensure active involvement of stakeholders and provide opportunities to stakeholders to contribute in finalizing the beta version and in understand the capabilities of the Risk Atlas in full potential.

RMSI will take the support of NDMA to identify and invite the stakeholders and provide the required logistics for the participants, venue locations and facilities required for the workshops. RMSI will prepare presentation materials, hand-outs, workbooks, reference sheets etc. to the participants during the workshop. The workshop will not only facilitate the dissemination of the findings of the study but will also keep all the stakeholders informed and be at the same level of understanding regarding the process/methodology as a result of which it would pave the way to develop a road map for Disaster Risk Reduction in the state.

Provided below is a tentative schedule for the final national workshop:

Table 3-5: Tentative agenda for final national workshop

S. No.	Theme	Topics	Duration

S. No.	Theme	Topics	Duration
1.	Fundamentals	Refreshment of fundamentals provided in the beta version training	9.30 to 10.30 AM
2.	Hazard, vulnerability and risk assessment	Run-through on the data development and assessment methodologies and results	11.00 to 12.00
3	Vulnerability and Risk Atlas	Methods on development of thematic maps in the Atlas	12.00 to 1.00 PM
4	Discussion of Risk Atlas	Capabilities and functionalities	2.00 to 3.00 PM
5	Mitigation and scenario building	Methodological steps involved in mitigation options and what-if scenario development Integration of mitigation options in development projects	3.30 to 4.30 PM
6	Feedback and Project closure	Review of Project exercise Review of training and knowledge gained Project closure validation session	4.30 to 5.30 PM

3.2.12 State Level Training

The objective of state level outreach is to provide the state level stakeholder a comprehensive training on use of the Risk Atlas application for future operations. This will be in addition to the national level workshops. The state outreach activities will be carried out after incorporation of the suggestions and recommendations of the beta version. The broad outline of the training activities at the state level will follow the same agenda mentioned above but the data discussion and analysis will be more focused to the particular state. The use case scenarios will also be considered with reference to that particular state. RMSI proposes 2 day outreach activities and a total of 7 training sessions. All the states in category 1 will have separate sessions and the adjoining states in the category 2 will be grouped. The UTs will be invited to the nearest state for the sessions. However, this tentative plan will be further discussed with NDMA to see the modalities and feasibility of grouping two states together for outreach activities. It is logical to consider adjoining states together as it is essential to have coordination between states for any mitigation and adaptation activities particularly for hazards like cyclone, which will often have regional impact.

Tentative schedule for the state level training

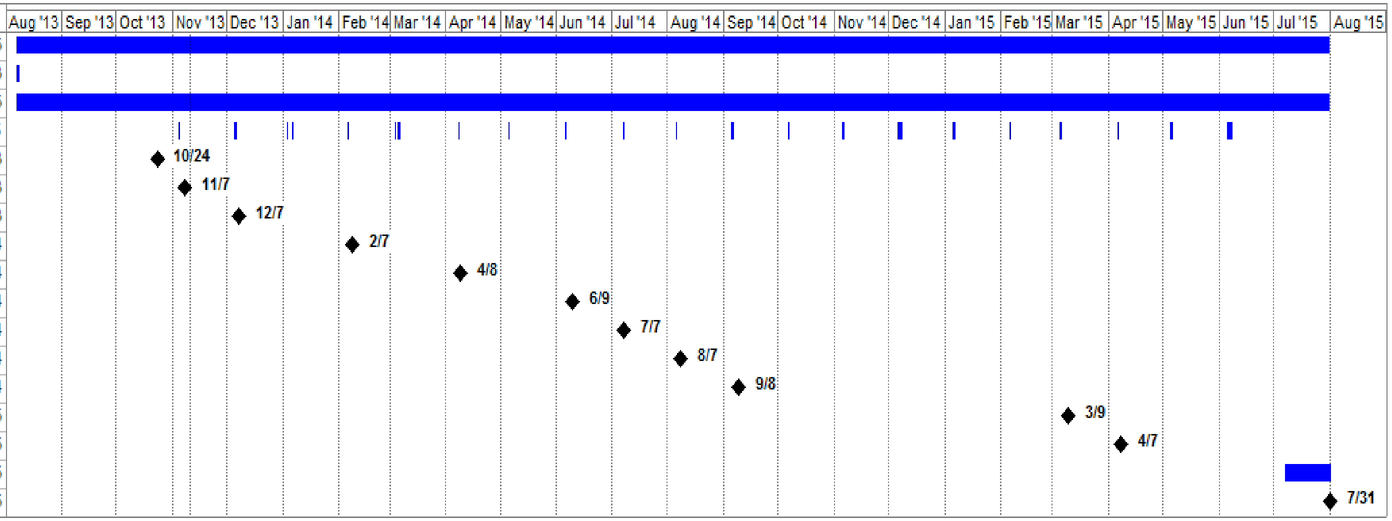
The State outreach program will be schedule on the 24th month of the project (July 2015).

S. No.	Date	State/UT
1.	06/7/2015	West Bengal and Andaman &Nicobar islands
2.	08/7/2015	Odisha
3.	10/7/2015	Andhra Pradesh
4.	12/7/2015	Tamilnadu and Puducherry
5.	20/7/2015	Gujarat
6.	22/7/2015	Maharashtra, Daman & Diu and Goa
7.	24/7/2015	Kerala, Karnataka and Lakshadweep

4 Work Plan

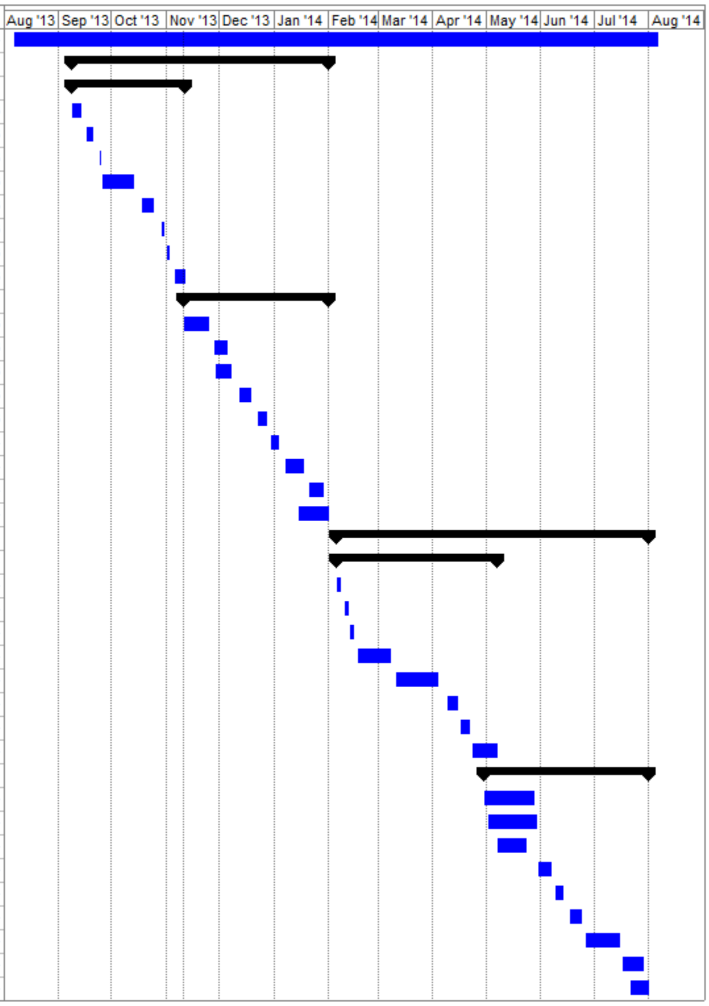
4.1 Project Management and Deliverables

ID	Task Name	Start	Finish
1	Project Initiation and Management	Wed 8/7/13	Fri 7/31/15
2	Project Initiation Meeting	Wed 8/7/13	Thu 8/8/13
3	Project Management	Wed 8/7/13	Fri 7/31/15
4	**Monthly progress reports**	**Mon 11/4/13**	**Mon 6/8/15**
27	Inception report	Wed 8/7/13	Thu 10/24/13
28	Data inventory and data review report	Thu 11/7/13	Thu 11/7/13
29	IT system specification report, functional a	Sat 12/7/13	Sat 12/7/13
30	Demonstration Hazard dataset and report	Fri 2/7/14	Fri 2/7/14
31	Demonstration Exposure/ Vulnerability dat	Tue 4/8/14	Tue 4/8/14
32	Demonstration Risk dataset and report	Mon 6/9/14	Mon 6/9/14
33	Prototype Composite Risk Atlas	Mon 7/7/14	Mon 7/7/14
34	Prototype Demonstration and presentation	Thu 8/7/14	Thu 8/7/14
35	Year 1 (interim) report	Mon 9/8/14	Mon 9/8/14
36	Beta Composite Risk Atlas	Mon 3/9/15	Mon 3/9/15
37	Demonstration and report - Beta version	Tue 4/7/15	Tue 4/7/15
38	State outreach and training workshops	Tue 7/7/15	Fri 7/31/15
39	Year 2 (close out) report	Fri 7/31/15	Fri 7/31/15



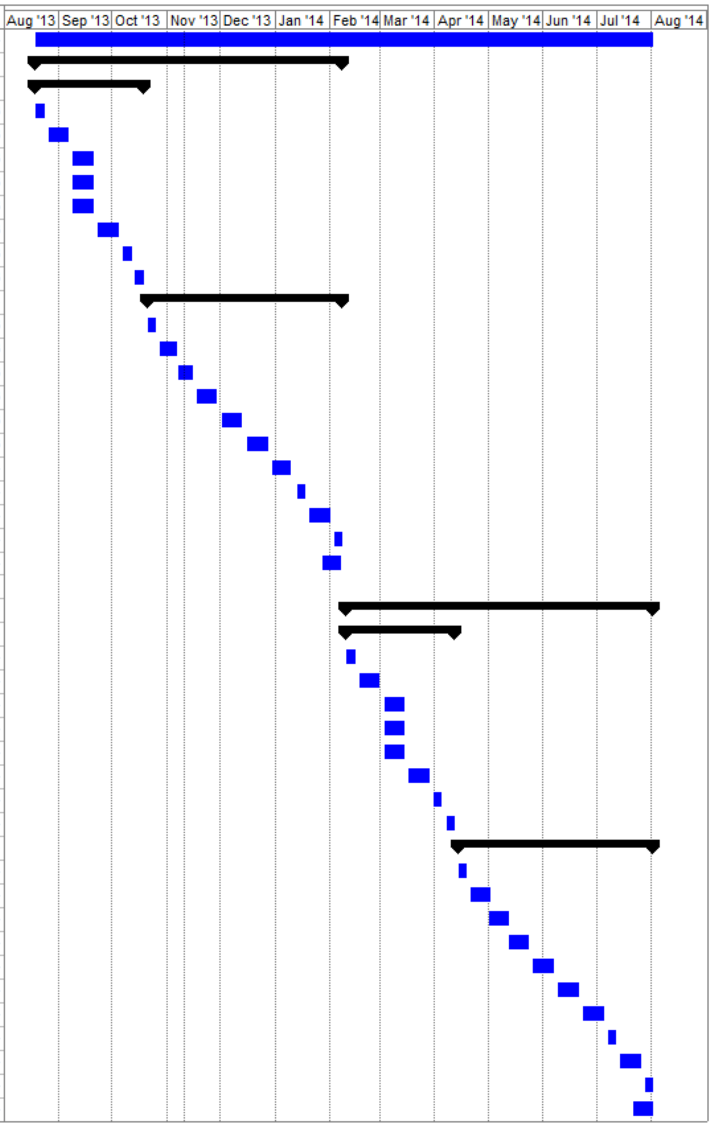
4.2 Cyclone Hazard Mapping and Risk Assessment

ID	Task Name	Start	Finish
41	**CYCLONE**	Wed 8/7/13	Tue 8/5/14
42	**Phase I- Model development for AP a**	**Mon 9/9/13**	**Fri 1/31/14**
43	**Cyclone Model Development**	**Mon 9/9/13**	**Mon 11/11/13**
44	Hazard data compilation: Analysi	Mon 9/9/13	Fri 9/13/13
45	Input parameters generation: Est	Tue 9/17/13	Fri 9/20/13
46	Prepartion of master catalogue: /	Tue 9/24/13	Tue 9/24/13
47	Calculation of return period and ε	Thu 9/26/13	Sun 10/13/13
48	Configuration of RMSI storm surç	Fri 10/18/13	Thu 10/24/13
49	Calibration of cyclone model	Tue 10/29/13	Wed 10/30/13
50	Validation of cyclone model	Fri 11/1/13	Sat 11/2/13
51	Simulation of deterministic cyclor	Wed 11/6/13	Mon 11/11/13
52	**Storm Surge Model Developmen**	**Mon 11/11/13**	**Fri 1/31/14**
53	Development/configuration of nu	Mon 11/11/13	Sun 11/24/13
54	Mesh generation for 2 identified ε	Thu 11/28/13	Thu 12/5/13
55	Prepartion of Bathymetry and To	Fri 11/29/13	Sat 12/7/13
56	Study and incorporation of initial	Thu 12/12/13	Wed 12/18/13
57	Calibration of storm surge model	Mon 12/23/13	Fri 12/27/13
58	Validation of storm surge model	Mon 12/30/13	Fri 1/3/14
59	Simulation of deterministic storm	Tue 1/7/14	Fri 1/17/14
60	Inland inundation zones mapping	Tue 1/21/14	Tue 1/28/14
61	Hazard Report- Part1	Wed 1/15/14	Fri 1/31/14
62	**Phase II-Remaining 11 states and 6 U**	**Wed 2/5/14**	**Thu 7/31/14**
63	**Cyclone Model Development**	**Wed 2/5/14**	**Tue 5/6/14**
64	Hazard data compilation: Analysi	Wed 2/5/14	Fri 2/7/14
65	Input parameters generation: Est	Mon 2/10/14	Tue 2/11/14
66	Prepartion of master catalogue: /	Thu 2/13/14	Fri 2/14/14
67	Calculation of return period and ε	Mon 2/17/14	Fri 3/7/14
68	Configuration of RMSI storm surç	Tue 3/11/14	Thu 4/3/14
69	Calibration of storm surge mode	Wed 4/9/14	Mon 4/14/14
70	Validation of cyclone model	Wed 4/16/14	Mon 4/21/14
71	Simulation of deterministic cyclor	Wed 4/23/14	Tue 5/6/14
72	**Storm Surge Model Developmen**	**Wed 4/30/14**	**Thu 7/31/14**
73	Development/configuration of AC	Wed 4/30/14	Tue 5/27/14
74	Mesh generation for remaining id	Fri 5/2/14	Thu 5/29/14
75	Prepartion of Bathymetry and To	Wed 5/7/14	Fri 5/23/14
76	Study and incorporation of initial	Fri 5/30/14	Fri 6/6/14
77	Calibration of storm surge model	Mon 6/9/14	Fri 6/13/14
78	Validation of storm surge model	Tue 6/17/14	Mon 6/23/14
79	Simulation of deterministic storm	Thu 6/26/14	Tue 7/15/14
80	Inland inundation zones mapping	Thu 7/17/14	Mon 7/28/14
81	Hazard Report- Part2	Mon 7/21/14	Thu 7/31/14



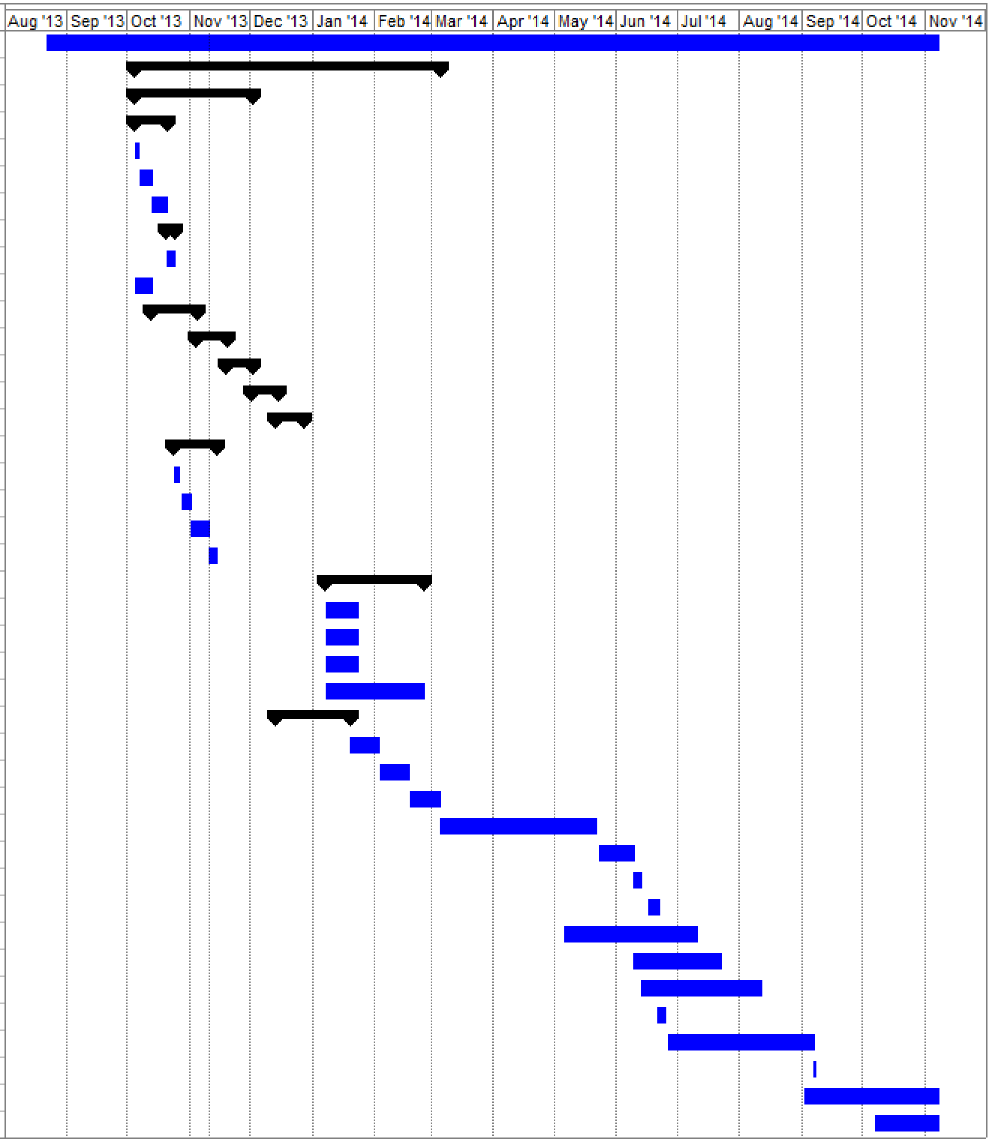
4.3 Flood Hazard Mapping and Risk Assessment

ID	Task Name	Start	Finish
83	**FLOOD**	Mon 8/19/13	Fri 8/1/14
84	**Phase I-10 Basins for AP and Orissa**	**Mon 8/19/13**	**Fri 2/7/14**
85	**Hydrological Model Development**	**Mon 8/19/13**	**Fri 10/18/13**
86	Processing of raw data	Mon 8/19/13	Fri 8/23/13
87	Basin Delineation	Mon 8/26/13	Fri 9/6/13
88	Met Model Creation	Mon 9/9/13	Fri 9/20/13
89	Scenario Determination	Mon 9/9/13	Fri 9/20/13
90	Estimation of Basin Parameters	Mon 9/9/13	Fri 9/20/13
91	Calibration of model	Mon 9/23/13	Fri 10/4/13
92	Validation of model	Mon 10/7/13	Fri 10/11/13
93	Stochastic Simulation	Mon 10/14/13	Fri 10/18/13
94	**Hydraulic Model Development**	**Mon 10/21/13**	**Fri 2/7/14**
95	Processing of raw data	Mon 10/21/13	Fri 10/25/13
96	Mesh generation - Orissa Basins	Mon 10/28/13	Wed 11/6/13
97	Mesh generation - AP Part1 Basi	Thu 11/7/13	Fri 11/15/13
98	Mesh generation - AP Part1 Basi	Mon 11/18/13	Thu 11/28/13
99	Incorporation of flow and sedime	Mon 12/2/13	Thu 12/12/13
100	Study and incorporation of initial	Mon 12/16/13	Fri 12/27/13
101	Calibration of flow model	Mon 12/30/13	Thu 1/9/14
102	Validation of model	Mon 1/13/14	Fri 1/17/14
103	Scenario Simulation	Mon 1/20/14	Fri 1/31/14
104	Flood zone mapping	Mon 2/3/14	Fri 2/7/14
105	Hazard Report- Part1	Mon 1/27/14	Thu 2/6/14
106			
107	**Phase II-Remaining 9 Basins other st**	**Mon 2/10/14**	**Fri 8/1/14**
108	**Hydrological Model Development**	**Mon 2/10/14**	**Fri 4/11/14**
109	Processing of raw data	Mon 2/10/14	Fri 2/14/14
110	Basin Delineation	Mon 2/17/14	Fri 2/28/14
111	Met Model Creation	Mon 3/3/14	Fri 3/14/14
112	Scenario Determination	Mon 3/3/14	Fri 3/14/14
113	Estimation of Basin Parameters	Mon 3/3/14	Fri 3/14/14
114	Calibration of model	Mon 3/17/14	Fri 3/28/14
115	Validation of model	Mon 3/31/14	Fri 4/4/14
116	Stochastic Simulation	Mon 4/7/14	Fri 4/11/14
117	**Hydraulic Model Development**	**Mon 4/14/14**	**Fri 8/1/14**
118	Processing of raw data	Mon 4/14/14	Fri 4/18/14
119	Mesh generation- Kerala and Kai	Mon 4/21/14	Thu 5/1/14
120	Mesh generation- Maharashtra G	Thu 5/1/14	Mon 5/12/14
121	Mesh generation- Gujarat + Uts	Mon 5/12/14	Fri 5/23/14
122	Incorporation of flow and sedime	Mon 5/26/14	Fri 6/6/14
123	Study and incorporation of initial	Mon 6/9/14	Fri 6/20/14
124	Calibration of flow model	Mon 6/23/14	Fri 7/4/14
125	Validation of model	Mon 7/7/14	Fri 7/11/14
126	Scenario Simulation	Mon 7/14/14	Fri 7/25/14
127	Flood zone mapping	Mon 7/28/14	Fri 8/1/14
128	Hazard Report - Part2	Mon 7/21/14	Fri 8/1/14



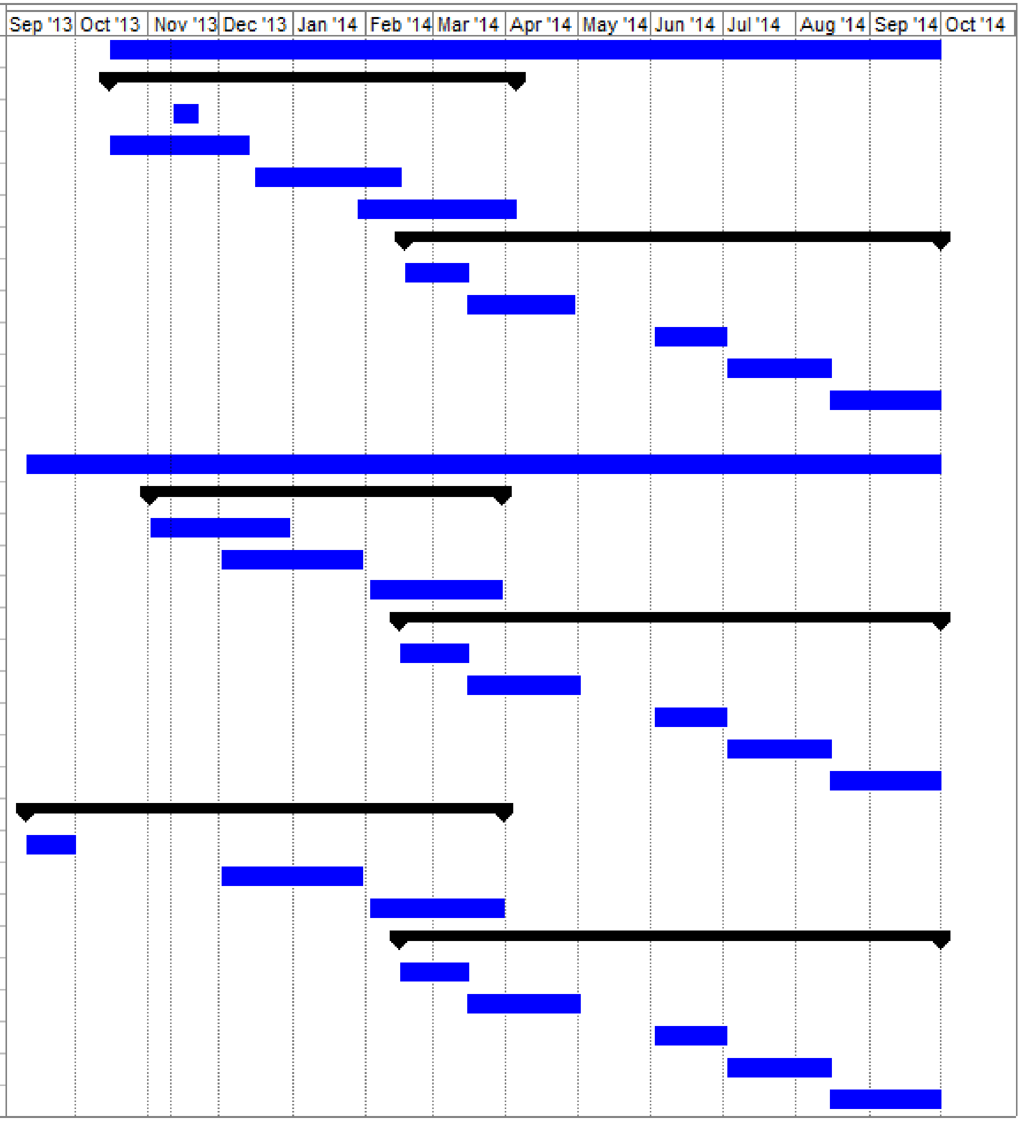
4.4 Exposure Data Development

ID	Task Name	Start	Finish
130	**EXPOSURE**	Thu 8/22/13	Fri 11/7/14
131	**Andhra Pradesh (93,000 sq km)**	**Sat 10/5/13**	**Wed 3/5/14**
132	**Data processing**	**Sat 10/5/13**	**Mon 12/2/13**
133	**Finalisation administrative ui**	**Sat 10/5/13**	**Sun 10/20/13**
134	State and district boundarie:	Sat 10/5/13	Sun 10/6/13
135	Mandal, talukas and village/(	Mon 10/7/13	Sun 10/13/13
136	Coastal line	Sun 10/13/13	Sun 10/20/13
137	**DEM Finalisation**	**Sun 10/20/13**	**Fri 10/25/13**
141	Processing of demographic data	Sun 10/20/13	Thu 10/24/13
142	Land use data QA as per NUIS s	Sat 10/5/13	Sun 10/13/13
143	**Transportation System**	**Sun 10/13/13**	**Mon 11/4/13**
151	**Essential facility**	**Mon 11/4/13**	**Tue 11/19/13**
160	**Utilities**	**Tue 11/19/13**	**Mon 12/2/13**
166	**Others**	**Mon 12/2/13**	**Sat 12/14/13**
171	**Ecological assets (Mangroves, cc**	**Sat 12/14/13**	**Fri 12/27/13**
174	**Computation of exposure value**	**Thu 10/24/13**	**Thu 11/14/13**
175	Finalization of structure type of \	Thu 10/24/13	Sat 10/26/13
176	Estimation of Built-up floor areas	Mon 10/28/13	Fri 11/1/13
177	Estimation of unit replacement co	Fri 11/1/13	Sun 11/10/13
178	Calculation of exposure value of	Sun 11/10/13	Thu 11/14/13
179	**Field survey**	**Tue 1/7/14**	**Tue 2/25/14**
180	Planning for field survey for data	Tue 1/7/14	Fri 1/24/14
181	Field survey	Tue 1/7/14	Fri 1/24/14
182	Data refinement and corrections	Tue 1/7/14	Fri 1/24/14
183	Field survey structure vulnerabili	Tue 1/7/14	Tue 2/25/14
184	**Quality Assurance**	**Sat 12/14/13**	**Sun 1/19/14**
188	Meta data file creation	Sun 1/19/14	Sun 2/2/14
189	Preparation of GIS maps for report	Mon 2/3/14	Mon 2/17/14
190	Report generation	Tue 2/18/14	Wed 3/5/14
191	Orissa	Wed 3/5/14	Wed 5/21/14
192	Andaman & Nicobar Island	Fri 5/23/14	Mon 6/9/14
193	Daman & Diu	Mon 6/9/14	Fri 6/13/14
194	Goa	Mon 6/16/14	Sat 6/21/14
195	Gujarat	Tue 5/6/14	Thu 7/10/14
196	Karnataka	Mon 6/9/14	Tue 7/22/14
197	Kerala	Fri 6/13/14	Mon 8/11/14
198	Lakshadweep	Sat 6/21/14	Wed 6/25/14
199	Maharashtra	Thu 6/26/14	Sat 9/6/14
200	Puducherry	Sat 9/6/14	Mon 9/8/14
201	Tamilnadu	Tue 9/2/14	Fri 11/7/14
202	West Bengal	Tue 10/7/14	Fri 11/7/14



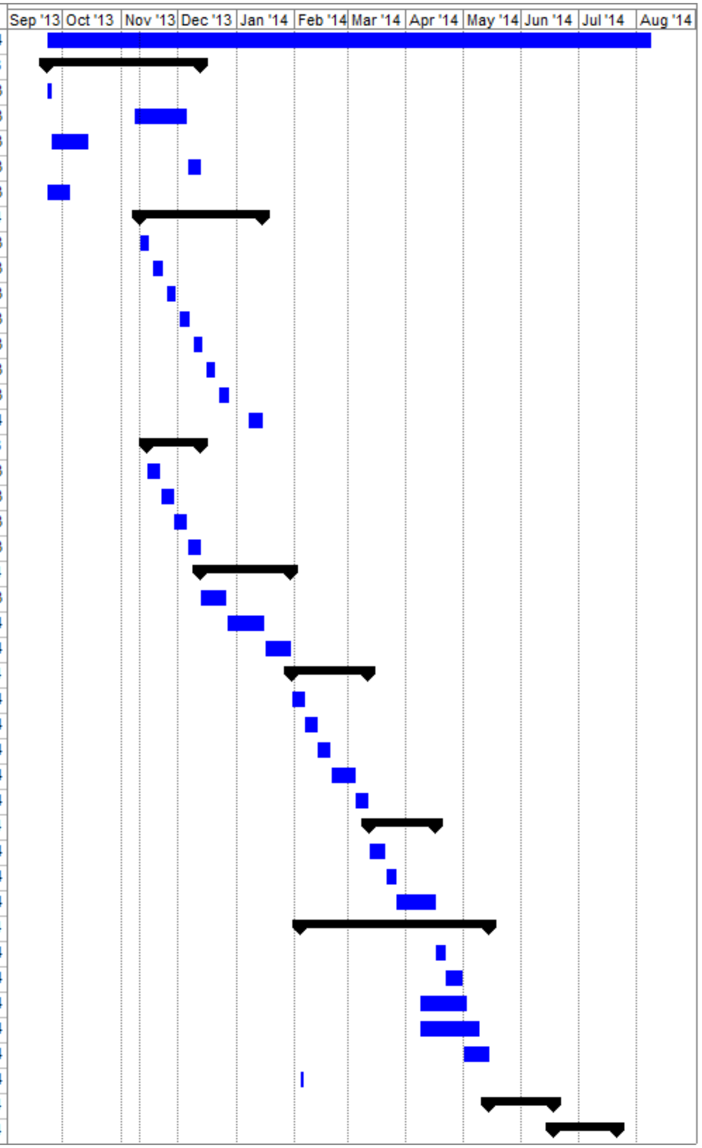
4.5 Vulnerability and Risk Assessment

ID	Task Name	Start	Finish
204	**Social Vulnerability**	Tue 10/15/13	Tue 9/30/14
205	**Phase I- Social vulnerability analysis f**	**Tue 10/15/13**	**Fri 4/4/14**
206	Identification of Socail vulnerability inc	Tue 11/12/13	Thu 11/21/13
207	Compilation and organising of data foi	Tue 10/15/13	Fri 12/13/13
208	Data analysis	Mon 12/16/13	Sat 2/15/14
209	Preparation of SVA report for 2 State	Tue 1/28/14	Fri 4/4/14
210	**Phase 2- Social vulnerability analysis**	**Mon 2/17/14**	**Tue 9/30/14**
211	Compilation and organising of data foi	Mon 2/17/14	Sat 3/15/14
212	Data analysis	Sat 3/15/14	Wed 4/30/14
213	Hotspot field survey 5 locations	Mon 6/2/14	Wed 7/2/14
214	Hotspot field survey rest 5 locations	Thu 7/3/14	Fri 8/15/14
215	Preparation of detailed SVA report fo	Fri 8/15/14	Tue 9/30/14
216			
217	**Phy Vulnerability & Risk Assessment**	Tue 9/10/13	Tue 9/30/14
218	**Phase I- Physical vulnerability analysi**	**Sat 11/2/13**	**Sun 3/30/14**
219	Developing vulnerability curve 2 State	Sat 11/2/13	Mon 12/30/13
220	Vulnerability assessment	Mon 12/2/13	Thu 1/30/14
221	Prepration of VA report for 2 States	Sun 2/2/14	Sun 3/30/14
222	**Phase 2- Physical vulnerability analys**	**Sat 2/15/14**	**Tue 9/30/14**
223	Developing vulnerability curve rest of	Sat 2/15/14	Sat 3/15/14
224	Vulnerability assessment	Sat 3/15/14	Thu 5/1/14
225	Hotspot field survey 5 locations	Mon 6/2/14	Wed 7/2/14
226	Hotspot field survey rest 5 locations	Thu 7/3/14	Fri 8/15/14
227	Preparation of detailed physical VA re	Fri 8/15/14	Tue 9/30/14
228	**Phase I- Risk Assessment for AP anc**	**Tue 9/10/13**	**Sun 3/30/14**
229	Collection of economic and loss data	Tue 9/10/13	Mon 9/30/13
230	Risk Assessment	Mon 12/2/13	Thu 1/30/14
231	Prepration of risk assessment report	Sun 2/2/14	Sun 3/30/14
232	**Phase 2- Risk Assessment for rest o**	**Sat 2/15/14**	**Tue 9/30/14**
233	Collection of economic and loss data	Sat 2/15/14	Sat 3/15/14
234	Risk Assessment	Sat 3/15/14	Thu 5/1/14
235	Detailed risk assessment for hotspot	Mon 6/2/14	Wed 7/2/14
236	Detailed risk assessment for hotspot	Thu 7/3/14	Fri 8/15/14
237	Prepration of detailed risk assessmen	Fri 8/15/14	Tue 9/30/14



4.6 Web based GIS Atlas Development

ID	Task Name	Start	Finish
239	**Web-GIS Development**	Mon 9/23/13	Fri 8/8/14
240	**SRS preparation**	**Mon 9/23/13**	**Thu 12/12/13**
241	TOC Creation	Mon 9/23/13	Tue 9/24/13
242	First draft	Fri 11/8/13	Thu 12/5/13
243	Second draft	Wed 9/25/13	Mon 10/14/13
244	Final based after Upmanyu's feedbac	Fri 12/6/13	Thu 12/12/13
245	UI Design	Mon 9/23/13	Fri 10/4/13
246	**Design of various engines**	**Mon 11/11/13**	**Wed 1/15/14**
247	Design for data access engine	Mon 11/11/13	Fri 11/15/13
248	Design of analysis engine	Mon 11/18/13	Fri 11/22/13
249	Design of reporting engine	Mon 11/25/13	Fri 11/29/13
250	Design of hazard module	Mon 12/2/13	Fri 12/6/13
251	Design of vulnerability module	Mon 12/9/13	Fri 12/13/13
252	Design of exposure module	Mon 12/16/13	Fri 12/20/13
253	Design of loss module	Mon 12/23/13	Fri 12/27/13
254	SRS submission, IT System specificat	Tue 1/7/14	Wed 1/15/14
255	**Coding for hazard module**	**Fri 11/15/13**	**Thu 12/12/13**
256	Coding for flood related hazard layers	Fri 11/15/13	Thu 11/21/13
257	Coding for Cyclone related hazrd laye	Fri 11/22/13	Thu 11/28/13
258	Addng hazard layers and fucnctional	Fri 11/29/13	Thu 12/5/13
259	Testing and bug fixing of hazard mod	Fri 12/6/13	Thu 12/12/13
260	**Coding for Exposure module**	**Fri 12/13/13**	**Wed 1/29/14**
261	Coding for Exposure module	Fri 12/13/13	Thu 12/26/13
262	Add exposure layers and functionality	Fri 12/27/13	Wed 1/15/14
263	Testing and bug fixing of exposure m	Thu 1/16/14	Wed 1/29/14
264	**Coding for vulnerability module**	**Thu 1/30/14**	**Tue 3/11/14**
265	Coding for vulnerability module	Thu 1/30/14	Wed 2/5/14
266	Coding for loss module	Thu 2/6/14	Wed 2/12/14
267	Add loss module related layers and re	Thu 2/13/14	Wed 2/19/14
268	Report generation	Thu 2/20/14	Tue 3/4/14
269	testing and bug fixing	Wed 3/5/14	Tue 3/11/14
270	**Integration of all the three modules**	**Wed 3/12/14**	**Wed 4/16/14**
271	Integration of all the three modules	Wed 3/12/14	Thu 3/20/14
272	Integration testing	Fri 3/21/14	Wed 3/26/14
273	Prototype of webbased risk atlas	Wed 3/26/14	Wed 4/16/14
274	**Preparation and submission of Beta v**	**Tue 2/4/14**	**Wed 5/14/14**
275	Preparation and submission of Beta v	Wed 4/16/14	Mon 4/21/14
276	Beta version insatllation at client end	Mon 4/21/14	Wed 4/30/14
277	User Accpatance testing	Tue 4/8/14	Fri 5/2/14
278	Bug report and use accpance report	Tue 4/8/14	Fri 5/9/14
279	Security audit	Thu 5/1/14	Wed 5/14/14
280	Application configured for public ip	Tue 2/4/14	Wed 2/5/14
281	**User Manual**	**Wed 5/14/14**	**Tue 6/17/14**
285	**Installation manual**	**Tue 6/17/14**	**Mon 7/21/14**



5 Deliverables

Following are the deliverables and will be delivered as per the time lines provided in the work plan.

Inception report	Oct 2013
Data inventory and data review report	Dec 2013
IT system specification report, functional architecture report and development schedule	Dec 2013
Demonstration Hazard dataset and report	Jan 2014
Demonstration Exposure/ Vulnerability dataset and report	Mar 2014
Demonstration Risk dataset and report	June 2014
Prototype Composite Risk Atlas	July 2014
Prototype Demonstration and presentation	Aug 2014
Year 1 (interim) report	Sept 2014
Beta Composite Risk Atlas	Feb 2015
Demonstration and report - Beta version	March 2015
National Workshop 1	Feb 2015
State outreach and training workshops	March 2015
National Workshop 2	May 2015
National Workshop 3	June 2015
Year 2 (close out) report	July 2015
Progress report	Monthly

6 `Details of States Selected for Prototype Development

Based on the discussion with PMU during the project kick off meeting it was decided to consider Andhra Pradesh and Odisha States for the Prototype development. The list of talukas of these State falling within the study area of 10 m MSL is provided in the Table 8-1 in Annexure 1.

7 QA Procedures

As part of Quality Assurance procedures, RMSI has in place a well defined quality control and assurance procedure for data development, model calibration and for Web-GIS application development. ISO 9001:2000 standards are followed for data development and CMMI and OGC compliance for application development. The models are calibrated using recent past events in the country to ensure that the model takes care of the local conditions and parameters of the study area.

7.1 Data Development

The quality procedure for exposure data development is described in section 3.2.4.5. As majority of the data for the analysis will be collected from various national departments, which follow standard quality procedures, RMSI will focus more on audit of completeness of the data.

For data development from satellite data for hotspot locations, RMSI will define quality control processes, which check the quality of data at different stages of data development. In case there is any administrative boundary mismatch in data received from different agencies, the boundary information from SOI will be used. While collecting the cost of physical assets, the prevailing rates of PWD as well as the private builders will be considered to calculate the actual value.

7.2 Model Development

The 'raw' data of bathymetry and topography obtained from different agencies will be checked for missing and erroneous values. The data on land topography adjacent to the coastline and the bathymetry along near-shore areas are of critical importance for accurate prediction by the model. Therefore, 'raw' data will be cleaned using various quality control (QC) checks to identify missing values and to flag suspected values. Two types of data validations will be carried out: replacement of erroneous values and missing values. For interpolating a missing value, either data from a number of stations surrounding a target station (spatial interpolation) or interpolation between observations over time (temporal interpolation) will be used.

The projection and datum of bathymetry/topography data obtained from various data sources could be different and need to be brought into the same system before they can be merged and used in the storm surge model. The data of different resolutions will be merged together with reference to the coastline of SOI and will be in WGS 84 project system.

The resolution of data is dependent on the source and geographical location. Therefore, a bilinear smoother will be used in order to reduce sharp bottom slope as well as to obtain the bathymetry data field to the required model resolution. With this procedure, sufficiently accurate and realistic bathymetry will be derived in shallow waters, which is crucial for determination of surges along the coast.

For cyclone rainfall induced flood hazard data development, the following quality assurance procedures will be applied during the hazard data and model development processes.

- In the river basin delineation process, delineated basin areas are compared with the other reported sources like research papers and publications.
- Check is applied on inclusion of major flow gauge stations incorporated in the basin delineation process, which are essential in the model calibration and validation process.
- Upstream gauge areas of various flow gauge stations are compared with other reported sources like research papers and publications.

- Checks are applied on number of sub basins with number of rivers, Longest Flow Path, Sub basin Centroid etc. It is ensured that number of sub basins, rivers, longest flow path, and sub basin centroids are equal.
- Map units in GIS, while delineating basin and river network, are checked. It is ensured that the map unit in GIS is followed after map projections.
- In the meteorological component of HEC-HMS, the sum of gauge weight for each sub basin is ensured to be at unity.
- Missing data period in time series data is checked and it is ensured that it is filled with appropriate method e.g. Linear Interpolation.
- Flood depth grid is checked for unusually high flood depth values as may be the case of sinks or depressions.

Model calibration will be carried out using recent events so that the hazard model can provide realistic values for the risk assessment.

7.3 Web-GIS application development

Quality Assurance and Quality Control functions are Critical Success Factors for software development. It is widely recognized that the ongoing maintenance of any IT system is significantly more costly if the system is not well structured, well designed and properly documented. Following are the quality assurance practices that will be adopted to ensure the quality of "Web-GIS Atlas":

This QA document will be prepared, which will bring together in one document the different aspects related to quality that will apply throughout the project. It aims at providing guidance to technical staff, testers involved in the project to measure how compliant the system is with the business requirements. It will be responsible for focusing on the problems/functionality or any modification with respect to requirement at any stage.

The QA for web-GIS development will follow the Agile model. As part of this, software development will be split into builds. Each build will be developed and sent to quality control team for testing. The primary objective throughout the testing will be to focus on the fulfillment of the requirements specified by NDMA and to demonstrate whether the system is fit to be used in the business.

Testing will be carried out during all the phases of application development in the following manner:

a) **Design Phase**: Initially, a test plan will be created and after the finalization of test plan test cases will be prepared. It will be ensured that there is no communication gap in the team.
b) **Development Phase**: During the development phase while the code is being written, the development team will simultaneously perform code review activities. As each module is prepared, unit testing will be performed for error detection.
c) **Integration Phase**: In the integration phase when all individual modules will be integrated with one another, system testing as a whole will be done followed by security, functional and performance testing. After this, a test report will be prepared that will focus on the observations that have been found while performing the testing.
d) **Operation Phase**: Once the observations that have been found during the integration phase are resolved by the development team, a regression testing will be done to ensure that the bugs have been resolved. This will ensure that they do not affect any other functionality. User acceptance testing will then be carried out.

The following testing strategy will be applied:

1. **Build Acceptance Criteria**

A build will be accepted only if the functionality provided in the particular build passes the following criterions:

- The System does not crash or become unstable.
- All the prerequisite documents are provided with the build.
- Unit testing has been performed.

2. Testing Strategy

The major purpose of the Web GIS based application is to provide a mechanism for data sharing, providing a platform for dynamic probabilistic risk analysis, assistance in disaster planning, preparedness, response and recovery and ground truthing abilities. Therefore, the primary concern in testing will be to focus on all these requirements. Test strategy will comprise of the following general tasks:

a) Understanding the requirements of SRS.
b) Reviewing the documentation, functionality and interface design with respect to user understanding and usability.
c) Testing large number of decision scenarios implemented in the application.

The identified bugs will be put into bugzilla to pass the test to move forward.

Any components/menu/options/icon would pass the test if it delivers 100% functionality without causing any direct or indirect failures during testing. The test for a particular component/menu/option/icon would fail if it affects the functionality of another module and the dependent module starts misbehaving. The functionality will be rejected for the following reasons:

- If functionality does not perform what it is suppose to do.
- The new functionality affects any other functionality.
- Application behaves randomly.

The test types include the following testing to ensure the quality delivery of the "Web-GIS Atlas".

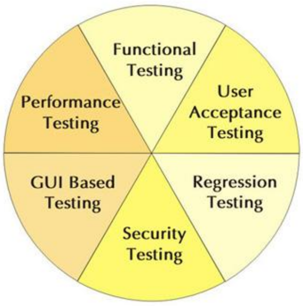


Figure 7:1 QA Types

a) Data Testing: The data and the database should be tested as a subsystem within the project to ensure database access methods and processes function properly without data corruption.
b) Function Testing: The goals of this testing will be to verify proper data acceptance, processing, and retrieval, and the appropriate implementation of the business rules. It aims at verifying the application and its internal processes by interacting with the application via the Graphical User Interface (GUI) and analyzing the output or results.
c) User Interface Testing: It will verify the user's interaction with the application. It will aim at checking the ease of access to the application by the user.
d) Performance Testing: It will aim at evaluating response time, transaction rates and other sensitive parameters.

e) Security Testing: Security testing to ensure that application is highly secured will be done by providing different users; one that will act as an administrator and the others will act as normal users.

f) Regression testing: It will ensure that all the components of the website are integrated well and are working to fulfill the requirement of the user.

g) Security testing: It will ensure that application is highly secured and is not prone to any known security attacks, for example, SQL injection, hacking user name and password etc.

h) User Acceptance Testing: This will be the final stage of testing where testing will be carried out by users to make sure that the website meets their requirements and standards.

3. Bug Tracking

To keep the track of bugs that will be found during testing an open source tool called Bugzilla will be used. This is a web-based bug tracker tool that will allow developers to keep track of outstanding bugs in Web GIS based application. Life cycle of Bugzilla is shown in Figure 7:2 where the bug passes through various states before it is closed.

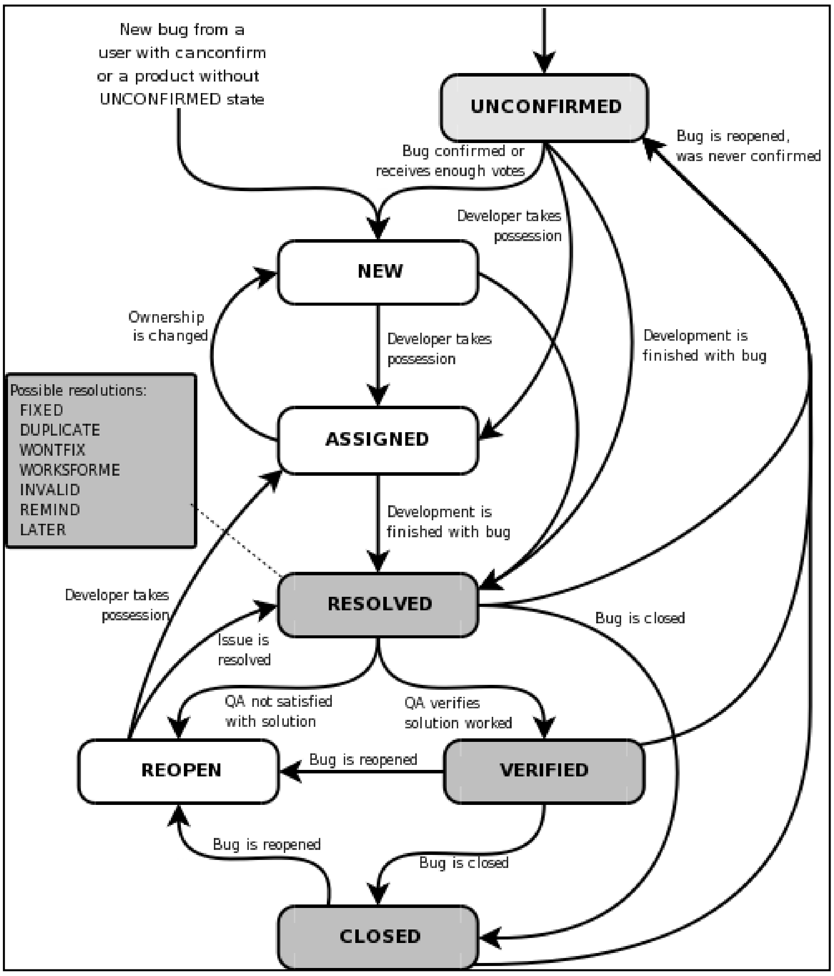


Figure 7:2: Life Cycle of Bugzilla

A Software Quality Analyst (SQA) for the project will be defined who is independent of the project management and who will report to the Senior Management and Quality Manager. SQA will be involved in ensuring that all processes are followed as defined in the plans and all project activities are following quality practices.

Quality Reviews, typically artifact and code reviews will be performed to assess the products / deliverables of the phase prior to delivering products

Audits, which fall into two categories – scheduled audits and snap audits, will be performed as appropriate to ensure that quality standards are met. Both types of audits are formal with an audit report being produced.

After the test plan is finalized, test cases are prepared. Some of the test cases that will be executed during testing are provided in Annexure 4.

Finally, regular tracking and status monitoring will be performed by RMSI Senior Management to ensure that project deliverables are being delivered on time and as per requisite quality standards

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8 Annexure 1

Table 8-1: Details of talukas, which will be considered for the study

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
Andaman & Nicobar	South Andaman		Ferargunj	1185	
	South Andaman		Port Blair	480	
	South Andaman		Little Andaman	692	
	North & Middle Nicobar		Rangat	1190	
	North & Middle Nicobar		Mayabundar	757	
	North & Middle Nicobar		Diglipur	1339	
	Nicobar		Carnicobar	129	
	Nicobar		Noncowry	473	
	Nicobar		Campbellbay	1147	
Andhra Pradesh	Vizianagaram	Bhogapuram		111	
	Chittoor	Varadayyapalem		328	Either Discrepancy In Tehsil Boundary Or Shape
	East Godavari	Ainavalli		95	
	East Godavari	Alamurui		77	
	East Godavari	Ambajipeta		70	
	East Godavari	Anaparthi		57	
	East Godavari	Atreyapuram		259	Either Discrepancy In Tehsil Boundary Or Shape
	East Godavari	Allavaram		106	
	East Godavari	Amalapuram		61	
	East Godavari	Bikkavolu		99	
	East Godavari	Gollaprolu		125	
	East Godavari	Ravulapalem		93	
	East Godavari	Rayavaram		75	
	East Godavari	Razole		85	
	East Godavari	Tuni		211	
	East Godavari	Uppalaguptam		117	
	East Godavari	I Polavaram		198	
	East Godavari	Kottapeta		84	
	East Godavari	Katrenikona		166	
	East Godavari	Tallarevu		288	Either Discrepancy In Tehsil Boundary Or Shape
	East Godavari	Kadiam		64	
	East Godavari	Kajuluru		112	
	East Godavari	Kakinada		109	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	East Godavari	Kapileswarapuram		116	
	East Godavari	Karapa		102	
	East Godavari	Malikipuram		92	
	East Godavari	Kottapalle		105	
	East Godavari	Mamidikuduru		98	
	East Godavari	Pedda Gannavaram		112	
	East Godavari	Mandapeta		107	
	East Godavari	Mummidivaram		97	
	East Godavari	Pamarru		124	
	East Godavari	Peddapudi		103	
	East Godavari	Sakhinetipalle		118	
	East Godavari	Samalkot		143	
	East Godavari	Pithapuram		122	
	East Godavari	Rajahmundry Rural		69	
	East Godavari	Rajahmundry Urban		31	
	East Godavari	Ramachandrapuram		105	
	East Godavari	Tondangi		169	
	Guntur	Amrutaluru		122	
	Guntur	Bhattiprolu		94	
	Guntur	Bapatla		261	
	Guntur	Chebrolu		128	
	Guntur	Cherukupalli		95	
	Guntur	Duggirala		143	
	Guntur	Chunduru		103	
	Guntur	Edlapadu		106	
	Guntur	Repalle		262	
	Guntur	Tadepalle		72	
	Guntur	Kakumanu		176	
	Guntur	Karlapalem		103	
	Guntur	Kollipara		109	
	Guntur	Kolluru		116	
	Guntur	Mangalagiri		138	
	Guntur	Nagaram		140	
	Guntur	Nizampatnam		183	
	Guntur	Peda Kakani		95	
	Guntur	Pedda Nandipadu		138	
	Guntur	Ponnuru		169	
	Guntur	Pittalavaripalem		70	
	Guntur	Tenali		18	
	Guntur	Vatticherukuru		114	
	Guntur	Vemuru		100	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Krishna	Avanigadda		73	Either Discrepancy In Tehsil Boundary Or Shape
	Krishna	Bapulapadu		218	
	Krishna	Bantummilli		124	
	Krishna	Challapalle		91	
	Krishna	Gudivada		106	
	Krishna	Mopidevi		83	Either Discrepancy In Tehsil Boundary Or Shape
	Krishna	Movva		139	
	Krishna	Mudinepalle		172	
	Krishna	Unguturu		145	
	Krishna	Ghantasala		115	
	Krishna	Gudlavalleru		123	
	Krishna	Guduru		125	
	Krishna	Kankipadu		94	
	Krishna	Kaikalur		159	
	Krishna	Kalidindi		174	
	Krishna	Koduru		212	
	Krishna	Kruttivennu		181	
	Krishna	Machilipatnam		398	
	Krishna	Mandavalli		13	
	Krishna	Mandavalli		160	
	Krishna	Nagayalanka		410	Either Discrepancy In Tehsil Boundary Or Shape
	Krishna	Nandivada		150	
	Krishna	Pamarru		119	
	Krishna	Pamidimukkala		117	
	Krishna	Pedana		138	
	Krishna	Peddaparupudi		8	
	Krishna	Peddaparupudi		89	
	Krishna	Totlavalluru		16	
	Krishna	Totlavalluru		105	
	Krishna	Vuyyuru		84	
	Nellore	Allur		186	
	Nellore	Bogole		180	
	Nellore	Chillakur		331	
	Nellore	Chittamur		264	
	Nellore	Dagadarti		248	
	Nellore	Doravarisatram		275	
	Nellore	Sullurpeta		263	
	Nellore	Tada		477	
	Nellore	Vakadu		239	
	Nellore	Gudur		246	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Nellore	Indukurupeta		140	
	Nellore	Jaladanki		302	
	Nellore	Kavali		323	
	Nellore	Kodavalur		109	
	Nellore	Kota		184	
	Nellore	Kovur		86	
	Nellore	Muttukuru		178	
	Nellore	Manubolu		220	
	Nellore	Nellore		350	
	Nellore	Venkatachalam		299	
	Nellore	Totapalligudur		154	
	Nellore	Vidavalur		164	
	Nellore			156	
	Prakasam	Chinna Ganjam		168	
	Prakasam	Chirala		103	
	Prakasam	Ulavapadu		184	
	Prakasam	Gudulur		244	
	Prakasam	Inkollu		142	
	Prakasam	Kottapatnam		163	
	Prakasam	Kandukur		218	
	Prakasam	Karamchedu		159	
	Prakasam	Maddipadu		164	
	Prakasam	Paruchuru		218	
	Prakasam	Nagulaupalapadu		252	
	Prakasam	Ongole		200	
	Prakasam	Singarayakonda		109	
	Prakasam	Zarugumalli		181	
	Prakasam	Tangutur		198	
	Prakasam	Vetapalem		90	
	Srikakulam	Amudalavalasa		102	
	Srikakulam	Echcherla		154	
	Srikakulam	Sompeta		119	Either Discrepancy In Tehsil Boundary Or Shape
	Srikakulam	Vajrapukotturu		131	
	Srikakulam	Srikakulam		153	
	Srikakulam	Gara		158	
	Srikakulam	Ichchapuram		102	
	Srikakulam	Kaviti		111	Either Discrepancy In Tehsil Boundary Or Shape
	Srikakulam	Kanchili		165	Either Discrepancy In Tehsil Boundary Or Shape
	Srikakulam	Kotabommali		146	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Srikakulam	Kusumala		220	Either Discrepancy In Tehsil Boundary Or Shape
	Srikakulam	Laveru		168	
	Srikakulam	Nandigam		180	
	Srikakulam	Narasannapeta		116	
	Srikakulam	Palasa		146	
	Srikakulam	Tekkal		128	
	Srikakulam	Santbommali		187	
	Srikakulam	Polaki		135	
	Srikakulam	Ranasthal		182	
	Vishakhapatnam	Achchutapuram		137	
	Vishakhapatnam	Bhimunipatnam		127	
	Vishakhapatnam	Elamanchili		120	
	Vishakhapatnam	Gajuvaka		108	
	Vishakhapatnam	Munagapaka		78	
	Vishakhapatnam	Nakkapalli		221	
	Vishakhapatnam	Paravada		142	
	Vishakhapatnam	Payakaraopeta		108	
	Vishakhapatnam	Pedda Gantyada		77	
	Vishakhapatnam	Pendurti		108	
	Vishakhapatnam	Rambilli		147	
	Vishakhapatnam	Sarvasiddhi Rayavaram		162	
	Vishakhapatnam	Visakhapatnam Rural		128	Either Discrepancy In Tehsil Boundary Or Shape
	Vishakhapatnam	Visakhapatnam Urban		95	Either Discrepancy In Tehsil Boundary Or Shape
	Vizianagaram	Denkada		123	
	Vizianagaram	Pusapatirega		161	
	West Godavari	Achanta		66	
	West Godavari	Attili		83	
	West Godavari	Akividu		108	
	West Godavari	Bhimadolu		210	
	West Godavari	Bhimavaram		183	
	West Godavari	Denduluru		181	
	West Godavari	Elamanchili		80	
	West Godavari	Undi		127	
	West Godavari	Ganapavaram		4	
	West Godavari	Ganapavaram		98	
	West Godavari	Mogalturru		136	
	West Godavari	Eluru		229	
	West Godavari	Iragavaram		78	
	West Godavari	Unguturu		197	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	West Godavari	Kalla		7	
	West Godavari	Kalla		154	
	West Godavari	Kovvuru		96	
	West Godavari	Kovvuru		3	
	West Godavari	Nidamarru		9	
	West Godavari	Narasapur		154	
	West Godavari	Nidamarru		113	
	West Godavari	Palakoderu		86	
	West Godavari	Palakollu		84	
	West Godavari	Peddapadu		167	
	West Godavari	Pentapadu		111	
	West Godavari	Penumantra		80	
	West Godavari	Penugonda		66	
	West Godavari	Peravalli		77	
	West Godavari	Poduru		89	
	West Godavari	Tanuku		75	
	West Godavari	Viravasaram		4	
	West Godavari	Viravasaram		95	
Daman & Diu	Diu	Diu		25	
Goa	South Goa	Mormugao		104	
	South Goa	Mormugao		104	
	North Goa	Ponda		259	
	North Goa	Dicholi		240	
	North Goa	Pernem		239	
	South Goa	Sasashti		290	
	South Goa	Kankon		353	
	South Goa	Quepem		317	
	North Goa	Tiswadi		201	
	North Goa	Bardez		254	
Gujarat	Ahmadabad		Barwala	479	
	Ahmadabad		Bavla	767	
	Ahmadabad		Dhandhuka	1775	
	Ahmadabad		Dholka	924	
	Ahmadabad		Sanand	770	
	Ahmadabad		Viramgam	790	
	Amreli		Rajula	633	
	Amreli		Jafrabad	1	
	Amreli		Khambha	581	
	Anand		Anklav	176	
	Anand		Borsad	405	
	Anand		Khambhat	1068	
	Anand		Tarapur	322	
	Banaskantha		Vav	1694	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Bharuch		Amod	430	
	Bharuch		Anklesvar	436	
	Bharuch		Bharuch	607	
	Bharuch		Hansot	534	
	Bharuch		Jambusar	1382	
	Bharuch		Jhagadia	775	
	Bharuch		Vagra	1574	
	Bhavnagar		Ghogha Mahal	654	
	Bhavnagar		Umrala	400	
	Bhavnagar		Sihor	692	
	Bhavnagar		Talaja	911	
	Bhavnagar		Valabhipur Mahal	588	
	Bhavnagar		Mahuva	1236	
	Jamnagar		Jamnagar	3025	Either Discrepancy In Tehsil Boundary Or Shape
	Jamnagar		Kalyanpur	1415	
	Jamnagar		Khambhaliya	1263	
	Jamnagar		Lalpur	1073	
	Jamnagar		Okha Mandal	653	
	Junagarh		Malia	506	
	Junagarh		Keshod	545	
	Junagarh		Kodinar	517	
	Junagarh		Manavadar	574	
	Junagarh		Sutrapada	315	
	Junagarh		Una	1511	
	Junagarh		Veraval	352	
	Junagarh		Mangrol	570	
	Kachchh		Abdasa	2162	
	Kachchh		Anjar	1149	
	Kachchh		Bhachau	1756	
	Kachchh		Bhuj	5227	
	Kachchh		Gandhidham	191	
	Kachchh		Lakhpat	1924	
	Kachchh		Rapar	2841	
	Kachchh		Mundra	855	
	Kachchh		Nakhatrana	1878	
	Kachchh		Mandvi	1384	
	Kachchh			20695	
	Khera		Matar	371	
	Navsari		Gandevi	282	
	Navsari		Jalalpore	475	
	Navsari		Navsari	242	
	Patan		Radhanpur	578	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Patan		Sami	1529	
	Patan		Santalpur	1274	
	Porbandar		Kutiyana	564	
	Porbandar		Porbandar	1101	
	Porbandar		Ranavav	562	
	Rajkot		Maliya	728	
	Surat		Chorasi	444	
	Surat		Palsana	192	
	Surat		Olpas	661	
	Surat		Suratcity	150	
	Surendranagar		Dhrangadhra	1326	
	Surendranagar		Dasada	1495	
	Surendranagar		Halvad	1206	
	Surendranagar		Lakhtar	729	
	Surendranagar		Limbdi	1124	
	Vadodara		Padra	515	
	Valsad		Pardi	414	
	Valsad		Umargam	346	
	Valsad		Valsad	495	
Karnataka	Uttar Kannada		Ankola	917	
	Udupi		Udupi	933	
	Uttar Kannada		Bhatkal	347	
	Dakshin Khand		Buntwal	759	
	Uttar Kannada		Karwar	733	
	Uttar Kannada		Honavar	745	
	Uttar Kannada		Kumta	581	
	Udupi		Kundapura	1556	
	Dakshin Khand		Mangalore	861	
	Alappuzha		Ambalappuzha	184	
	Alappuzha		Chengannur	149	
	Alappuzha		Chertala	332	
	Alappuzha		Kartikappalli	235	
	Alappuzha		Kuttanad	313	
	Alappuzha		Mavelikkara	236	
	Ernakulam		Aluva	550	
	Ernakulam		Kochchi	139	
	Ernakulam		Kanayannur	321	
	Ernakulam		Kunnattunad	477	
	Ernakulam		Muvattupuzha	449	
	Ernakulam		Paravur	194	
	Kannur		Kannur	352	Either Discrepancy In Tehsil Boundary Or Shape
	Kannur		Talasseri	1214	Either Discrepancy In Tehsil Boundary Or

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
					Shape
	Kannur		Talipparamba	1399	
	Kasargod		Kasargod	995	
	Kasargod		Hosdurg	984	
	Kollam		Kottarakkara	370	
	Kollam		Pathanapuram	1472	Either Discrepancy In Tehsil Boundary Or Shape
	Kollam		Karunagappally	178	
	Kollam		Kollam	389	
	Kollam		Kunnattur	144	
	Kottayam		Kottayam	515	
	Kottayam		Minachil	693	
	Kottayam		Vaikom	323	
	Kottyam		Changanasseri	268	
	Kozikode		Vadakara	579	
	Kozikode		Koilandi	742	
	Kozikode		Kozhikkod	1032	
	Malappuram		Eranad	816	
	Malappuram		Ponnani	203	
	Malappuram		Tirur	417	
	Malappuram		Tirurangadi	259	
	Palakkad		Ottappalam	854	
	Pathanamthitta		Adoor	336	
	Pathanamthitta		Kozhenchery	922	
	Pathanamthitta		Mallappally	161	
	Pathanamthitta		Thiruvalla	168	
	Thiruvananthpuram		Neyyattinkara	584	
	Thiruvananthpuram		Chirayinkeezhu	383	
	Thiruvananthpuram		Thiruvananthapuram	315	
	Thrissur		Chavakkad	246	
	Thrissur		Kodungallur	149	
	Thrissur		Mukundapuram	1323	
	Thrissur		Talappilly	689	
Lakshadweep	Kavaratti			5	
	Kavaratti			0	
	Kavaratti			2	
	Lakshadweep			30	
Maharashtra	Greater Mumbai			62	
	Raigarh	Alibag		485	
	Raigarh	Mhasla		1106	
	Raigarh	Mangaon		906	
	Raigarh	Murud		237	
	Raigarh	Panvel		586	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Raigarh	Pen		486	
	Raigarh	Roha		620	
	Raigarh	Srivardhan		233	
	Raigarh	Uran		293	
	Raigarh			5	
	Ratnagiri	Chiplun		1089	
	Ratnagiri	Dapoli		854	
	Ratnagiri			8	
	Ratnagiri	Guhagar		623	
	Ratnagiri	Khed		1011	
	Ratnagiri	Mandangarh		419	
	Ratnagiri	Lanja		739	
	Ratnagiri	Rajapur		1181	
	Ratnagiri	Ratnagiri		922	
	Ratnagiri	Sangameshwar		1238	
	Ratnagiri			0	
	Sindhudurg	Devgarh		766	
	Sindhudurg	Kudal		890	
	Sindhudurg	Malvan		612	
	Sindhudurg	Savantwadi		1336	Either Discrepancy In Tehsil Boundary Or Shape
	Sindhudurg	Vengurla		208	
	Suburban Mumbai			420	
	Thane	Bhiwandi		672	
	Thane	Dahanu		982	
	Thane	Kalyan		301	
	Thane	Thane		385	
	Thane	Palghar		1064	
	Thane	Talsari		257	
	Thane	Vasai		523	
Odisha	Baleswar		Basta	351	Either Discrepancy In Tehsil Boundary Or Shape
	Baleswar		Baleshwar	603	Either Discrepancy In Tehsil Boundary Or Shape
	Baleswar		Jaleswar	705	Either Discrepancy In Tehsil Boundary Or Shape
	Baleswar		Baliapal	320	Either Discrepancy In Tehsil Boundary Or Shape
	Baleswar		Soro	750	Either Discrepancy In Tehsil Boundary Or Shape
	Baleswar		Similia	277	
	Bhadrak	Bhadrak	Chandabali	2429	Either Discrepancy In Tehsil Boundary Or

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
					Shape
	Cuttack	Cuttack	Cuttack	1732	Either Discrepancy In Tehsil Boundary Or Shape
	Ganjam		Khallikote	613	Either Discrepancy In Tehsil Boundary Or Shape
	Ganjam		Purusottampur	364	Either Discrepancy In Tehsil Boundary Or Shape
	Ganjam		Patrapur	492	Either Discrepancy In Tehsil Boundary Or Shape
	Ganjam		Berhampur	327	Either Discrepancy In Tehsil Boundary Or Shape
	Ganjam		Chatrapur	303	
	Ganjam		Kanishi	288	Either Discrepancy In Tehsil Boundary Or Shape
	Jagatsinghpur	Jagatsinghpur	Jagatsinghpur	1673	Either Discrepancy In Tehsil Boundary Or Shape
	Jajpur	Jajpur	Jajpur	2793	Either Discrepancy In Tehsil Boundary Or Shape
	Kendrapara	Kendraparha	Kendraparha	2472	Either Discrepancy In Tehsil Boundary Or Shape
	Khordha	Khordha	Khordha	1862	Either Discrepancy In Tehsil Boundary Or Shape
	Khordha	Bhubaneswar	Bhubaneswar	929	Either Discrepancy In Tehsil Boundary Or Shape
	Mayurbhanj	Baripada	Baripada	3999	Either Discrepancy In Tehsil Boundary Or Shape
	Puri	Puri	Krushnaprasad	3379	Either Discrepancy In Tehsil Boundary Or Shape
Pondicherry	Puducherry			35	Either Discrepancy In Tehsil Boundary Or Shape
	Puducherry			67	Either Discrepancy In Tehsil Boundary Or Shape
	Puducherry			66	Either Discrepancy In Tehsil Boundary Or Shape
	Puducherry			20	Either Discrepancy In Tehsil Boundary Or Shape
	Puducherry			25	Either Discrepancy In Tehsil Boundary Or Shape
	Puducherry			55	Either Discrepancy In Tehsil Boundary Or Shape
	Puducherry			30	Either Discrepancy In Tehsil Boundary Or

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
					Shape
	Karaikal			24	Either Discrepancy In Tehsil Boundary Or Shape
	Karaikal			26	Either Discrepancy In Tehsil Boundary Or Shape
	Karaikal			43	Either Discrepancy In Tehsil Boundary Or Shape
	Karaikal			27	Either Discrepancy In Tehsil Boundary Or Shape
	Karaikal			21	Either Discrepancy In Tehsil Boundary Or Shape
	Karaikal			22	Either Discrepancy In Tehsil Boundary Or Shape
Tamil Nadu	Chennai		Mylapore Tiruvallikkeni	33	
	Chennai		Fort Tondiarpet	26	
	Chennai		Mambalam Guindy	42	
	Chennai		Perambur Purasavakkam	33	
	Chennai		Egmore Nungambakkam	31	
	Cuddalore		Chidambaram	603	
	Cuddalore		Cuddalore	532	
	Cuddalore		Kattumannarkoil	458	
	Kanchipuram		Tambaram	237	
	Kanchipuram		Chengalpattu	781	
	Kanchipuram		Cheyyur	612	
	Kanchipuram		Tirukkalukkunram	360	
	Kanyakumari		Agasthiswaram	287	
	Kanyakumari		Kalkulam	654	
	Kanyakumari		Vilavancode	408	
	Nagapattinam		Nagapattinam	313	
	Nagapattinam		Kilvelur	283	
	Nagapattinam		Vedaranyam	675	
	Nagapattinam		Mayiladuturai	422	
	Nagapattinam		Sirkazhi	464	
	Nagapattinam		Tarangambadi	294	
	Nagapattinam		Thirukkuvalai	146	
	Pudukkottai		Arantangi	492	
	Pudukkottai		Avadiyarkovil	426	
	Pudukkottai		Manamelkudi	218	
	Ramanathapuram		Kadaladi	630	
	Ramanathapuram		Paramakkudi	768	
	Ramanathapuram		Ramanathapuram	885	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Ramanathapuram		Tiruvadanai	980	
	Thanjavur		Pattukkottai	731	
	Thanjavur		Peravurani	289	
	Thiruvarur		Mannar Gudi	537	
	Thiruvarur		Nidamangalam	249	
	Thiruvarur		Nannilam	238	
	Thiruvarur		Thiruvarur	149	
	Thiruvarur		Kudavasal	325	
	Thiruvarur		Tirutturaipundi	439	
	Tirunelveli		Radhapuram	901	
	Tiruvallur		Ambattur	289	
	Tiruvallur		Ponneri	696	
	Tiruvallur		Gummidipundi	423	
	Tuticorin		Ottapidaram	770	
	Tuticorin		Sattankulam	378	
	Tuticorin		Srivaikuntam	618	
	Tuticorin		Tuticorin	372	
	Tuticorin		Vilattikulam	889	
	Tuticorin		Tiruchendur	493	
	Villupuram		Tindivanam	999	
	Villupuram		Vanur	468	Either Discrepancy In Tehsil Boundary Or Shape
	Villupuram		Villupuram	898	Either Discrepancy In Tehsil Boundary Or Shape
West Bengal	Bardaman		Kalna - Ii	168	
	Delta		Delta	1	
	Eastmednipur		Egra	920	Either Discrepancy In Tehsil Boundary Or Shape
	Eastmednipur		Kanthi	1195	Either Discrepancy In Tehsil Boundary Or Shape
	Eastmednipur		Haldia	648	Either Discrepancy In Tehsil Boundary Or Shape
	Eastmednipur		Tamluk	1052	Either Discrepancy In Tehsil Boundary Or Shape
	Haora		Shyampur 1	119	
	Haora		Udaynarayanpur	107	
	Haora		Domjur	93	
	Haora		Uluberia 2	101	
	Haora		Bally Jagachha	86	
	Haora		Uluberia 1	96	
	Haora		Sankrail	61	
	Haora		Panchla	68	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	Haora		Bagnan 1	74	
	Haora		Amta 1	116	
	Haora		Jagat Ballavpur	124	
	Haora		Bagnan 2	74	
	Haora		Shyampur 2	92	
	Haora		Amta 2	132	
	Hugli		Haripal	177	
	Hugli		Pursura	98	
	Hugli		Arambag	298	
	Hugli		Singur	193	
	Hugli		Jangipara	157	
	Hugli		Tarakeswar	115	
	Hugli		Chanditala I	90	
	Hugli		Goghat I	177	
	Hugli		Khanakul I	167	
	Hugli		Khanakul Ii	119	
	Hugli		Chanditala Ii	66	
	Hugli		Chinsurah Magra	91	
	Hugli		Balagarh	190	
	Hugli		Dhaniakhali	265	
	Hugli		Pandua	271	
	Hugli		Polba Dadpur	277	
	Hugli		Serampur Uttarpara	83	
	Nadia			151	
	Nadia			0	
	Nadia			3	
	Nadia			275	
	Nadia			340	
	Nadia			315	
	Nadia			0	
	Nadia			2	
	Nadia			1	
	Nadia			2	
	Nadia			2	
	Nadia			0	
	North Pragana		Swarupnagar	201	
	North Pragana		Baduria	205	
	North Pragana		Haora	155	
	North Pragana		Deganga	209	
	North Pragana		Barrackpur -I	168	
	North Pragana		Sandeshkhali -Ii	187	
	North Pragana		Hingalganj	269	
	North Pragana		Bongaon	338	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	North Pragana		Gaighata	240	
	North Pragana		Rajarhat	143	
	North Pragana		Sandeshkhali -I	178	
	North Pragana		Minakhan	149	
	North Pragana		Barasat- Ii	117	
	North Pragana		Basirhat -I	120	
	North Pragana		Hasnabad	157	
	North Pragana		Barasat- I	146	
	North Pragana		Amdanga	130	
	North Pragana		Basirhat -Ii	132	
	North Pragana		Barrackpur -Ii	158	
	North Pragana		Habra -Ii	128	
	North Pragana		Habra -I	126	
	North Pragana		Bagda	221	
	Pashchim Medinipur		Mohanpur	128	
	Pashchim Medinipur		Pingla	234	
	Pashchim Medinipur		Dantan -I	247	
	Pashchim Medinipur		Dantan -Ii	170	
	Pashchim Medinipur		Narayangarh	498	
	Pashchim Medinipur		Sabang	284	
	Pashchim Medinipur		Debra	353	
	Pashchim Medinipur		Keshpur	476	
	Pashchim Medinipur		Daspur -I	164	
	Pashchim Medinipur		Daspur -Ii	155	
	Pashchim Medinipur		Chandrakona -I	214	
	Pashchim Medinipur		Ghatal	226	
	Pashchim Medinipur		Chandrakona -Ii	180	
	South 24 Parganas		Gosaba	481	
	South 24 Parganas		Magrahat -Ii	106	
	South 24 Parganas		Diamond Harbour -I	88	
	South 24 Parganas		Canning -Ii	264	
	South 24 Parganas		Budge Budge -I	40	
	South 24 Parganas		Namkhana	221	
	South 24 Parganas		Sagar	279	
	South 24 Parganas		Mathurapur	138	
	South 24 Parganas		Mathurapur -Ii	226	
	South 24 Parganas		Kulpi	227	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	South 24 Parganas		Kakdwip	246	
	South 24 Parganas		Jaynagar -I	154	
	South 24 Parganas		Canning -I	195	
	South 24 Parganas		Patharpratima	548	
	South 24 Parganas		Gosaba	320	
	South 24 Parganas		Magrahat -I	96	
	South 24 Parganas		Mandirbazar	124	
	South 24 Parganas		Falta	140	
	South 24 Parganas		Budge Budge -Ii	98	
	South 24 Parganas		Baruipur	162	
	South 24 Parganas		Diamond Harbour -Ii	102	
	South 24 Parganas		Jaynagar -Ii	123	
	South 24 Parganas		Bishnupur -I	92	
	South 24 Parganas		Sonarpur	195	
	South 24 Parganas		Bhangar -I	176	
	South 24 Parganas		Bhangar -Ii	166	
	South 24 Parganas		Kultali	335	
	South 24 Parganas		Bishnupur -Ii	81	
	South 24 Parganas		Thakurpukur Mahestola	120	
	South 24 Parganas			95	
	South 24 Parganas	Sagar		7	
	South 24 Parganas	Lakshmikantpur		8	
	South 24 Parganas	Lakshmikantpur		30	
	South 24 Parganas	Lakshmikantpur		44	
	South 24 Parganas	Lakshmikantpur		40	
	South 24 Parganas	Lakshmikantpur		61	
	South 24 Parganas	Lakshmikantpur		3	
	South 24 Parganas	Lakshmikantpur		18	
	South 24 Parganas	Lakshmikantpur		20	
	South 24 Parganas	Lakshmikantpur		15	
	South 24 Parganas	Lakshmikantpur		11	
	South 24 Parganas	Lakshmikantpur		62	
	South 24 Parganas	Lakshmikantpur		65	
	South 24 Parganas	Lakshmikantpur		18	
	South 24 Parganas	Lakshmikantpur		92	
	South 24 Parganas	Lakshmikantpur		18	
	South 24 Parganas	Lakshmikantpur		111	
	South 24 Parganas	Lakshmikantpur		16	
	South 24 Parganas	Lakshmikantpur		45	
	South 24 Parganas	Lakshmikantpur		38	
	South 24 Parganas	Lakshmikantpur		225	
	South 24 Parganas	Lakshmikantpur		63	

State	District	Subdivision	Talukas/Tehsil	Area (Sq Km)	Remarks
	South 24 Parganas	Lakshmikantpur		15	
	South 24 Parganas	Lakshmikantpur		35	
	South 24 Parganas	Lakshmikantpur		144	
	South 24 Parganas	Lakshmikantpur		26	
	South 24 Parganas	Lakshmikantpur		33	
	South 24 Parganas	Lakshmikantpur		642	
	South 24 Parganas	Lakshmikantpur		14	
	South 24 Parganas	Lakshmikantpur		52	

9 Annexure 2

List for Key stakeholders for intimating

Consulting Services for Hazard, Risk and Vulnerability Assessment for 13 states and UT's in India under NCRMP NDMA

1. Survey of India
2. NRSA and State Remote Sensing Centers
3. Archeological Survey of India
4. IMD
5. Census of India
6. Department of Earth Science
7. State Coastal Zone Management Authority and National Centre for Sustainable Coastal Management
8. Town and Country Planning Authority all States and UTs
9. PWD all States and UTs
10. CPWD
11. NHAI
12. Railways
13. Port Authority
14. Statistical Department all States and UTs
15. State electricity organizations
16. Telecommunication dept.
17. Municipal Corporations/ Metropolitan Corporation all States and UTs
18. Health Dept/Education/Police/Fire Dept/ all States and UTs
19. Minister of Commerce & Industry (Heavy/ Small/Medium)
20. INCOIS
21. NIO, Goa
22. Dept. of Science and Technology
23. Central Water Commission (CWC)
24. State Water Resources, Irrigation Dept.
25. State Departments of Revenue and Disaster Management all States and UTs

10Annexure 3

Data List for Consulting Services for Hazard, Risk and Vulnerability Assessment for 13 states and UT's in India under NCRMP NDMA

Sl. No.	Data	Agency Identified for Data Collection
	Exposure data	
1.	Administrative Boundary Map	Survey of India
2.	Census Data (State, district, block village level and demographic information including population, gender, age, etc)	Census of India
3.	Census Housing Table Data	Census of India
4.	Coastal Zone Management Plans	Department of Earth Science, State Coastal Zone Management Authority, National Centre for Sustainable Coastal Management
5.	Dynamic growth rate of the concerned States	Town and Country Planning Authority, Planning Commission, Ministry of Finance
6.	Transportation (roads, rails, bridges, ports, ferries, airports)	PWD/CPWD/NHAI/Railways/Port Authority/AAI/ Statistical Department
7.	Utilities (water, electric, communication, oil and natural gas)	PHED/State electricity organizations/telecommunication dept./ONGC-GAIL/ Statistical Department, Municipal Corporations/ Metropolitan Corporation
8.	Critical facilities (hospitals, police stations, schools, fire stations)	Health Dept/Education/Police/Fire Dept/Statistical Department (both National and State)
9.	Industrial and commercial buildings	Minister of Commerce & Industry (Heavy/ Small/Medium), Department of Industries (State), Department of Commerce,
10.	Others (religious and heritage structures)	SOI/ASI/ Statistical Department
	Data for hazard mapping and risk assessment	
1.	Land Use Land Cover (LULC) maps	NRSA, State Remote Sensing Centers
2.	High Resolution Digital Elevation Model	Survey of India (Contours)/NRSA/ State Remote Sensing Centers
3.	Satellite Images	NRSA/Space Application Centre
4.	Soil Maps	NBSS&LUP/Department of Agriculture, Soil and Landuse Survey of India, Geological Survey of India (GSI), NATMO
5.	Coastal Bathymetry	Survey of India/INCOIS/NIO/ NDMA/ GSI/Dept. of Science and Technology
6.	Catalogue of Cyclones and Flood Events	IMD/ NDMA
7.	Weather data (daily rainfall, temperature, wind) minimum for the period of last three decades	IMD
8.	River Flow data for Major Gauge Stations	Central Water Commission (CWC)

9.	Water Infrastructure Information (Levees, Dams, Barrages)	Central Water Commission/State Water Resources, Irrigation Dept.
10.	Chronological disaster memoirs	NDMA/ State Departments of Revenue and Disaster Management
11.	Details on the recent disaster events	Department of Revenue and Disaster Management
12.	Details on available infrastructures for effective Disaster Management	Department of Revenue and Disaster Management/NDMA/State Disaster Management Authority

11Annexure 4

Table 11-1: Test cases for web GIS application

Functionality/ Module	Sub Module/ Functionality	Test Case ID	Test Case	Test Environment-- OS/Browser	Expected Results	Actual Result
Required fields	All the modules wherever applicable	1	Leave the compulsory field blank.	Google chrome ,IE & Mozilla Firefox	Screen requiring data entry should be marked with asterisk or proper message should be generated if any required box is left blank.	
Toolbar items	All the modules wherever applicable	2	Click all the toolbar items individually.	Google chrome ,IE & Mozilla Firefox	Every tool item should perform its work or if not a message should be there.	
Font type and font size	All the modules wherever applicable	3	Check for the font size, type and color of the text and images in the application as well as in the report.	Google chrome ,IE & Mozilla Firefox	Font size should not be very large or small. Also image color should be bright and clearly visible.	
	All the modules wherever applicable	4	Check for the heading , title and layer names in the application.	Google chrome ,IE & Mozilla Firefox	Heading, title and layer names should be consistent.	
Onscreen instructions	All the modules wherever applicable	5	Hover mouse over the toolbar items.	Google chrome ,IE & Mozilla Firefox	A brief description of that toolbar item should be there.	
Icons	All the modules wherever applicable	6	Check for the consistency of icons in the app.	Google chrome ,IE & Mozilla Firefox	Icons used in the application (reports & homepage) should be consistent, of same size and clearly visible.	
Controls	All the modules wherever applicable	7	Check for size of various buttons, checkbox, dropdown if any and their	Google chrome ,IE & Mozilla Firefox	Controls if enabled should work and should be of same size and their names	

Functionality/ Module	**Sub Module/ Functionality**	**Test Case ID**	**Test Case**	**Test Environment-- OS/Browser**	**Expected Results**	**Actual Result**
			names.		should be meaningful and they should be properly aligned.	
Dialog box consistency	All the modules wherever applicable	8	Open dialog boxes and check for various controls on it.	Google chrome ,IE & Mozilla Firefox	Various controls (if any) should not have save/ok on one screen and cancel on other.	
Home page						
	Country layer	9	Check for the layer's list.	Google chrome ,IE & Mozilla Firefox	The layers should be as per study area (Afghanistan, Bhutan, Nepal and Maldives).	
	View of home page	10	Check for various items, controls shown on home page.	Google chrome ,IE & Mozilla Firefox	Home page should show the dockable search panel, toolbar, table of contents ,map window and result panel.	
Layers		11	Click on checkbox corresponding to each layer one at a time or more than one.	Google chrome ,IE & Mozilla Firefox	The layer checked should be visible on the map window.	
		12	Compare the legend of layer with the map displayed.	Google chrome ,IE & Mozilla Firefox	The color formation should match with the legend of the selected layer as per defined range.	
Opacity		13	Right click on the layer and check for opacity.	Google chrome ,IE & Mozilla Firefox	Opacity feature should be there.	
		14	Check the layers, for which opacity feature is available.	Google chrome ,IE & Mozilla Firefox	Option to change the opacity for all the polygon layers (except admin boundaries) should be there.	
		15	Check for range of	Google chrome ,IE & Mozilla	Range of opacity is	

Functionality/ Module	Sub Module/ Functionality	Test Case ID	Test Case	Test Environment-- OS/Browser	Expected Results	Actual Result
			opacity.	Firefox	classified as : 0 , 0.2,0.4,0.6,0.8 and 1.	
Toolbar panel						
	Toolbar items	16	Check for various items given in toolbar.	Google chrome ,IE & Mozilla Firefox	It should comprise of all those icons which are mentioned in requirements.	
	Toolbar- info tool	17	click on info tool but do not select any layer and then click on map.	Google chrome ,IE & Mozilla Firefox	Information should not be displayed in the results dialog and an appropriate message should be displayed.	
		18	Click on the point inside map whose info is required.	Google chrome ,IE & Mozilla Firefox	info of the selected layer w.r.t the point clicked on will get generated in results dialog.	
		19	click on info tool and check any checkbox only (do not click on the label name) corresponding to a layer and then click on map	Google chrome ,IE & Mozilla Firefox	information must not be displayed in the result dialog.	
Layer Data						
		20	Click on layer data tool but do not select any layer.	Google chrome ,IE & Mozilla Firefox	Information should not be displayed in the results panel and an appropriate message should be displayed.	
		21	Check any checkbox only (do not click on the label name) corresponding to a layer and click on layer data tool.	Google chrome ,IE & Mozilla Firefox	Information must not be displayed in the result panel.	

Functionality/ Module	Sub Module/ Functionality	Test Case ID	Test Case	Test Environment--OS/Browser	Expected Results	Actual Result
		22	Click on the label name of a layer & click on layer data tool.	Google chrome ,IE & Mozilla Firefox	All the information related to the layer selected should get populated in the result panel.	
Generate map						
		23	Click on generate map tool.	Google chrome ,IE & Mozilla Firefox	Generate map tool window should get open.	
		24	Check for the layers given in generate map window.	Google chrome ,IE & Mozilla Firefox	all the layers as shown in the table of contents should be there in generate map window as well.	
		25	Do not select any layer and generate map.	Google chrome ,IE & Mozilla Firefox	Map should not get generated and message should be populated as minimum one layer has to be selected.	
		26	Option to export it in excels.	Google chrome ,IE & Mozilla Firefox	Option should be there to export in excel.	
		27	Export the map in excels, pdf and word format..	Google chrome ,IE & Mozilla Firefox	Map should get exported into the desired format.	
Generate report						
		28	Generate various reports.	Google chrome ,IE & Mozilla Firefox	Reports as per requirements should get generated.	
		29	Export the report in excel, pdf and word format.		Report should get exported into the desired format.	
Data						
		30	Generate reports	Google chrome ,IE & Mozilla Firefox	Data generated by the application should match with the data given by the modeling team.	
		31	Click on layers in the layer	Google chrome ,IE & Mozilla	Every layer should be in	

Functionality/ Module	**Sub Module/ Functionality**	**Test Case ID**	**Test Case**	**Test Environment--OS/Browser**	**Expected Results**	**Actual Result**
			panel	Firefox	conformity.	
Role based access						
		32	Access the information which normal user is not supposed to access.	Google chrome ,IE & Mozilla Firefox	Information access given to administrator should not get access by the normal user.	
Performance Testing						
	Response time	33	Generate each of the report one at a time and note the response time.	G. Chrome, IE and Mozilla Firefox	Report should get generated within 5-10 sec.	
	Stress					
		34	Provide continuous load on the data, application.	Google chrome ,IE & Mozilla Firefox	There should not be any breakdown while loading any data and generation of reports and maps.	

END OF INCEPTION REPORT