Hazard, Vulnerability and Risk Assessment of Guwahati City, Silchar, Dibrugarh Towns and Dhemaji District, Assam

Manual

North Eastern Space Applications Centre (NESAC)
Government of India, Department of Space
Umiam-793103, Meghalaya

North Eastern Space Applications Centre (NESAC)
Document Control Sheet

1	Security Classification	Restricted
2	Distribution	Project Team members and Project Scientists of Partner Institutions
3	Type of Document	Project Execution Manual
4	Title	Manual on RS and GIS Based inputs on Hazard Vulnerability Risk Assessment of Guwahati city, Silchar, Dibrugarh towns and Dhemaji district, Assam
5	Number of Pages	Pages 60, Figures 12, Tables 10, Annexure 5, References 70
7	Scrutiny Mechanism	Compiled by Project Coordinator, NESAC; Reviewed by Project External Advisory Committee; Approved/Controlled by Director, NESAC
8	Sponsor(s)	Assam State Disaster Management Authority (ASDMA) Department of Revenue and Disaster Management, Govt of Assam, Dispur, Guwahati
9	Date of Initiation	October, 2010
10	Date of Publication	May, 2011
11	Abstract	The study was taken up for ASDMA, Govt of Assam to conduct Multi-Hazard Vulnerability and Risk Assessment studies for Guwahati city, Silchar, Dibrugarh towns and Dhemaji district, Assam on 1:10,000 scale for the city/towns and on 1:25,000 scale for the district. The state of Assam is susceptible to number of natural hazards, for example, Flood, Landslide, Earthquake as well as it also has threat from manmade hazard like Industry. With increasing population growth, societal exposures to various hazards are increasing. Hence it has been called to analyze potential hazards and to assess related vulnerability and risks. To facilitate this and to maintain uniform mapping procedures/standards methodology and technical guidelines are compiled.
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Preface

Natural catastrophes such as earthquakes, landslides, flood, cyclone, drought etc, have always caused a major problem in many developed and developing countries. Though, by itself any of the natural catastrophes does not considered as a disaster until destruction in terms of damage to population and property is encountered. However, in recent years, the growth of population and the diffusion of haphazard development over hazardous areas have sharpened the impact of natural catastrophes or hazards worldwide. In addition, manmade hazard mainly due to accidental failure of industries is a growing threat to any of the community. The State of Assam is vulnerable to various natural hazards and already witnessed many disasters incidences other than the recurring problem of flood during rainy season. The city like Guwahati is also experiencing landslide related disaster during monsoon season causing threat to the population dwelling on the hills and the intensity of such incidences are increasing day by day. The state also has number of medium to large scale industrial set up primarily related to natural gas and oil sector other than various small scale industries. However, most of the natural and manmade catastrophic events are intrinsically complex phenomenon caused by a large set of factors many of which are still unidentified.

With the technological advancement, losses caused by a disastrous event can be avoided or minimize if timely measures are taken even if it cannot be prevented. The Hazard Zonation Maps are one of the important inputs for such pre-disaster planning. In this regard North Eastern Space Applications Centre (NESAC) has taken up an initiative to address the multi hazard zonation, vulnerability and risk assessment for Guwahati City, Dibrugarh and Silchar Towns in 1: 10,000 scale and Dhemaji district in 1: 25,000 scale. This study has been proposed by Assam State Disaster Management Authority (ASDMA) under the Revenue and disaster management department, Government of Assam to address different hazards and to assess both social and physical vulnerability and associated risks.

It is expected that the study will strengthen ASDMA the ways and means of extending similar approach to entire Assam towards minimizing the damage caused by natural and manmade (industrial) hazards to the population and property. It is further expected that the report and atlas would serve as reference for disaster management and other concerned officials for developmental planning not only for Assam but also to the North Eastern Region in general.

(S. Sudhakar)

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1 PROJECT BACKGROUND

1.1 Background

Natural disasters like, floods/flash floods, landslides, earthquake, cyclone, and volcanic eruptions etc, have always constituted a major threat to the society, hence both developed and developing countries are concerned about their systematic management. In addition, safety measures, emergency preparedness and response (during and after) for Major Accident Hazard (MAH) industrial sites are also becoming an integral part for the decision makers. This is because relocation of these sites or sensitive neighbourhood like residential areas, important infrastructural set up etc. are rarely possible. The State of Assam, India with its relatively immature topography, fragile geologic base and active tectonics is vulnerable to various natural hazards like earthquake, flood, landslide etc. Some major industrial installations especially of petrochemical products also make the state vulnerable to industrial hazard. In recent years, the growth of population with unplanned development of settlements in steep slopes and other hazardous areas have increased their relative vulnerability towards natural hazards. However, most natural catastrophic events are intrinsically complex phenomenon caused by a large set of factors, such as unstable slopes, tectonic movements, river dynamics, geological settings, climate change and many more of which several are ill-known or unmappable. Thus prediction of hazards in space and time is, however, a very difficult task. It requires the acquisition of various resource maps in spatial domain, large number of historical records and sophisticated models for assessing nature of disasters and vulnerable areas. In recent times, in spite of these constraints several sound, hazard investigations have been carried out and some of them constitute a reliable starting point for evaluating future hazards, social and physical vulnerability towards them and aimed to assess risk within an area.

A project has been proposed to address different hazards and to assess both social and physical vulnerability and associated risks by Assam State Disaster Management Authority (ASDMA) under the Revenue and disaster management department, Government of Assam for Guwahati city, Dibrugarh and Silchar townships along with the flood prone district of Dhemaji to NESAC.

Over view of the project as executed by NESAC is given briefly in the chapters 1 and 2 with respective details in chapter 3.

1.2 Project Objectives

The project has numbers of objectives formulated by ASDMA which will be achieved with the support of various local bodies/ agencies, central and state departments, academic institutions working in the field of disaster management and active participation of ASDMA. The details of the objectives are given below.

(i) To identify and acquire relevant data sources such as historical and scientific data related to hazards, government records, hazard maps, satellite imageries, research documents and publications for conducting hazard assessment.

(ii) To assemble database for various hazards in order to assess their frequency, geographical distribution and magnitude, and present them statistically and analytically.

(iii) To provide adequate scientific analysis in respect of causation, frequency and magnitude for each hazard while establishing their probabilistic estimates.

(iv) To conduct an assessment of physical vulnerability which includes housing, critical infrastructure, lifelines and essential facilities such as, schools, hospitals, in structural terms, present their vulnerability to hazards.

(v) To conduct a detailed assessment of social patterns of vulnerability, which include vulnerabilities associated with gender, weaker sections, disability, widow hood and other social handicaps.

(vi) To present an economic analysis of the impact of past disasters and assess their impact in statistical and analytical terms.

(vii) To prepare GIS based hazard maps on 1:10,000 scale for Guwahati city, Silchar & Dibrugarh towns and 1:25,000 scale for Dhemaji district and the area likely to be affected.

(viii) To represent different types of vulnerabilities on GIS maps, and prepare a composite vulnerability and potential multi hazard map for the city/town/district.

(ix) To prepare an atlas, showing both hazards and vulnerability together for the city/town/district.

(x) To provide broad recommendations for integrating the concerns of hazard and vulnerability reduction in the development strategy.

1.3 Study Area

Four different study areas of Assam have been identified by ASDMA to carry out the HRVA exercise. These are,

(a) Guwahati city, bounded by 26˚03 ' to 26˚08 ' N latitude and 91˚33 ' to 92˚55 ' E longitude. The municipal area of the city is about 216 sq. km while metropolitan area is about 261 sq.km. The city has total 60 wards within municipal area.

(b) Dibrugarh town, bounded by 27˚22' to 27˚30' N latitude and 94˚52' to 95˚00' E longitude. The town has an area of about 20 sq. km.

(c) Silchar town, bounded by 27˚45 ' to 27˚53 ' N latitude and 92˚45 ' to 92˚53 ' E longitude. The town has an area of about 60 sq. km and 28 wards within municipal area.

(d) Dhemaji district, bounded by 26˚ 56 ' 52" to 27˚ 53 ' 07 " N latitude and 94˚ 09' 17 " to 95˚ 28 ' 36 " E longitude with an approx area of about 3129 Sq. Km.

1.4 Hazards to be addressed

Depending upon the terrain conditions and considering the historic hazardous/ disaster events of the study areas, it has been decided to address following hazards for preparation of Hazard Zonation Maps and also to assess vulnerability and risk associated to each hazard.

- o Flood Hazard and related phenomenon
- o Landslide Hazard and related phenomenon
- o Industrial Hazard and related phenomenon and
- o Seismic Hazard and related phenomenon

1.5 Overall methodology

As the nature of work is unique involving multi hazard component along with vulnerability and risk assessment so the overall methodology (Fig 1) to be followed in this study is proposed into three main phases. These are:

1. Collection of baseline data and historic hazardous/ disaster events under hazard scenario development phase.
2. Preparation of Flood, Landslide, Industrial and Seismic Hazard Zonation maps.
3. Assessment of physical and social vulnerability and preparation of risk maps using standard analysis techniques.

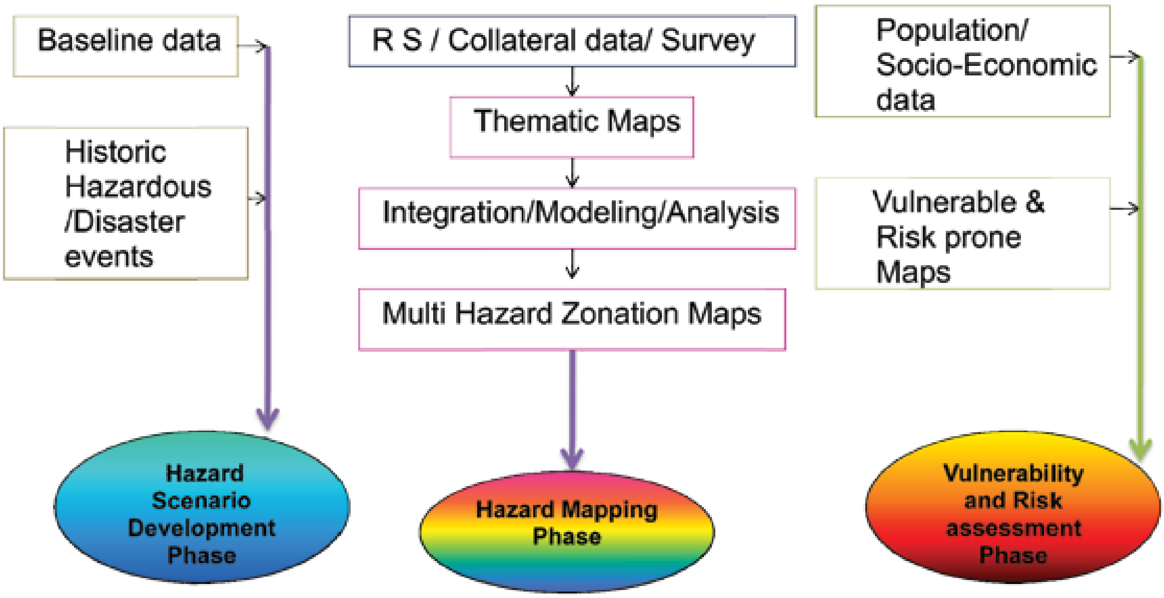


Figure 1. Overall methodology of the project

Meanings of some of the key words to be used in the context of the study are given below for quick understanding.

Hazard means the probability of occurrences of a potentially damaging phenomenon within a specific period of time and within a given area (Varnes, 1984). Hazard can be natural or man-made.

Vulnerability means the degree of damage of a specific element at risk (eg. Population, building etc.) by a specific hazardous phenomenon with certain intensity. It is the function of hazard intensity or type and the characteristics of the elements, which are at risk (Westen, 2004).

Risk means the expected number of lives lost, persons injured, damage to property or disruption of economic activity because of a particular hazardous phenomenon. Risk is often represented by,

Risk = Hazard x Elements at risk x Vulnerability

However, a potentially damaging phenomenon (Hazard), such as earthquake, landslide or flood by itself is not considered a disaster when it occurs in uninhabited areas or not in close proximity to any infrastructure. It is called a Disaster when it occurs in a densely populated area, close to infrastructures and results in a large destruction in terms of loss of life and damage to property.

1.6 Deliverables of the project

The major outcomes of the project are,

- Hazard Zonation maps for flood, landslide, earth quake and Industrial hazard
- Multi Hazard Vulnerability and Risk Maps.
- All hazards, vulnerability and risk prone areas depicted in an Atlas (A3 size).

2 BASELINE DATA AND INFORMATION

2.1 Mapping unit

The administrative maps showing ward wide city and towns is the unit considered for generating hazard maps for Guwahati city, Dibrugarh and Silchar towns while for Dhemaji district, the unit considered for hazard mapping is the administrative map showing village boundaries. The essential base line data required for this project are

- o Ward boundary maps of Guwahati City, Dibrugarh and Silchar Towns
- o Village boundary map of Dhemaji district.

2.2 Projection parameter and Scale of Mapping

In order to meet the present need and considering the scope to accommodate data bases and information generated and/ or available with various organizations it has been decided to organize all the geospatial databases in to following projection system,

Projection : UTM

Datum : WGS84

In the present study, all the maps will be generated in 1: 10,000 scale for Guwahati City, Dibrugarh and Silchar Towns and for Dhemaji district the maps will be represented in 1: 25,000 scale.

2.3 Classification System

The thematic maps will be generated by visual interpretation and on screen digitization from remotely sensed data in consensus with published maps and literatures. Further, the thematic maps will be classified following National Natural Resource Management System (NNRMS) standard developed by ISRO.

Methodologies to be adopted for each hazard zonation mapping will be elaborated in chapter 3.

2.4 Satellite data

Space borne remotely sensed data proved to be reliable and cost effective source for the generation of digital geospatial databases. The Cartosat-I, stereo data with 2.5 m spatial resolution will be mainly used for generation of Digital Elevation Model (DEM). Cartosat-I and LISS IV MX merged data will be used for thematic mapping in 1: 10, 000 scale. IRS LISS IV Multispectral data with 5.8 m spatial resolution will be used for thematic mapping in 1: 25,000 scale required for Dhemaji district.

2.5 Monitoring and Quality Evaluation

An advisory committee has been constituted taking experts from various Organizations like Geological Survey of India (GSI), National Remote Sensing Centre (NRSC), Regional Remote Sensing Centre (RRSC), Space Applications Centre (SAC), various Universities. The committee will ensure quality of the data base generated under the project.

3 HAZARD ZONATION MAPS

3.1 Flood Hazard Zonation

Floods are one of the most recurrent hydro-meterological disasters in the globe and a sizeable portion of the world population suffer from flood every year. India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for one fifth of global death count due to floods. About 40 million hectares or nearly 1/8th of India's geographical area is flood-prone. The problem of riverine flooding is getting more and more acute due to human intervention in the flood plain. There must be a realization that minimizing the risk and damage from floods may be more rational way of flood management rather than formulating structural measures along the dynamic rivers.

Flood hazard mapping and flood inundation modeling are the vital components in flood mitigation measures and land use planning, and are prerequisites for the flood insurance schemes. As flood itself cannot be prevented but the damages due to flood can be mitigated with proper planning and preparedness in community level. For that it is very important to identify the degree of hazard associated with various portions of a flood plain. Hence flood hazard zonation is an important component of overall flood management strategy. There are different types of flood based on causal factors and domain of occurrence. Most prominent types of floods are River flood, Dam break flood, coastal flood, urban flood, flood due to glacier avalanche etc.

Urban flooding is specific in the fact that the cause is a deficiency of drainage capacity in an urban area. As there is little open soil that can be used for water storage nearly all the precipitation needs to be transport to surface water or the sewage/sewerage system. High intensity rainfall can cause flooding when the city sewage/sewerage system and draining canals do not have the necessary capacity to drain away the amounts of rain that are falling. Water may even enter the sewage system in one place and then get deposited somewhere else in the city on the streets.

River flood mapping is the process of determining inundation extents and depth by comparing river water levels with ground surface elevation. Flood hazard maps generally are a composition of water depth, flood extent, flow velocity and flood duration. This is a basic and important Indicator for the flood plain land use development planning and regulations. River flood hazard mapping was first initiated in 1988 by the Hydrologic Engineering Centre (HEC) of the U.S. Army Corps of Engineers (USACE).

Causal factors for urban flash flooding:

(a) High intensity rainfall trigerrring flash floods,
(b) Improper and hap-hazard urbanization pattern,
(c) Inadequate capacity of storm water drainage system,
(d) Topographic anomalies,
(e) Encroachment / land filling/ siltation in natural reservoirs / wetlands, etc.

Causal factors for riverine flooding:

(a) Inadequate channel capacity to convey high discharge,
(b) Migration of river channel from one flow path to another,
(c) Erosion of bank line leading to breach of embankment,
(d) Upstream failure of a hydraulic structure as dam, weir, etc.

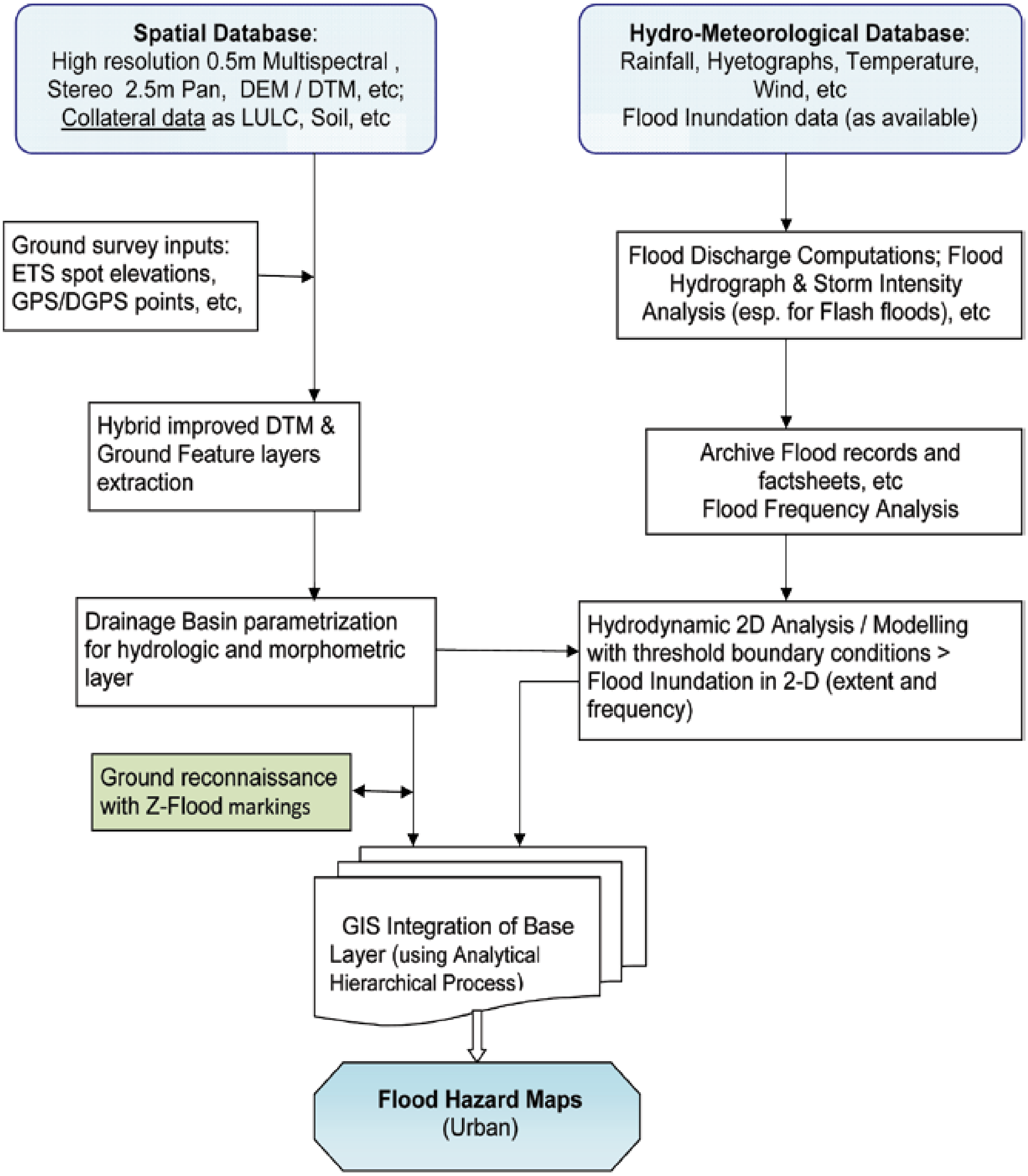
3.1.2.1 Methodology for Urban and Flash Flood hazard zonation

The existing methods for flood plain mapping can be grouped into the following three major categories namely the analytical method, the historical method and the physiographic method (Smith & Ward, 1998). All these three methods share two common steps for flood plain mapping; determination of water surface profiles and transfer of water elevation from profiles to maps. Essentially these three methods use the same procedure to delineate flood plain boundaries by determining the flood elevation at each river cross section. The analytical approach is mostly adopted for urban and flash flood management, which requires development of system-based hydrologic and hydraulic models that are laid on parameters as base flood elevation (BFE) information, storm intensity, etc.

Urban flood studies are undertaken to analyze flooding problems in developed watersheds generally characterized by localized inundation, relatively short response time, etc. Presently, a number of hydrological routines and model packages are available to analyse and model urban flooding. Some of the commonly used packages are INFOWORKS, MIKE-FLOOD (DHI), SOBEK, TUFLOW, LISFLOOD-LP, CCHE2D, HEC- packages – HMS/ GeoHMS/ RAS/ GeoRAS (USACE), FEMA (Federal Emergency Management Agency) authored tools (FLO-2D, RiverFLO-2D, Quick-2, CHECK-2), etc. All of these packages are based on the basic equations of continuity, mass and momentum which are subsequently derived to the St. Venant's flow principles. The basic variation in the packages lies in the computational and grid schemes used to solve these equations. All the packages are assayed for suitability of model with the present project with respect to data availability and 'localized' environmental conditions. The urban flooding environment requires an integrated simulation of the flash flood discharge computations built on a composed micro-topographical grid network, followed with drainage flow routing across the urban floodplain. InfoWorks provides water utilities with a uniquely effective tool with which to undertake hydrological modeling of the complete urban water cycle. InfoWorks-ICM provides a practical method for analysis of urban flooding, however its operational control and boundary assumptions give constraints with the present project requirements. MIKE FLOOD (DHI) is a tool that integrates the one-dimensional models MOUSE (MIKE URBAN), MIKE 11 and the two-dimensional model MIKE 21 into a single, dynamically-coupled modelling system. Use of a coupled approach enables the best features of both 1D and 2D models to be utilized for urban flood modelling, whilst at the same time limitations of resolution, grid-layer preparation, data intensiveness, etc are generally encountered while using MIKE packages. FEMA tools do not holistically contain rainfall-runoff simulation to compute flood discharges for an 'ungauged' or 'partially-gauged' urban watershed, as is the case with present study where no flood discharge data is available. The same has to be computed using limited meteorological data available.

In order to perform urban flash flood hazard mapping under these envelopes of data redundancy, an integrated platform of HEC-HMS (Hydrologic Engineering Centre - Hydrological Modeling System) and HEC-RAS (River Analysis System) is chosen to be the viable option for hydrologic rainfall-runoff modelling and hydraulic flood simulation, respectively. The hydrologic model is assigned for computing flash flood discharges with storm rainfall inputs in the urban watershed. The hydraulic model will provide flood flow simulation in the intricate urban grid network with customized results in GIS environment. The derived outputs will be used to generate the final flood hazard based on water depth and flow velocity maps. All these discretization and layer creation are well-suited in the GIS compatible built-in modules viz., HEC-GeoHMS (Geospatial

Hydrological Modelling System) and HEC-GeoRAS (Geospatial River Analysis System). Interpretative hydrodynamic data input, relative time consumption, and adaptive outputs powered by choice of various flexible computational schemes makes it the user-driven choice for the project work. In conjunction, Environmental Protection Agency (EPA) - Storm Water Management Model (SWMM), first developed in 1971, is used for dynamic rainfall-runoff simulation model for single event or long-term (continuous) simulation of runoff quantity and quality primarily for storm water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas. SWMM continues to be widely used throughout the world for planning, analysis and design related to storm-water runoff, combined sewers, sanitary sewers, and other drainage systems in urban areas.



Overall workflow for urban Flood Hazard zonation

3.1.2.2 Methodology for riverine Flood hazard zonation (for Dhemaji district)

The overall work required for riverine flood hazard zonation is divided in to various components. The following maps have been proposed to generate for study areas as input for further evaluation towards meeting requirement for river floods. The basic data pertaining to infrastructure covering various aspects are to be generated along with base map of the study area.

a) Creation of base maps: The base map is prepared incorporating all administrative boundaries such as district, revenue circle etc. In addition all major roads and drainages are to be generated. All layers to be generated in 1:25,000 scale.

b) Generation of detailed information: Supportive information related to favourable flooding condition such as occurred embankment breaches, river confluence, flood plains,

c) Generation of flood hazard Weightages: A multi-criteria analysis based on proximity to different hazard conditions to divide the entire flood plain into different hazard zones. Following table explains the allocation of weightages.

Criteria	Very Low (1-2)	Low (3-4)	Medium (5-6)	High (7-8)	Very High (9-10)
Normalized Differential Water Index (NDWI)	0-93	93-112	112-132.5	132.5-173	173-255
Normalized Differential Moisture Index (NDMI)	0-108	108-122	122-139	139-157	157-255
Elevation	>95m	90-95m	85-90m	80-85m	<80m
Proximity to drainage Confluence	>11km	8-11km	5-8 km	2-5 km	<2km
Proximity to embankment breaches	>8 km	6-8 km	4-6 km	2-4 km	<2 km
Actual inundation layers (NRSC)	1 time flooded	2 times flooded	3 times flooded	4 times flooded	
5 times flooded					
TOTAL	**0-12**	**12-24**	**24-36**	**36-48**	**48-60**

3.1.3 Data requirements

Keeping in view the requirement of various inputs towards achieving the objective of both the urban and riverine flooding components, following broad categories of data have been projected.

Hydro-meteorological data

- Rainfall data in daily interval for a last 25 years
- Daily discharge and water level data of rivers and major sewer-storm / drainage channels flowing in the study AOIs
- Cross-section and Longitudinal profiles of rivers and major drainage / sewer channels

Collateral data

- Field maps of river configuration, embankment breach, etc.
- Historical flood inundation maps
- Historical event based flood reports
- Sewer and drainage layout map of for each respective city
- Municipal Ward map.

Ground survey data

- DGPS/GPS location nodes of Z-flood zones and drainage network
- Spot elevation Z-points with vertical resolution accuracy ≤ 0.5m, for close contour intervals and fine resolution DTM/TINs.

3.1.4 Data Integration and Modeling

3.1.4.1 Theory of flood routing

Urban floodplain areas have significant effects on inundation flows. Large-scale modelling of such zones thus requires a special treatment to involve flooding at relatively short durations and depths. Shallow-water models account for the reduction in storage and in the exchange sections due to presence of buildings and other structures on the floodplains, and are most appropriate to analyse such problems (Soares-Frazão et al. 2008, Sole & Zuccaro 2005). Using this concept, the governing equations in two dimensions of space can be written in conservation form as follows (Hervouet et al., 2000; Guinot and Soares-Frazão, 2006),

$$\frac{\partial U}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} = S \qquad (2)$$

where, U is the vector of unknown variables – wetted area and discharge (Q); F is the vector of the flux quantifying discharge, static momentum and acceleration due to gravity; G is the source vector of the longitudinal variation of the static momentum defined by bed and friction slope.

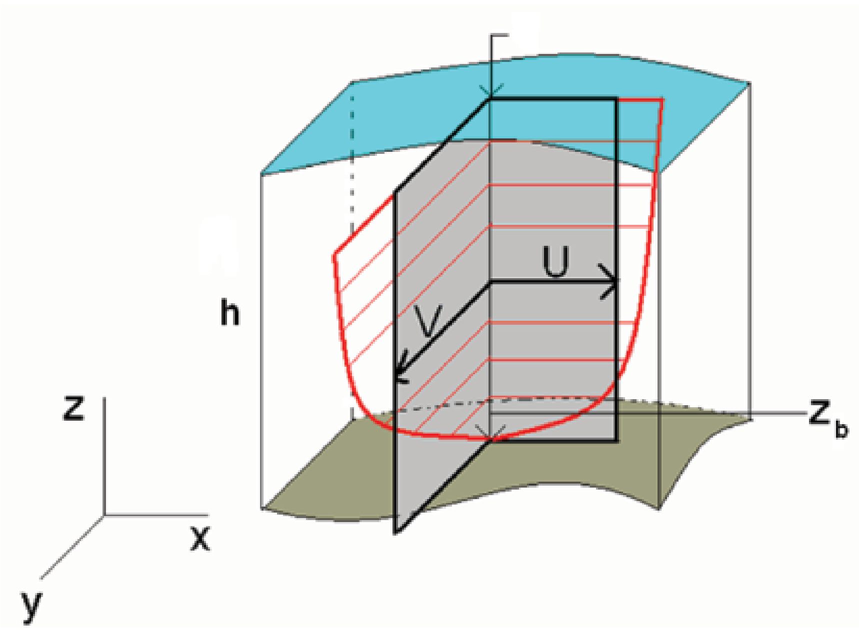


Fig.3 Cartesian co-ordinate system in a typical flow differential scheme

The introduction of the flux and source terms modifies the De Saint Venant's equations accordingly for shallow water flow, as

$$\frac{\partial h}{\partial t}+\frac{\partial (hu)}{\partial x}+\frac{\partial (hv)}{\partial y}=0 \quad (3)$$

continuity eqn.

$$\frac{\partial (hu)}{\partial t}+\frac{\partial (hu^2)}{\partial x}+\frac{\partial (huv)}{\partial y}+gh\frac{\partial h}{\partial x}=-gh\frac{\partial z_b}{\partial x}-gn^2u\frac{\sqrt{u^2+v^2}}{h^{1/3}}+\nu\frac{\partial}{\partial x}\left(\frac{\partial (hu)}{\partial x}\right)+\nu\frac{\partial}{\partial y}\left(\frac{\partial (hu)}{\partial y}\right) \quad (4)$$

x momentum eqn

$$\frac{\partial (hv)}{\partial t}+\frac{\partial (huv)}{\partial x}+\frac{\partial (hv^2)}{\partial y}+gh\frac{\partial h}{\partial y}=-gh\frac{\partial z_b}{\partial y}-gn^2v\frac{\sqrt{u^2+v^2}}{h^{1/3}}+\nu\frac{\partial}{\partial x}\left(\frac{\partial (hv)}{\partial x}\right)+\nu\frac{\partial}{\partial y}\left(\frac{\partial (hv)}{\partial y}\right) \quad (5)$$

y momentum eqn.

where g is the gravitational acceleration, h is the water depth, u and v are the x- and y-velocity components in the curvilinear co-ordinate system, respectively, zb is the bank level; the first three terms on the right-hand side (eqns. 4 and 5) are the source terms arising from the part of the pressure balance not accounted for in the flux terms (bottom slopes and porosity variations) in the x- and y-directions, respectively. Figure 3 above defines the cartesian co-ordinates system for the flow differential scheme.

3.1.4.2 Model adopted (with special emphasis for urban flash flood)

Analytical frame

A hydrodynamic module to interact with intense data exchange, representation and staging at a fine scale adequate enough to reflect the urban geometry is built in the form of a 'coupled flood simulation platform'. The basic framework in the coupled flood simulation platform integrating hydrologic and hydraulic models for the determination of urban flash flood and river flood consists of five parts:

(i) The extraction of geospatial data for use in the hydrological and hydraulic models (HEC-GeoHMS and HEC-GeoRAS).

(ii) The hydrologic model which develops rainfall-runoff from a design rainfall or historic rainfall event (HEC-HMS).

(iii) The hydraulic model which routes the runoff through stream channels to determine water surface profiles (including depth and velocity) at specific locations along the stream network (HEC-RAS).

(iv) Drainage and sewer flow modeling in SWMM.

(v) A tool for floodplain mapping and visualization (HEC-GeoRAS).

The first module acquires all the information about the urban territory (such as micro-topography / DTM, position of squares and streets, etc.) from files obtained in a GIS environment and it is able to represent the results. The second module invokes hydrological models to simulate the rainfall-runoff process based on rainfall design hyetograph extracted using SCS (Soil Conservation Service) guidelines. A synthetic design storm is developed for a given return period and the same return period is then associated to its runoff peak flow and volume using a theoretical distribution as the Gumbel type distribution. For historical storm series, a statistical analysis is conducted to compute the return periods of the runoff peak flow and volume. The hydrologic model with Initial and Rate Loss method, Snyder Unit Hydrograph transform with the Muskingum-Cunge routing is developed for computing flash flood discharges in the urban watershed. In parallel, the SCS methods along with the Unit Hydrograph methods will be adopted for relative assessments of final outputs. The third module comprise of hydraulic models in order to simulate the behaviour of the flow in the major streams/drainage channels and urban floodplain using a numerical finite difference scheme for the attenuation of the numerical fluctuations. The runoff hydrographs which were generated in the hydrological modelling were used as the main input for hydraulic modeling in HEC-RAS. The fourth module is vitally composed of urban runoff component of SWMM which operate on a collection of sub-catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM, transport this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub-catchment, and the flow rate, flow depth, and quality of water in channels and closed conduits during a simulation period comprising of multiple time steps. The last module simulates the propagation of the flood volumes with geospatial configurations onto the urban network schematization.

The proposed model has a graphical interface able to receive the input data necessary for the hydrodynamic simulation, in particular: water-bed geometry, urban geometry of streets and drainage, hydrograph, friction factors (both in-bed and out-bed) and spatial and time integration interval. These data will be stored in a database and can be modified and refreshed by an external program. Using the GIS module, the urban mesh block geometry has been discretized in a series of tanks (generally in the centre of the squares) linked by channels (sample as in Fig. 4). The tanks represent the storage capacity of a portion of urban mesh block geometry. The relevant area of each tank is automatically calculated with the Thiessen polygons. Geospatial hydrological schemes will be used to extract watershed / sub-units (tanks) attributes (sample as in Fig. 5).

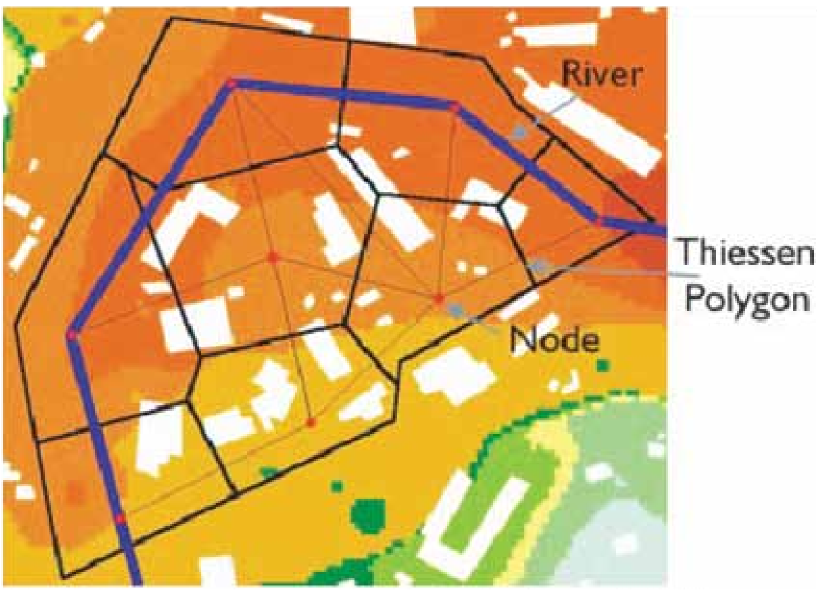


Fig.4 Urban environment schematization on TIN layer

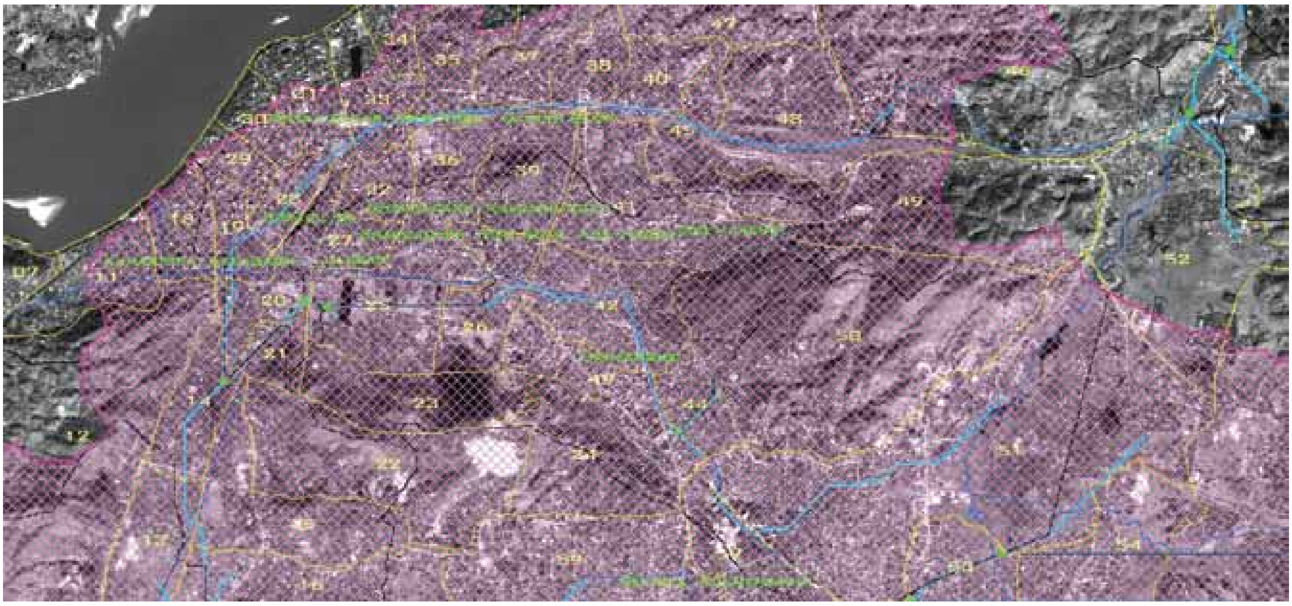


Fig.5 Schematization of units as 'tanks' and 'channels' for urban flood simulation

The model computes, for each time step, the values for the discharge and the wetted area for each cross section, as functions of the values assumed in the previous time step in the same section and in the two adjacent sections. To simulate the flood propagation inside the potentially affected area, a series of representative points of the storing capacity of the open spaces is set. The out-bed inundation module simulates the flow of the flood volumes out-flowing from the drainage-bed. To simulate the flood propagation inside the potentially affected area, a series of representative points of the storing capacity of the open spaces is set. SWMM provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations, and viewing the results in a variety of formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses. The results of the simulations will provide the extents of the inundated area for a respective threshold discharge / flood run-off, the water depth for each time step and for each node and the maximum water depth for each node. In the absence of historical data HEC-RAS model together with the GeoRAS serve as "model of reference" for the validation also in conjunction with satellite data acquired during real-time flood inundation events. The proposed model facilitates calculations of flood propagation in urban areas in quasi bi-dimensional modality.

3.1.4.3 Conceptual frame

Flood hazard denotes the probability and severity of occurrences of a flood of a certain magnitude. The magnitude is determined from flash flood discharges and thresholds as derived from the hydrological modeling system. Flood Hazard indexed by flood severity is characterized by water level, flood duration and flood frequency. Based on flood level, flood extent maps are generated from derived flood extent from a digital elevation model (DEM) built upon high resolution spatial dataset and Z-flood spot elevations (ground survey) by separating pixel values into areas below and above the high flood level, thereby delineating areas that would or would not be flooded (MacKinnon, 2004).

Then, using the flood extent map, the flood depth raster map was clipped to display flood depth values solely within the extent of the flood. The Flood depth pixel values will then be classified into different flood hazard zones. While spatial extent and flood depth will be used for flood mapping, it will be tried on to integrate flood duration and flood flow velocity to help evaluate flood severity.

3.1.5 Expected Output

Under ***Riverine Flood Hazard*** component (Dhemaji District) the following outputs will be generated:

(a) Revenue circle wise flood hazard map with classification of no hazard , low hazard, moderate hazard & high hazard areas with village boundaries overlaid.

(b) District wise report on flood hazard with special emphasis on flood induced sand deposited areas.

Under ***Urban Flood Hazard*** component (Guwahati, Silchar, Dibrugarh), following outputs will be generated:

(a) Flood hazard zonation maps showing wards of no hazard, low hazard, moderate hazard & high hazard with major and minor infrastructures such as roads, residential areas, commercial areas, etc overlaid.

(b) Related reports on action plans on flood hazards for all the cities/ towns.

Table 1 shows the colour code to be adopted for showing various flood hazards classes depicting the degree of hazard in the Flood Hazard zonation maps:

Tentative degree of Flood Hazard	Colour Code
No (≈ Nil) Flood Hazard	[pink]
Low Flood Hazard	[yellow]
Moderately Flood Hazardous	[dark brown]
Highly Flood Hazardous	[red]

3.2 Landslide Hazard Zonation

3.2.1 Introduction

Landslides, as one of the major natural hazards, account every year for enormous property damage in terms of both direct and indirect costs. Landslide is also one of the major natural hazards in North East India which falls in the medium to high and high category of the Global Landslide Susceptibility Map. The term "landslide" encompasses events such as rock falls, topples, slides, spreads, and flows (Varnes, 1996). They are natural events which may occur due to or without human intervention, invariably leading to an increase in shear stress or decrease in shear strength of the slope-forming materials. They are triggered by a variety of external stimuli, such as rainfall, earthquakes, water level change, volcanic activity, forest fires, storm waves or rapid stream erosion etc. In addition, as development expands into unstable hill slope areas under the pressures of increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites, etc., have become important triggers for landslide occurrences (Dai et al., 2002). Landslides occur when the balance between the pull of gravity on material on a slope and the forces (friction and strength of material) acting to hold it in place is upset by some change. Slope stability is evaluated by computing a safety factor (SF) defined as the ratio of the resisting forces to the driving forces. However, Landslides in nature may be more complex than is esteemed by current conceptual representations. To understand type of landslide, it is important to know landslide classification system and nomenclature.

Landslides are classified by the type of material involved and the type of movement executed by the slope material. Additional criteria are the rate of movement and the water content of the material; these two are commonly related. Landslide classification by Varnes (1978) is given in the table 2. Landslide movement rates range from few centimeters over many years to many kilometers per second. Material can be rock or soil. Soil is further divided into debris, which contains pieces of

Table 2: Types of Landslide (after Varnes, 1978)

Type of movement		Type of material		
		Bedrock	Engineering soil	
			Coarse-grained	Fine-grained
Fall		Rock fall		
Slide	Translational	Rockslide	Debris slide	
	Rotational	Rock slump	Slump	
Flow	Rapid		Debris avalanche	Mudflow
			Debris flow	Earth flow
	Slow	Rock creep	Talus creep	Soil creep

rocks and earth, which is primarily composed of sand, silt, and clay. Debris may also include other components, such as trees and construction materials. There are three types of movements, namely fall, in which loose material falls or bounces down a slope; flow, in which material is distorted and moves as a fluid; and sliding, in which the landslide involves relatively undeformed material moving along a discrete surface. Flows can be further classified by their rate of movement. Very rapid flow down a steep slope (usually involving very wet material) is an avalanche, and extremely slow flow deformation is known as creep. Keller (1987) has slightly modified Varn's classification and has divided landslides into two groups based on the patterns of movements. They are translational and rotational movements. In translational sliding, materials move on a flat surface along geological planes of weakness within rock slopes. Common translational slip planes include fractures, bedding planes, clay partings and foliation planes. Rotational slides are most common for soil slopes but are also associated with slumping in rock slopes especially where a permeable rock overlies a weak rock (Keller, 1987). However Varne's classification is still the widely referred landslide classification system. Landslide classification is useful mostly as a tool in thinking about how and why landslides occur.

3.2.2 Methodology

Since early 70's the landslide event has been studied considering various aspects by the scientist's world over. Landslide hazard and risk zoning and mapping for urban and rural areas is widely performed around the world (Siddle et al., 1991, Lee et al., 1991, Hutchinson and Chandler 1991, Hutchinson et al., 1991, Morgan et al., 1992, Carrara et al., 1991, and 1992, Moon et al., 1992).The most straightforward approach to Landslide Hazard Zonation (LHZ) is a landslide inventory, based on interpretation of aerial photograph/ remote sensing (RS) imagery, ground survey using Global Positioning System (GPS), and integrating the data base of historical occurrences of landslides in an area using Geographic Information System (GIS). The various approaches adopted for landslide hazard zonation are divided in to three categories, these are

- ***Heuristic Approach:*** This is further divided in to two types. Firstly, Geomorphological analysis or the direct mapping method, the basis for this approach was outlined by Kienholz (1978). In this case the Hazard is determined directly in the field by the geomorphologist. Secondly, to overcome the problem of the "hidden rules" in Geomorphological mapping, other qualitative methods have been developed based on qualitative map combination.

- ***Statistical Approach:*** In statistical Landslide Hazard analysis, the combinations of factors that have led to landslides in the past are determined statistically and quantitative predictions are made for landslide free areas with similar conditions. Two different statistical approaches are used in landslide hazard analysis, namely Bivariate and Multivariate statistical analysis.

- ***Deterministic Approach:*** The method is applicable only when the geomorphological and geological conditions are fairly homogenous over the entire study area and the landslide types are simple. The advantage of these "white box models" is that they are based on slope stability models, allowing the calculation of quantitative values of safety factors however, high degree of oversimplification is the main problem with the method. This method is usually applied for translational landslides using the infinite slope model (Ward and Simons, 1982).

In India, landslide studies were initiated in the year 1880, with R.D Oldham's study of the Nainital Landslip. Geological Survey of India (GSI) has been involved in the site-specific investigations of a number of landslides particularly those related to communication routes, urban settlements and River Valley projects. The first landslide inventory in the Himalayan terrain was carried out by Lakhera (1982), using RS and GIS techniques. Use of Geoinformatics was evaluated by many experts like Champati ray (1996, 2004); Champati ray et al., (1996, 1997, and 2004); Sarkar et al., (1995, 2004) and many more. Champati ray (2000) evaluated the cost-effective methodology for landslide hazard zonation using RS & GIS. Due to the catastrophic nature of landslides, Government of India under a recent directive has completed a major project with the help of the Department of Space and several other organizations on landslides hazard zonation in user identified strategic locations of Himachal Pradesh and Uttar Pradesh and North East Region of India. Majumdar (1980) gave first potential ratings of nil, low, generally low, moderately high and very high or severe, to the zones in North Eastern Region by combining relief and geological maps. After that a number of institutions (CRRI, CBRI, and GSI etc.) have been engaged with landslide investigations and their stabilization in various parts of North Eastern States and the problem of slope instability in North East India has attracted number of workers from all over the world.

3.2.2.1 Details and Limitations of the Conventional Approach

The Guidelines adopted by Bureau of Indian Standards (BIS) for preparation of landslide - Hazard zonation maps in mountainous terrains is mainly for Macro-zonation in the scale of 1:50,000 (IS 14496: Part 2, 1998; reaffirmed in 2007). The BIS guideline is knowledge based rating and LHZ maps are prepared by superimposing the thematic maps (lithology, structure, slope, relative relief, land use and land cover and hydrogeology) using Landslide Hazard Evaluation Factor (LHEF) rating scheme and calculating the Total Estimated Hazard (TEH). The unit of study as recommended by BIS for LHZ is a slope facet. A slope facet is a part of hill slope showing consistent slope direction and inclination. The slope facets over a region are generally delineated from SOI Topographical maps considering ridges, spurs, gullies and rivers. The maximum LHEF ratings for the causative factors like lithology, structure, slope morphology, relative relief, land use and land cover and hydrological condition are 2, 2, 2, 1, 2 and 1, respectively is a 10 point rating system. Apart from the LHEF rating of the causative factors, as detailed above, BIS guideline further suggests that a 100m to 200 m strip on either side of major faults, thrusts and intra-thrust zone shall be awarded an extra rating of 1.0 to consider higher landslide susceptibility depending upon intensity of fracturing. LHEF values of each (along with extra rating for regional thrusts, where applicable) have been summed up to get the THHD values of individual facet. Depending on the THED values the facets are grouped in to Very Low Hazard (< 3.5), Low Hazard (3.5-5.0), Moderate Hazard (5.0-6.0), High Hazard (6.0-7.5) and Very high Hazard (>7.5) classes. However, Anbalagan et al., (2008) has modified this methodology by accommodating more detailed aspects of inherent causative factors responsible for slope instability and incorporating effects of external causative factors such as seismicity and rainfall as correction ratings. At present there is no Guidelines available for Landslide Hazard Zonation on Meso Scale (1:5000/10,000) and for further large scale.

3.2.2.2 Approach to be adopted

Field techniques, despite being very precise, are usually not sufficient to achieve this goal, as they mostly provide point-based measurements. With the advent of technology, various advances have taken place in the field of hill slope failure assessment both in the spatial and temporal domain. Remotely sensed data can be used for deriving thematic information on various geo-indicators such as lithological variation, geotechnical conditions, hydrogeology, vegetation density, land use/land cover pattern (Rengers and Soeters, 1993; van Western, 1993). Very high resolution imagery (QuickBird, IKONOS, CARTOSAT-1and 2) has become the best option now for landslide mapping and number of operational sensors with similar characteristics is growing year by year (van Westen et al., 2007).

In absence of Guidelines for Landslide Hazard Zonation (LHZ) in large scale (1:10,000) and on the basis of the experience gathered in course of LHZ Mapping following BIS as well as RS & GIS techniques and most importantly considering the scope and objective of the project and the potential of space-based inputs and advancement in the field of geo-informatics, methodology has been decided incorporating more recognized important causative factors of landslide. The overall methodology is shown in the flow chart of (Fig 7). As the study area is densely populated and hill slope alterations are increasing alarmingly. In addition to space based inputs field as well

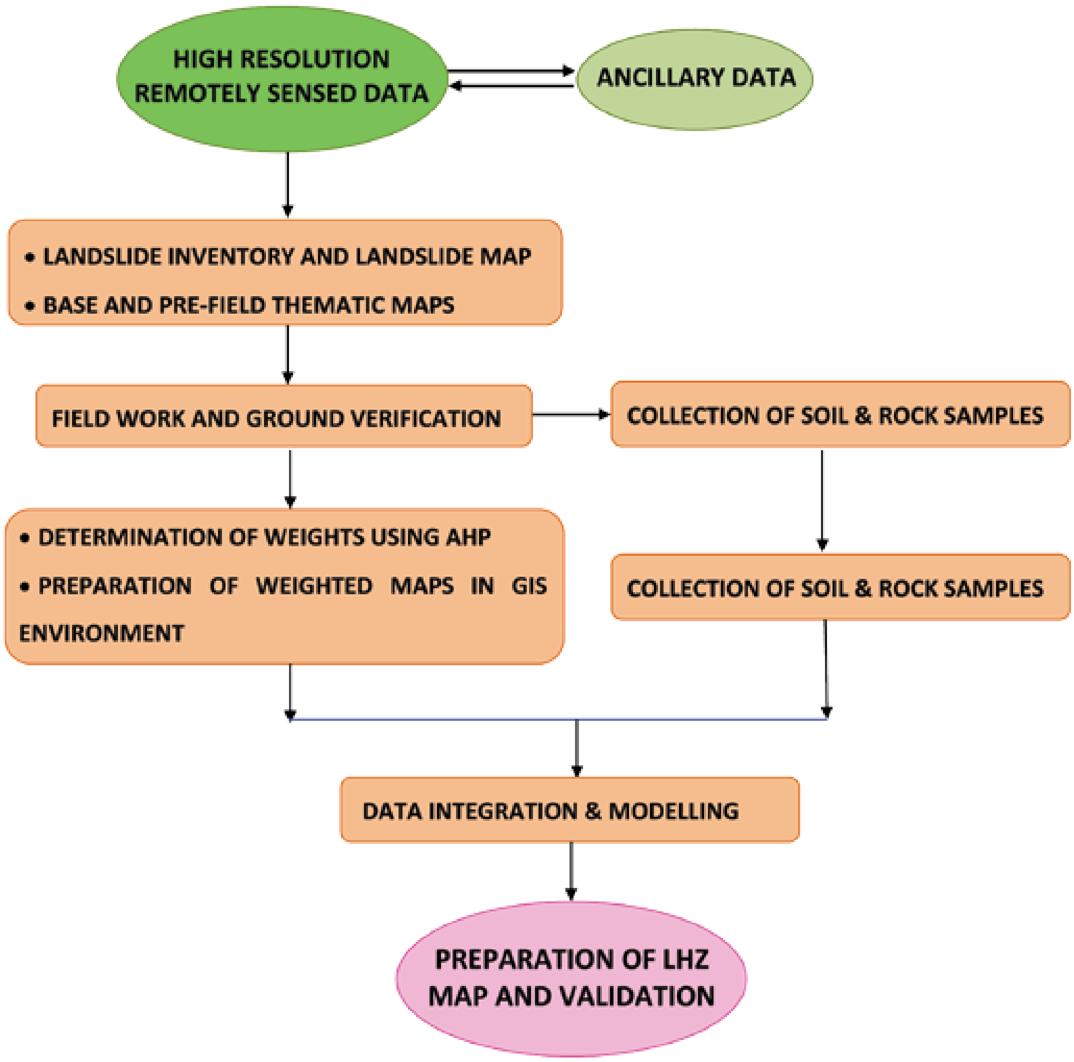


Figure7: Flow chart of the Methodology for LHZ mapping

as laboratory investigations will also be carried out to determine Rock Quality Designation (RQD) and strength of Rock or Soil following standard procedures. Detailed field Mapping of Attitude of dominant structural discontinuities to establish their relationship with slope orientation for identification of possible mode of failure will also be carried out.

The different components of the work can be classified under four broad heads,

a. Detailed Landslide Inventory of past landslide incidencs
b. Preparation of thematic maps and their ground verification and integration in GIS environment
c. Investigation of soil and ground verification of thematic maps
d. Both field and Laboratory investigation of soil and rock.

Landslide Inventory will be prepared studying details of past and present landslide (Annexure I) partly with the aid of remotely sensed data, visit of landslide affected sites and in consultation of historical records. The final product will be landslide map showing the spatial distribution of landslides, represented at scale or as points (Wieczorek, 1984).

Thematic maps related to various geo-environmental parameters will be extracted mainly from remotely sensed data of high spatial resolution. A number of thematic maps will be prepared which are thought to play a significant role in causing slope instability, namely, drainage & drainage density map, lithological map, structural & lineament density map, geomorphological map, rock weathering map, landslide map, land use/land cover map, slope-discontinuity relationship map (in case of sedimentary terrain), soil texture map, soil depth map, slope gradient & slope aspect map, triggering factors etc along with base map. Thematic interpretation and map preparation will be carried out in consultation with published literatures, maps and detailed field survey following NNRMS standards. These maps after finalization will be integrated following Heuristic Approach. Suitable weights and ranks will be assigned to various classes of thematic maps and thematic maps respectively using Analytical Hierarchical Process developed by Satty (1980).

Field Work will be carried out for preparation of landslide inventory and to verify pre-field thematic maps with the ground reality.

3.2.3 Data requirement

To fulfill the objectives few collateral data (spatial and non spatial) need to be collected from both primary and secondary sources as described below in addition to satellite data mentioned in the chapter 1. Collateral data regarding rainfall, earthquake and land use changes will be analyzed to assess the role of major triggering factors of past landslide incidences.

a) SOI Topographical Map (78N/12 and 78N/16) on1:50,000 for base line information like name of the locality etc.

b) Information about past and present slide and other related data from official records and other sources for preparation of landslide map.

c) Antecedent rainfall as well as rainfall intensity data for each landslide events.

d) Earthquake data related to each landslide events.

e) Published literatures and geological, ground water and other thematic maps for reference.

f) Demographic information

3.2.4 Data Integration and Modeling

Many methods and techniques have been proposed to evaluate the landslide hazard and produce maps portraying its spatial distribution i.e. landslide hazard zonation. The proposed study aims to predict where failures are most likely to occur without any clear indication of when they are likely to take place. A "black-box" model of slope instability is built up on the assumption that the factors which caused slope-failure in a region are the same as those which will generate landslides in the future thus the general model can be explained by following equation,

$$L=B_0+B_1X_1+B_2X_2+B_3X_3+\ldots\ldots\ldots\ldots B_mX_m \ldots\ldots\ldots\ldots (1)$$

Where L is the presence or absence of landslides in each terrain unit, the X's are input predictor variables or instability factors measured or observed for each terrain-unit, and the B's are coefficients estimated from the data through techniques which are dependent on the statistical/heuristic tool selected. For this study Analytic Hierarchy Process (AHP), a decision analysis approach developed by Satty (1980) will be used in estimating 'B' values of equation 1. The AHP will be use to establish a hierarchical structure for all affecting geo-factors and to acquire the weight of each factor by pair-wise comparison. A draft matrix is given in the annexure II; however in this the assigned Intensity of Importance may change after the field survey and detailed study. Schematic representation of the model is given in the figure 8.

3.2.5 Final Output

The Landslide Hazard Zonation (LHZ) map thus generated for the hills of Guwahati city in 1:10,000 scale will be divided into five classes, namely, Very Low Hazard Zone (VLHZ), Low Hazard Zone

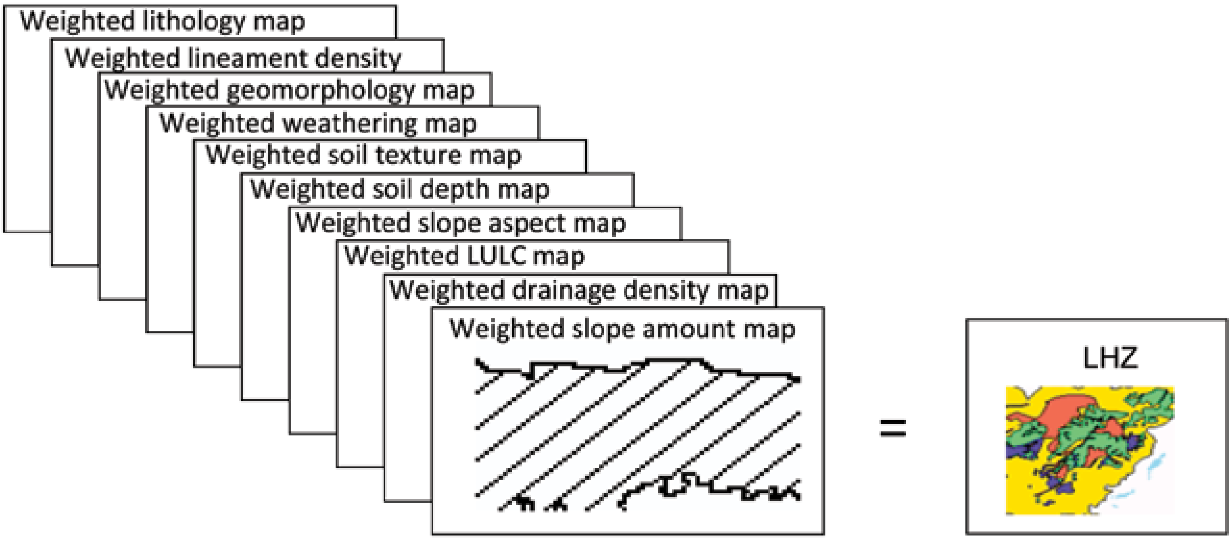


Figure 8: Schematic representation of LHZ model

(LHZ), Moderate Hazard Zone (MHZ), High Hazard Zone (HHZ) and Very High Hazard Zone (VHHZ). In the LHZ map these classes will be represented by distinct colour coding (Table 3) which will help in assessing the vulnerable wards within the hilly area.

Table 3: Colour code to be adopted for representing landslide hazards classes

Degree of Hazard	*Colour Code*
Very Low Hazard Zone	
Low Hazard Zone	
Moderate Hazard Zone	
High Hazard Zone	
Very High Hazard Zone	

3.3 Industrial Hazard Zonation

3.3.1 Introduction

Industries play a vital role in the development of a nation. However, the world has witnessed a number of serious industrial disasters since 1970s. Especially during the past two-three decades, disasters seem to be increasing over time irrespective of region or type of hazard. Industrial hazard is one of the technological hazards and defined as "accidental failures of design or management affecting large scale structures, transport systems or industrial activities which present life-threatening risk on a community scale" (Cutter 1993). It can happen at any stage in the process of production, together with extraction, processing, manufacture, transportation, storage, use, disposal etc. and posed a threat to people and property. On the other hand, all the negative effects that are caused by an industry on the human being, environment (air, land and water) and ecosystem (flora and fauna) are collectively known as industrial hazards. Types and effects of industrial hazard depend on the types of industries in an area and can be categorized as physical, chemical, biological and may be psychological. World has witnessed some of the major industrial disaster, for example, explosion of Nypro (UK) site at Flixborough on 1st June 1974 that severely damaged and killed 28 people, Bhopal Gas tragedy on 3rd December, 1984 that killed more than 2,000 people, explosion of AZF fertilizer plant, France on 21st September, 2001 that killed thirty people and injured nearly two thousand five hundred people as well as explosion of Chernobyl nuclear power plant on 26th April, 1986 may be mentioned that has created panic and concerned issue for global discussion

However, before addressing the problem, it is important to know probable most disastrous industrial hazard in an area and its Sources and Types. Mostly potentially damaging industrial hazard is considered as one of the technological hazard posed by industries as well as their interrelated activities which may be primarily from various sources such as hazardous chemical, petrochemical, chemical warehouses and storages, transportation of hazardous substances, fire, explosion, toxic release etc.

Fire is a complex chain reaction where a fuel combines with oxygen to generate heat, smoke as well as light and most of the chemical fires are triggered by one of the following ignition sources such as sparks, static electricity, heat, or flames from another fire. However, if a chemical is above its auto ignition temperature it will spontaneously catch on fire without an external ignition sources. There are two types of fire, namely, Jet Fires and Pool Fire. Jet Fires occurs when a flammable chemical is rapidly released from an opening in a container and immediately catches fire. The primary associated hazard with jet fire is thermal radiation. It is also referred as flame jet. Pool Fire occurs when flammable liquid forms a puddle on the ground and catches on fire. In this case also the primary associated hazard is thermal radiation.

Explosion is a sudden, intense release of energy that often produces a loud noise, high temperatures and flying debris and generates nearly instantaneous pressure wave travelling at the speed of sound. There are two types of fire, namely, Boiling Liquid Expanding Vapour Explosion (BLEVEs) and Vapour Cloud Explosion. BLEVEs typically occur in closed storage tanks that contain a liquefied gas. Propane is an example of a chemical that has been involved in many BLEVEs accidents. Thermal radiation hazard is primarily associated with BLEVEs. When a flammable chemical is released in to the atmosphere, it forms a vapour cloud that will disperse as it travels downwind known as Vapour Cloud Explosion. If the cloud encounters an ignition source, the parts of the cloud where the concentration is within the flammable range will burn.

3.3.2 Methodology

In true sense, a very limited number of works have been carried out to generate Industrial Hazard Zonation map. Majority of the studies carried out in this subject are to analysis Post Disaster Scenario and Environmental Impact Assessment.

3.3.2.1 Review of various Approaches

Geoinformatics plays a significant role in studying industrial hazard and understanding its impact in the surroundings. Its relevance was attempted by many for vulnerability and risk assessment. In addition high resolution remotely sensed data provides valuable clues in the identification and location of hazardous industrial installations with accurate dimension and extent.

An integrated analysis of industrial hazard, vulnerability and risk assessment for land use planning using RS and GIS for Haldia Town, WB, was carried out by Sengupta (2007). A benchmark exercise for evaluating the risk of a hazardous establishment and the area risk resulting from it using GIS was analyzed in Hungary by JRC (EC), (2007). Using GIS as a tool, studies on major accident risks connected with industrial and transportation activities in Ravenna area (Italy) has been carried out by Franco et al (2000). Givri (2000) reported the detection of a very hot spot in the Chernobyl area using TIROS-NOAA weather satellite and later confirmed with Advanced Very High Resolution Radiometer. Finco and Hepner, (1999), developed the environmental relationships between industrial sources, surface dispersion pathways of liquids and dense gases using GIS as a real-time emergency response system.

3.3.2.2 Approach to be adopted

Considering the need to have an industrial hazard zonation map of the four study areas a methodology has been formulated through integrated approach using the strength of geoinformatics. The overall methodology is shown in the figure 9. However, efforts will be given to those stationary facilities having high potential of accident that produced/manufacture or store/handle significant quantities of hazardous materials. These are oil refineries, storage terminals, LPG bottling plants, chemical plants and facilities which use large quantities of hazardous materials during the manufacture of their products. Small amounts of hazardous materials are likely to cause problems only in a localized area unless they have unusual and extremely dangerous properties.

Pipelines are another means of transportation of petroleum liquids such as crude oil, gasoline, liquefied natural gases (LNG), liquefied petroleum gases (LPG) etc. from one facility to other. However, the study/analysis of pipelines will be excluded under this project mainly because of two reasons, firstly, maximum length of these pipes are mostly laid under the ground which cannot be detected using optical remote sensing data. Secondly, some of the information required for hazard zonation is restricted due to various security measures. Again, it is also important to note that the overall hazard/threat analysis process is based on the possible accident with an estimation of worse-case scenarios within any facilities. For example, assessment will be done by assuming the storage tank is filled to its maximum capacity at a highest temperature on a particular time of day of the year. In the first moments of an accident time is critical aspect. The result of the analysis will be an additional aid in existing onsite and offsite safety management plan as well as in emergency planning and response for efficient, rapid, and comprehensive mitigation of adverse impacts.

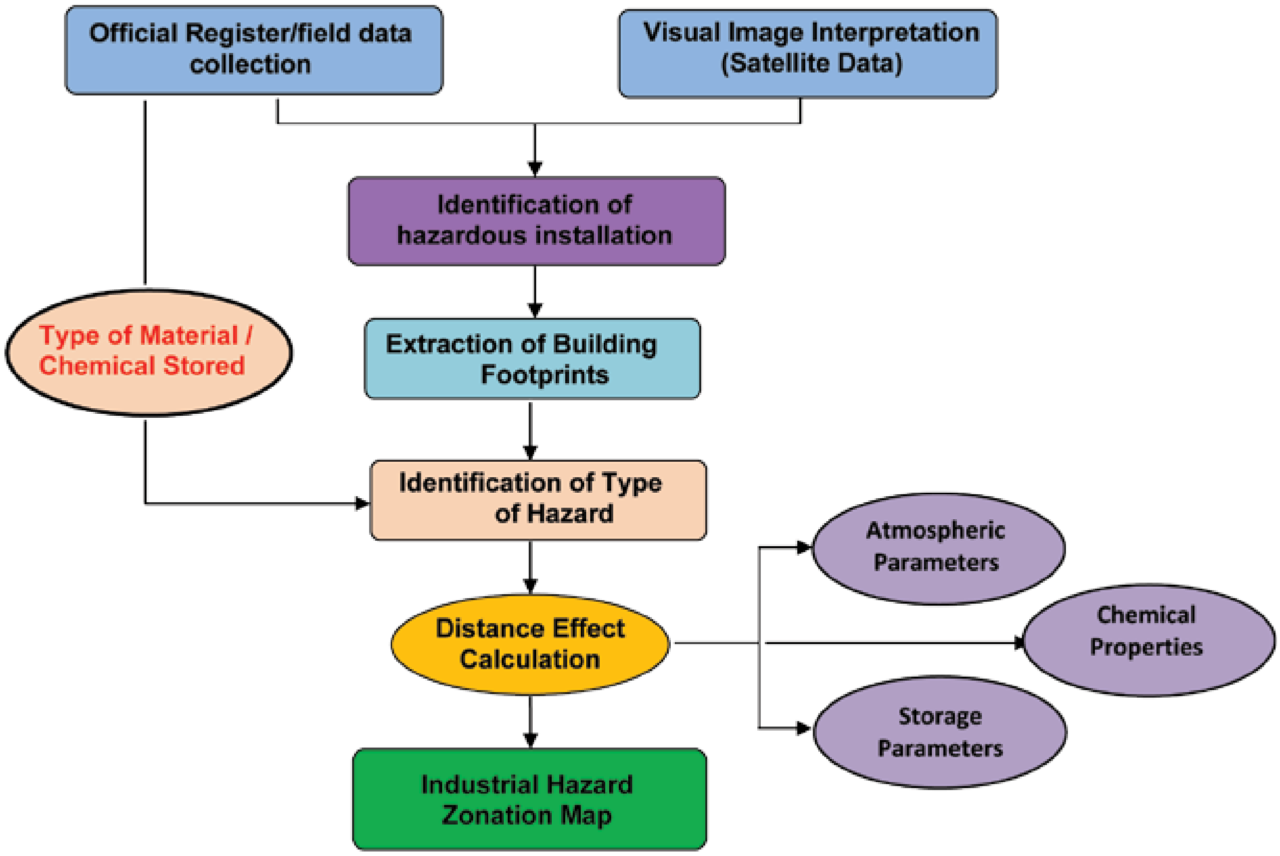


Figure.9 Methodology Flow Chart for IHZ

In this study different types of key accidental hazards that may be produced by release of Toxic chemicals, Jet fires, Pool fire, BLEVEs (Boiling Liquid Expanding Vapour Explosion) and Vapour Cloud Explosion will be analysed individually based on the various types of parameters for example, atmospheric, physical, chemical properties of the material etc.

The present study will be carried out through following steps –

a) Data collection
b) Data preparation (with pre & post field interpretation),
c) Field survey and analysis.

Data collection

This step involves the collection of data from different government and semi-government organizations, concerned departments as well as interaction with local residents. However, major part of the data collection will be from field survey. Prior to the actual data collection different formats are designed for collection of different parameters as given in Annexure II.

Data preparation

Under this pre-field interpretation stage, building foot prints of different hazardous installations will be extracted from remotely sensed data. Mapping of industrial installations will be carried out in consultation with the official records collected from Dept of Industries and Commerce. Some of the industrial installations in and around Guwahati city is identified (figure 10) due to their regular geometry and planned construction justify the use of remotely sensed data for this study. This step will also involve mapping of land use land cover with special emphasis of settlement areas in and around the industrial areas.

Field survey

Field survey will be conducted to verify the pre-field maps and also to collect details about the mapped industries.

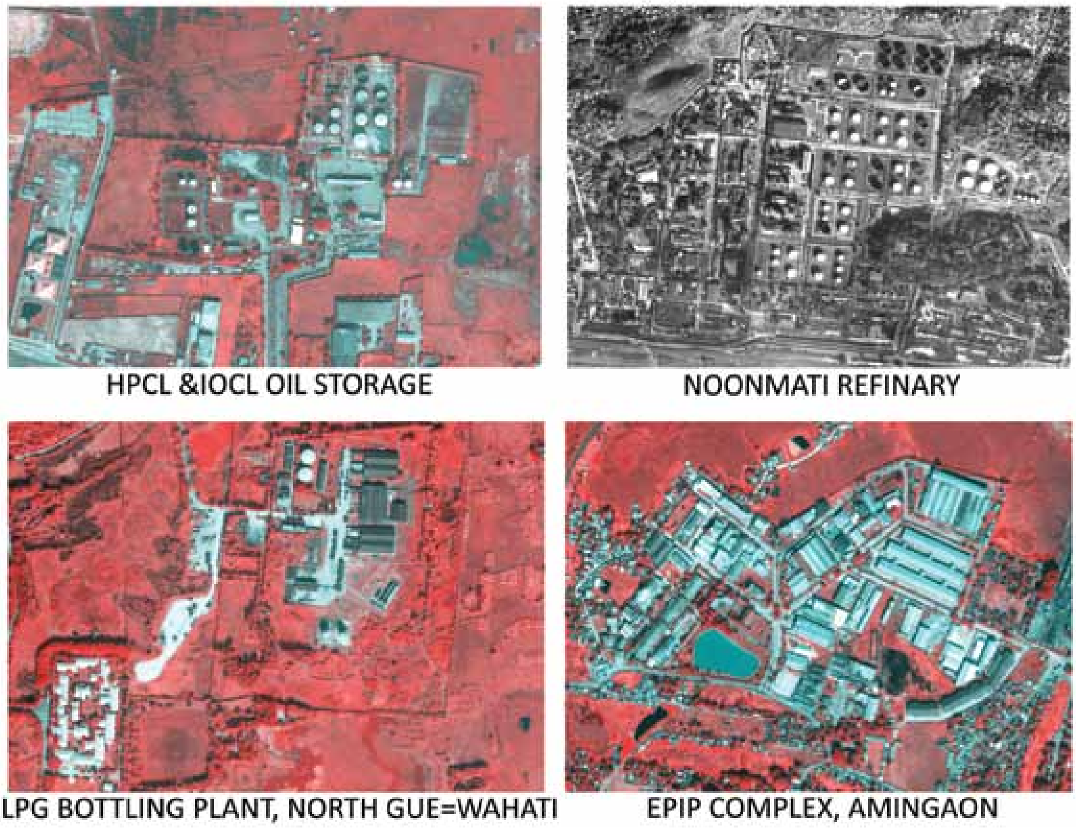


Figure 10. Images of some industrial set up of Guwahati City

3.3.3 Data requirement

To fulfill the objectives of industrial hazard zonation mapping a number of collateral data (Annexure II) need to be collected from various sources as described below in addition to satellite data mentioned in the chapter 1.

a) Type of Hazardous Installations
b) History of past Hazardous incidents
c) Last 10 years daily wind data of industrial area

In addition to these environmental parameters will also be measured using various instruments existing with NESAC, Umiam. These data will help in assessing the flow direction of gaseous substances in case of accidental release.

3.3.4 Data Integration and Modeling

Preparation of industrial hazard zonation map is largely depends on availability of collateral data to be collected from concerned departments/organizations. In the process various parameters of a particular chemical such as molecular weight, ambient boiling point, temperature etc. will be integrated. In addition, other parameters viz. atmospheric data (wind speed and direction, air temperature, relative humidity, cloud cover), storage data (type of storage-horizontal-vertical cylinder or sphere, length & diameter, volume and chemical mass in the storage/tank) will also be incorporated at the time of integration in the GIS environment. Integration of above mentioned parameters is solely dependent on information regarding type and amount of chemical stored in a particular installation. Thus, according to the data availability regarding the type of industry and chemicals, amount of storage, etc for various installations in the four study areas, data base will be integrated using combination of two or more software mentioned below

i. ARCHIE 1.0 (Automated Resources for Chemical Hazard Incident Evaluation)developed by Federal Emergency Management Agency, U.S Department of Transportation and U.S Environmental Protection Agency, Washington

ii. ALOHA 5.4.1.2 (Areal Locations of Hazardous Atmosphere) developed by U.S Environmental Protection Agency and National Oceanic and Atmospheric Administration, Washington

iii. ARIPAR 4.0 A GIS Based Software Tool for Risk Assessment and Management in Industrial Areas, developed by Institute for the Protection and Security of Citizen, Italy.

3.3.5 Final Output

The final threat or hazard zonation map created by different types of chemical/material will be prepared according to the Level of Concerned (LOC) e.g. in case of toxic release, an LOC is a threshold concentration of the gas i.e. the concentration above which hazard is believed to exist and each zone will be shown in different colours such as red, orange and yellow. The red zone will represents the worst hazard and the orange and yellow zones represent areas of decreasing hazards (Table 4). However, no LOC represents an exact line between hazardous and non-hazardous conditions, because people differ in their sensitivity to chemicals (for example, old, sick, or very young people may be more sensitive to chemicals than healthy adults) and other hazards. The overall threat zone will be bounded by a confidence line.

The hazard zonation map thus prepared will be used in the assessment of vulnerability and risk of the cities and towns. The information provided in the industrial hazard zonation map(s) form a suitable database for the assessment of vulnerability and risk and moreover at the same time planning for emergency response if any incidents occur. In addition, such type of information will enable to take up a precise decision for future planning and development of the study areas.

Table 4: Colour code to be adopted for representing industrial hazards classes

Degree of Hazard	***Colour Code***
Low hazard	
Moderate hazard	
High hazard	
Confidence line	

3.4 Seismic Hazard Zonation

3.4.1 Introduction

The hazards associated with earthquakes are referred to as seismic hazards and the practice of earthquake engineering involves identification and mitigation of seismic hazards. Microzonation has generally been recognized as the most accepted and useful tool in seismic hazard assessment and risk evaluation. The microzonation defines ground motion characteristics taking into account source and site conditions [TC4-ISSMGE, 1999]. Over the years, most of the urban cities in India have undergone a phenomenal growth for various socioeconomic reasons. Thus, the vulnerability of our cities, being exposed to different types of natural and manmade hazards, have increased considerably necessitating a proper hazard evaluation, particularly for the high population-density urban centers lying in higher seismic zones. Earthquake hazard zonation for urban areas, mostly referred to as seismic microzonation, is the first and most important step towards a seismic risk analysis and mitigation strategy in densely populated regions (Slob et al., 2002). Earthquake disasters are inevitable but it is possible to minimize the aftermath of an earthquake if the zones that are more susceptible to undergo maximum ground motion are identified. Seismic microzonation seems to be an answer to the need for mitigation against the seismic hazards as it gives a realistic map in terms of ground motion at a higher resolution.

Seismic microzonation is the generic name for subdividing a region into individual areas having different potentials of hazardous earthquake effects, defining their specific seismic behavior for engineering design and land-use planning. The role of geological, geophysical and geotechnical data is becoming very important in microzonation, particular for planning of city urban infrastructure, which can recognize, control and prevent seismic hazards (Bell et al., 1987; Legget, 1987; Hake, 1987; Rau, 1994; Dai et al., 1994, 2001; Van Rooy and Stiff, 2001). The basis of microzonation is to model the rupture mechanism at the source of an earthquake, evaluate the propagation of waves through the Earth to the top of bed rock, determine the effect of local soil profile and thus develop a seismic hazard map indicating vulnerability of an area. Seismic microzonation also helps in designing buried lifelines such as tunnels, water and sewage lines, gas and oil lines, and power and communication lines. (Sitharam and Anbazhagan, 2008).

Damage pattern due to an earthquake depends largely on the local site condition and the social infrastructures of the region with the most important condition being the intensity of ground shaking at the time of earthquakes. Contrasting seismic response is observed even within a short distance over small changes in geology, soil condition of the site. Preparation of seismic microzonation maps of major urban centers has been recognized as a priority area of seismic hazard mitigation programme in India. Some 27 cities in India have a population of one million or more. These 27 cities contain about 25.6% of the total urban population of the country. This is compounded by the fact that while geographically, 57.1% of the country area is under seismic zones III, IV and V of BIS (2002), 66% of the population and 63% of the housing are located within these zones (Seismic Microzonation Manual, 2011). Cities in India, which fall in seismic zones III, IV and V and having a population exceeding half a million, are recommended to have seismic microzonation maps in 1:10,000 to 1:5,000 scales. Making improvements on the conventional macrozonation and regional hazard maps, microzonation of a region generates a detailed map that predicts the hazard at much smaller scales (Sitharam and Anbazhagan, 2008). Consequently, a scientifically assessed hazard and risk map is an essential guide for urban agglomerations, particularly those, where numerous elements are at risk. Seismic microzonation, thus, is a principal component of pre-disaster mitigation efforts

3.4.2 Methodology

Earthquake damage, basically depend on three factors: earthquake source and path characteristics, local geological and geotechnical site conditions, structural design and construction features. Seismic microzonation should address the assessment of the first two groups of factors. In general terms, seismic microzonation is the process of estimating the response of upper most soil layers for earthquake excitations, and thus the variation of site characteristics is represented on the ground surface. Seismic microzonation requires multidisciplinary approach with major contributions from geology, geophysics, seismology and geotechnical engineering (Sitharam and Anbazhagan, 2008). In seismic microzonation, it is required to quantify the spatial variation of the subsurface response on a typical earthquake that can be expected in the area. In order to quantify the expected ground motion, it is thus necessary to determine the manner in which the seismic signal is propagating through the subsurface. Propagation is particularly affected by the local geology and the geotechnical ground conditions at a site. Large amplification of seismic signal generally occurs in areas where layers of low seismic velocity overlie material with high seismic velocity, i.e. where soft sediments cover bedrock or more stiff soils (Slob et al., 2002).

In recent times, several seismic microzonation projects have been reported across the globe. These studies mainly include assessment of predominant frequency for site amplification, effective shear wave velocity for the uppermost 30m thick sediment (Vs 30) and deterministic seismic scenarios while site specific probabilistic hazard analysis is slowly emerging for engineering decisions (Seismic Microzonation Manual, 2011). In India, seismic microzonation work with a foreign collaboration was initiated in Jabalpur city in the year 1998 (Mishra, 2004) and subsequently for a few important cities vulnerable to earthquake hazards. These cities are Delhi (Rao and Mohanty, 2001; Parvez et al., 2002; Singh et al., 2002; Mukhopadhyay and Bormann, 2004; Mohanty et al., 2007), Sikkim (Nath, 2005; Pal et al., 2008), Guwahati (Nath et al., 2008a), Bangalore (Sitharam et al., 2006; Sitharam and Anbazhagan, 2007; Anbazhagan et al., 2010), Dehradun (Mahajan et al., 2007), and Mumbai (Raghukanth and Iyengar, 2006).

3.4.2.1 Conventional Approach

An extensive review of methodologies adopted worldwide and India with their limitations are discussed in details in the Seismic Microzonation Manual and Hand Book (2011), issued by Geosciences division, Ministry of Earth Sciences (MoEs) and also by Sitharam and Anbazhagan (2008). An expert committee identified by the MoEs formulated the guidelines for Seismic microzonation. According to that, a framework that addresses the pertinent technical issues highlighted through the state-of-the-art practices and methodologies are:

Source Characterization

Seismic sources are generally characterized by well defined physical parameters like corner frequency (fc), seismic moment (M0), and stress drop (Δσ) derived directly from waveform data (Nath et al., 2008b). Development of homogenous moment magnitude based earthquake catalogues spanning several hundred years (historical and instrumental periods) is an essential work component to quantify seismicity distribution, the magnitude frequency relation (b-value) and the expected maximum magnitude in a study area.

Characterization of Wave Path Model

The attenuation of seismic waves along the propagation path connecting the earthquake source and the recording site is attributed to the combined effect of i) intrinsic attenuation and ii) scattering and deflection. This attenuation characteristic is known as Quality (Q) factor. It depends on the tectonic setup and regional geology. The Q is also frequency dependednt.

Site Characterization

Site response estimation characterizes the expected ground motion (amplification) at the site of interest. Techniques used widely to quantify site response either from the earthquake data (Field and Jacob, 1993) or from ambient ground noise data (Nakamura…..). Basically it estimates the horizontal to vertical spectral ration (H/V ratio) and the predominant frequency range at which the amplification (H/V ratio) is high.

Typical site characterization of a terrain includes the following:

1. Geo-hazard attributes
   - Geomorphological (including relief) features
   - Landuse patterns
   - Near-surface lithological structure
   - Tectonic and structural organization.

2. Geotechnical parameters
   - Geo-hydrological properties
   - Standard Penetration Test (SPT) N values
   - Factor of Safety against soil liquefaction
   - Density

3. Geophysical parameters
   - Basement topography (resistivity and shallow seismic data)
   - Shear Wave Velocity (V_s^{10}, V_s^{30}, V_s^{50} and V_s^{Avg})

The V_s^{10}, V_s^{30}, V_s^{50} and V_s^{Avg} distributions correspond to average shear wave velocity from the ground surface to depths of 10 m, 30 m, 50 m and the basement.

4. Site Response (Seismological data)
   - Response spectra
   - Interpreted thematic distribution of:
     - Predominant Frequency (f_0)
     - Peak Amplification (A_0) at the predominant frequency.

There are however, some fundamental disagreements amongst researchers on the details of the procedures for assessing earthquake site response of several thousand meter deep alluvial deposits (Pyke, 1979).

Ground Motion Simulation and Hazard Prediction

Quantitative assessment of seismic hazard necessitates measurement of peak ground motion parameter, such as the peak ground acceleration (PGA) from earthquake records. Paucity of strong ground motion data records under conditions similar to design earthquakes in terms of tectonic regime, earthquake size, local geology, and near fault conditions necessitates analytical or numerical approaches for a realistic prognosis of the possible seismic effects. The strong ground motion study would involve development of database comprising realistic synthetic strong ground motion data, site specific ground motion prediction equations and interpreted thematic distributions of:

- Peak Ground Acceleration (PGA) and
- Period-specific Spectral Acceleration (SA) according to targeted building typology.

3.4.2.2 Levels of Microzonation

There are various ways to look at the stages of seismic microzoning. The broad approach involve three levels of Seismic microzonation expressed as Grade l: General Zonation, Grade 2: Detailed Zonation and Grade 3: Rigorous Zonation as favored by the Technical Committee on Earthquake Geotechnical Engineering of the International Society of Soil Mechanics and Foundation Engineering.

A microzonation study is designed to map different components of local seismic hazard of a study area at a scale, generally between 1:5,000 and 1:25,000 (Bard et al., 1995).

The study includes:

1) mapping of active tectonic structures/faults
2) modification of the seismic signal due to local geomorphological conditions
3) evaluation of induced phenomena such as liquefaction, settlements, landslides etc.

The methods used to achieve these vary in complexity according to the degree of precision sought. Three levels of precision are generally adopted. These are A, B & C, which signify a range from the most rudimentary to the most refined level of precision.

Level A

The most rudimentary level of study is generally based on a compilation and interpretation of available data. It is the least expensive study and the scale of microzonation ranges from 1:100,000 to 1:50,000.

Level B

This intermediate level of study provides much more reliable results than those for Level A. Specific surveys are generally carried out during this study level, including drilling, trenching, geological sampling etc. The cost of this study remains reasonable, and the scale of microzonation generally ranges from 1:25,000 to 1:10,000.

Level C

This study is only carried out in areas where a very detailed level of mapping is required. Specific surveys and detailed calculations are involved. The cost of this study is high, but may be necessary in areas of high earthquake hazard risk. This scale of microzonation ranges from 1:10,000 to 1:5,000.

3.4.2.3 Seismic microzonation issues related to India

Sitharam and Anbazhagan (2008) have broadly classified various issues related to seismic microzonation into three major groups, these are seismology related, grade and geology related and geotechnical related issues. Considering the relevance, the details cited by them are given below.

Preparation of detailed seismo-tectonic map

Before starting the microzonation work a detailed seismotectonic map for the study area needs to be prepared by considering up to date seismicity, geological and seismotectonic details for a circular area of radius 300km (approximately 200miles) around the study area as per Regulatory Guide 1.165(1997).

Seismic hazard estimation

So far most of seismic microzonation maps published in India is based on the deterministic seismic hazard analysis by considering scenario earthquake. However, seismic microzonation hazard maps need to consider uncertainties involved in the earthquake, and produce the hazard map with required probability and return periods. Hence, special attention may be given to the probabilistic seismic hazard estimation, where the uncertainty is quantified and hazards are represented with required probability exceeded in particular years.

Grade and Geology

The grade/level of the seismic microzonation maps is desired based on scale of the study and method of estimating hazard parameters as suggested by the TC4 committee of ISSMGE (1993). Geology is considered for initial stage of the seismic microzonation mapping. Most of the seismic microzonation maps produced in India, has given more importance to the geology. But recently, it is proved that considering the geological units as the only criteria in seismic microzonation is not appropriate (Ansal et al., 2004). It is suggested that geology map may be regarded as the basic information to plan detailed site investigations and to control the reliability of the results obtained by site characterizations and site response analyses.

Geotechnical Issues

Like hazard estimations, another key issue in the seismic microzonation is the estimation of effects of earthquake. Basically earthquake effect can be grouped as two major groups, site effects and induced effects. These effects are based on geotechnical properties and behavior of the subsurface materials during the earthquake. Hence, more importance needs to be given to the geotechnical properties rather than geology. Review of case studies shows that geotechnical properties are not critically handled for assessing the site and induced effects. Site effects are combination of soil and topographical effects, which can modify the characteristics (amplitude, frequency content and duration) of the incoming wave field. Most of the microzonation studies evaluate average shear wave velocity (Vs30) irrespective of locations. However, revision of this practice is also suggested by many as Vs30 is not a standard parameter to reflect the site effects.

3.4.2.4 Recent microzonation Framework

The guideline for Seismic Microzonation Framework as formulated by the Ministry of Earth Sciences is given in figure 11. The scheme outlines compilation of information related to seismicity, identification of potential seismic source zones, development of seismicity models, and maximum earthquake prognosis at the regional level supported by earthquake catalogues and other relevant data such as active fault database. The local level assessments involve mapping of surficial geological and geomorphological features supported by 2D/3D subsurface models, development of geotechnical database, and evaluation of different surficial soil attributes (e.g., density, rigidity, compressibility, damping factor, water content, etc.), and the basement topography. The prevalent seismic characteristics, in terms of predominant frequency, site response, path and source attributes, are generally established through an analytical and numerical treatment of the waveform, microtremor and geotechnical data, and thereupon, a deterministic assessment is performed by means of strong ground motion simulations. Additional evaluations include those related to relevant earthquake induced effects such as soil liquefaction and landslides. Eventually, a composite assessment is taken up of the geological, geotechnical, and seismological attributes to deliver the seismic microzonation map in terms of a hazard index map.

3.4.3 Approach to be adopted

The state of Assam lies in zone V of seismic zone map of India (BIS, 2002) and has experienced very high intensity for the past seismic events of 1869 (M 7.6),Cachar Earth Quake; 1897(Ms 8.7) Shillong

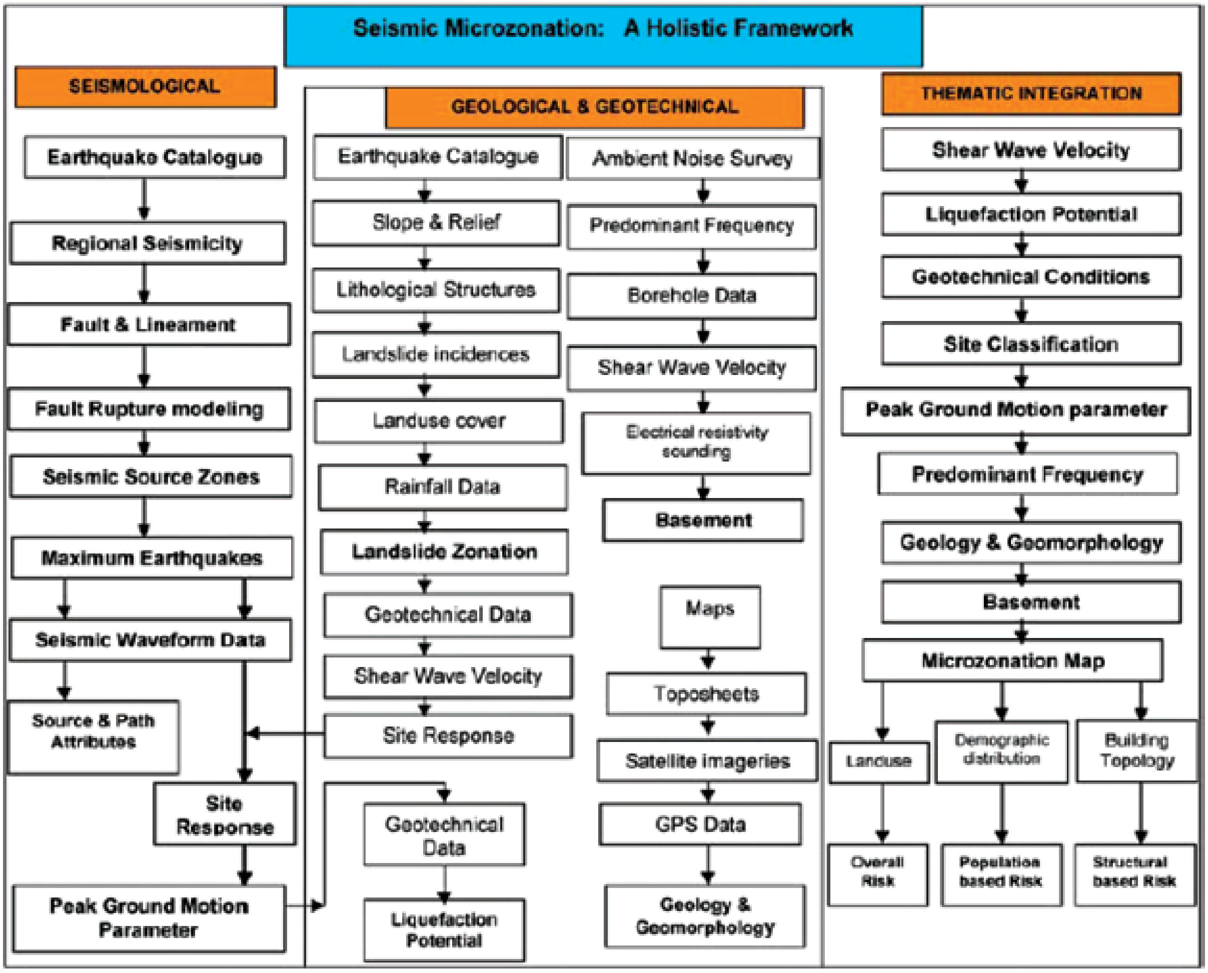


Figure.11 Methodology Flow Chart for SHZ, (Seismic Microzonation Manual, 2011).

Earth Quake; 1950 (Ms 8.7), Assam Earth Quake. Hence preparation of seismic microzonation map needs careful evaluation anticipating such devastating earthquake in future. Fundamentally, an approach depends on the data availability, the study region/ terrain under consideration.

Considering the scope, objective, scale of HRVA project and also fund related constrain it is decided to address Level B of microzonation map following the published guidelines by Ministry of Earth Sciences (2011). Emphasis will be given in assembling the existing databases available with various organizations, namely Geological Survey of India, State Geology and Mining Directorate, previous case studies by MoES etc. Since site effects and induced effects of an earthquake depend enormously on geotechnical properties and behavior of subsurface materials during the earthquake, importance will be given to the properties of soil.

3.4.4 Data requirement

To fulfill the objectives a large number of collateral data (spatial and non spatial) need to be collected from both primary and secondary sources as described below in addition to satellite data mentioned in the chapter 1.Since the mapping scale of Guwahati City, Dibrugarh and Silchar Towns is 1: 10,000 and for Dhemaji district is 1:25,000, it is desired that all the required data/ maps will be of appropriate scale for 300km radius area around the four study areas. These are,

a) SOI Topographical Map for base line information like name of the locality etc.
b) Detailed Information about past Earthquakes for preparation of Seismotectonic map.
c) Regional Seismicity Map
d) b-value map
e) Detailed Fault/ Lineament maps of the study areas.
f) Far and Near Field Seismic source Zones
g) PGA contour/ maps
h) Shear velocity (Vs10, Vs30) maps
i) Predominant frequency map
j) Site Amplification map
k) Bore Hole /SPT survey data/Maps
l) Relevant Geotechnical data for Site characterization
m) Relevant Geotechnical data for Source characterization
n) Geotechnical data related to Liquefaction Potential of the study areas
o) Subsurface Geophysical data
p) Subsurface Soil Information from borehole lithology
q) Water table map
r) Published literatures, and geological, ground water and other thematic maps for reference.
s) Demographic information

3.4.5 Data Integration and Modeling

Various thematic layers viz., Peak Ground Acceleration (PGA) contour, Seismo-tectonic map, surface and subsurface geology, different soil types/depth, groundwater level and bedrock depth etc will be integrated in GIS environment. The integration will be performed following a pair-wise comparison of Analytical Hierarchy Process (AHP) wherein each thematic map will be assigned with a weight in the scale of 1: 9 depending on its contribution towards the seismic hazard. The details of AHP, developed by Satty (1980) are described in previous chapters. Nakamura H/V spectral ratio technique, empirical relations to be used for computing the site response factor near surface shear wave velocity Vs10, Vs30 etc.

3.4.6 Final Output

The Seismic Hazard Zonation (SHZ) map thus generated will be divided into five classes, namely, Very Low Hazard Zone (VLHZ), Low Hazard Zone (LHZ), Moderate Hazard Zone (MHZ), High Hazard Zone (HHZ) and Very High Hazard Zone (VHHZ). In the SHZ map these classes will be represented by distinct colour coding (Table 5) which will help in assessing the vulnerable sites/wards within the study areas.

Table 5: Colour code to be adopted for representing Seismic hazards classes

Degree of Hazard	***Colour Code***
Very Low Hazard Zone	
Low Hazard Zone	
Moderate Hazard Zone	
High Hazard Zone	
Very High Hazard Zone	

4. VULNERABILITY AND RISK ANALYSIS

4.1 Introduction

Vulnerability is defined as the degree of damage of elements at risk (Building, economic and society) for a specific endangering phenomenon (natural or man-made hazard) with certain intensity. Thus, vulnerability is the function of hazard intensity or type and the characteristics of the elements, which are at risk (Westen, 2004). The method to be used for vulnerability assessment in this study will be qualitative in nature. The method will refer the expression of degree of vulnerability in terms of very high, high, moderate or low. The vulnerability assessment for buildings and population will be limited to evaluating the social group and building vulnerability only as per mapping unit (not individual building). Vulnerability will be calculated as separate aspect for the entire study area, depending on the type of hazard and element at risks.

Risk is defined as the probability of harmful consequences, or expected loss (of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human induced hazards and vulnerable/capable conditions. Risk assessment is the method of generating risk maps in which the different levels of relative risk are represented for analysis and evaluation. Risk assessment will carried out in a qualitatively manner by considering the hazard zones as deduced from hazard zonation map, elements at risk falling in the specific hazard zone and evaluation of vulnerability of people building and lifelines. Risk assessment will be be carried out using the following basic equation:

$$\text{Risk} = \text{Hazard} * \text{Vulnerability} * \text{Amount of elements at risk}$$

In this study, information on the elements at risk (Table 6) will be generated.

4.2 Inputs Datasets

Population vulnerability analysis for each study area will be carried out by integrating population distribution based on daily activities pattern, work profile, temporal distribution and composition. Administrative and Town Boundary data will be used to assess the vulnerability of a suitable administrative unit. High resolution data in association with ward/village maps and other collateral information will be used to identify the location of buildings to assess the overall vulnerable zones for each hazard landslide, flood, industrial and earthquake. The emphasis will be on those areas spread on high, medium and low hazard zones of a particular hazard with intensive stratified random sample collection and the rest of the area intensity will be through random sampling.

Table 6: Elements at Risk

<table>
<tr><td rowspan="2">Building
• Residential
• Institutions
• Educational
• Cultural /Recreation/Religious
• Commercial
• Industrial
• Transportation
• Miscellaneous</td><td>Economic
• Commercial & Administrative Activities areas
• Access to these areas</td></tr>
<tr><td>Societal
• Vulnerable age categories
• Gender</td></tr>
</table>

Following are the input data required for vulnerability and risk assessment:

i) Census population data: This data will be collected from Census of India 2001-2011. Composition of population and age-wise population will be extracted for analysis Ward wise population data, in case of cities/or towns, and village wise in case of district

ii) Population distribution and Daily activity patterns: it is proposed to conduct household surveys for collecting data on population composition, main activities and occupation. Stratified Random samplings technique will be applied for conducting the survey. A questionnaire for these surveys designed for this proposed is enclosed (Annexure III)

iii) Population/Household Density:-Population density for each ward, (in case of city/town) each village (in case of a district) will be calculated based on number per unit area. Household density will also be calculated for the same

iv) Building Inventory: Building information will be obtained from existing databases, and census data. Generation of building footprints using high-resolution data sets and non spatial information will be added from ground surveys (Annexure IV).

4.3 Methodology

The methodology adopted for multi-hazards vulnerability and risk assessment is presented in the form of a flow chart (Figure.12) and given below:

4.3.1 Vulnerability Assessment

Information about distribution of population and building characteristics in relation to the existing hazards is an important element in vulnerability analysis. Vulnerability of population and buildings of a particular place varies with types of hazards and also changes in different time periods. Under this project, vulnerability will be analysed for different hazards as follows:

4.3.1.1 Socio-economic Vulnerability Assessment

Socio-economic vulnerability assessment is required for preparedness, response, recovery, and mitigation in reducing vulnerability or improving local resilience to hazards (Cutter and Emrich, 2006:102). Social vulnerability is partially the product of social inequalities (Cutter and Emrich, 2006:103), which includes locational inequalities, characteristics of communities and the built environment. All these contribute to the social vulnerability of places. The Socio-economic Vulnerability Indicator to be used in this study will include the following:

- Composition of Population and Age wise population
- Population Distribution- Vulnerable groups
- Population Density- household & persons
- Daily Activities pattern

In the present study, Analytic Hierarchy Process (AHP) will be used to calculate the relative importance, or weights of the factors and indicators chosen. Using AHP, the weights, or relative importance of factors and indicators contributing to social vulnerability will be calculated. AHP is a widely used multi-criteria evaluation (Saaty, 1980) method. The basic rationale of AHP is organized by the breaking down the problem into smaller constituent parts at different levels. The method is usually offered with the pair-wise comparison technique that simplifies preference ratings among decision criteria. A hierarchical classification under the four broad categories will include composition of population, population distribution population density and daily activities

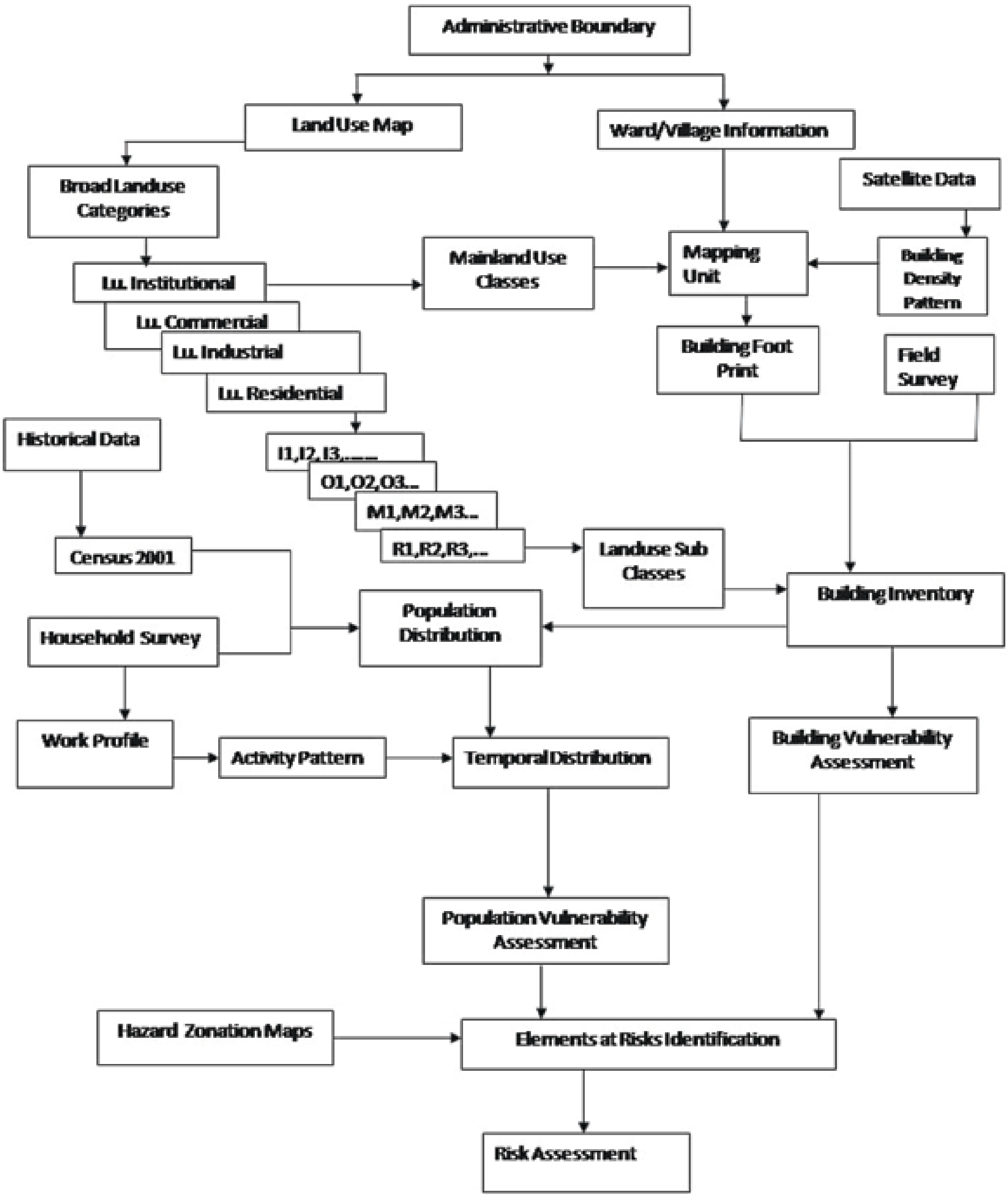


Figure 12: Methodology for Multi-Hazards Vulnerability and Risk Assessment

pattern. Those over 60 and those under 14 years old will be considered more vulnerable. Females will be considered more vulnerable than males. Dense to highly dense populated areas will be more vulnerable than lesser dense areas. Densely populated housing units are considered to be more vulnerable. In average house occupancy, larger households were considered more vulnerable than smaller households. In this study each indicator will be measured on a 0 to 9 ordinal scale based on their frequency and contribution to social vulnerability. For example, precarious housing condition will be measured in the following manner:

- 0-20 percent in a ward/village: 1
- 20-30 percent in a ward/village: 3
- 30-40 percent in a ward/village: 5
- 40-50 percent in a ward/village: 7
- Above 50 percent in a ward/village: 9

For those wards/villages having vulnerable groups the following criteria were used:

- Within 0-200 female/children/elderly population: 1
- Within 200-400 female/children/elderly population: 3
- Within400-600 female/children/elderly population: 5
- Within600-800 female/children/elderly population: 7
- For more than 800 female/children/elderly population: 9

The Social Vulnerability Index (SVI) for each wad/village will be calculated by multiplying the weight of each indicator in its obtained grade from the 0-9 ordinal scale assessment:

$$SVI = \sum_{i=1}^{n} \sum_{j=1}^{m} w_i g_j$$

Wherein Wi is the weight of the iit indicator and the gj is the jth grade obtained by that indicator from the 0-9 ordinal scale assessment.

4.3.1.2 Building Vulnerability Assessment

The assessment of building vulnerability has a great importance to many type hazards. This assessment can use as a base for population vulnerability assessment and secondly the elements at risk can be ascertain. The analysis will be carried out by using two methods. The first method uses the mapping units, which are consisting of groups of buildings (or in certain cases single building), bounded by streets, or a particular types of land use (e.g. water body, agricultural land, etc). The second method divides each study area in to grids with size of 1Km2*1Km2. Suitable method will be selected based on the types of hazard and scale of mapping.

In the building vulnerability assessment, the important attribute that will define building vulnerability to different hazards are shown in Table 6. Building Weightages and Ranking will be assigned based on the type of hazard as well as buildings characteristics.

Table 7: Building characteristics for determining building vulnerability for different hazards.

Building Attributes	Flood Hazard	Landslide Hazard	Industrial Hazard
Structure	+	++	+
Height/No. Of floors	++	++	++
Wall material	++	++	++
Roof material	-	-	++
Age and Quality	+	+	+
Distance from object	+	++	++
Openings	++	++	++
Protecting Walls	++	++	=
Water Tank	++	++	-

(++ = Very important, + = important, - = Not important)

The classification of buildings into different uses will be considered. This will help in knowing which time of the day is the different types of uses are more vulnerable. The uses of buildings are categorized into six classes namely:

i. Residential: Buildings ranging from high, medium, and low density with multiple unit to single unit, high rise structures or row/group houses in cities/towns.

ii. Commercial: Buildings located in areas which are predominantly for the sale of products and services along the main/street. Commercial category includes Central Business District (CBD); retail and whole sale business and hospitality outlets, warehouse market yards and others.

iii. Public and Semi-Public: These are the area used for place of work, education, religious activities, health, cantonment, social, cultural centres, law and order, essential service centres and commercial establishment

iv. Industrial: Industrial classes includes from light manufacturing to heavy/extensive or hazardous manufacturing plants

v. Mixed built up: The mixed built up class is used for those built up areas where the individual use cannot be separated due to multiple functions, where more than one-third (30%) intermixture of the use or uses occurs in a specific area, it can be classifies as mixed built up.

vi. Vacant land: Vacant lands are those where the areas are left unutilised or kept for future development

vii. Open space: Areas will include parks, green spaces, and other open areas for e.g., playing fields, natural landscapes

4.3.1.3 Landslide Vulnerability Assessment

Vulnerability of buildings will be different from one hazard to another hazard. Location of building with respect of the landslide, density of buildings (centre of settlement, apartment building or commercial building) and transportation sector will be considered as important factors for vulnerability assessment. The vulnerability of population inside buildings, i.e., people being hit by a landslide, largely depends on the temporal spatial probability of the people inside the building at the time of occurrence of the landslide. The temporal and spatial distribution of population and buildings will be considered in the landslide vulnerability assessment.

4.3.1.4 Flood Vulnerability Assessment

In flood vulnerability assessment three components will be taken into consideration, as shown in table 8. The scoring of the different components is shown in Table 9.

Table8: Components in Flood Vulnerability Assessment

Social Components	**Economic Components**	**Infrastructure Components**
Population Density	Land Use	Number of Housing Units
Population in flood Areas	Proximity to river	Type of Housing units
Closeness to inundation area	Closeness to inundation area	
Population Close to flooding area	% of urbanised area	
% of younger and older		
% of urbanised area		

Table 9: Flooding transect- showing the scoring of the components

Vulnerability					
Score	Land use	Score	Proximity to River (m)	Score	Population Composition
1	Dense Built-up	5	0-49	1	0-14
2	Sparse Built-up	4	50-99	2	60 above
3	Agriculture	3	100-149	3	Female
4	Forest	2	150-199	4	15-60
5	Open Space	1	200+		

4.3.1.5 Industrial Vulnerability Assessment

In industrial vulnerability assessment the following components will be taken into consideration:

i) Building characteristics- In this building type, roof material, building material and number of stories will be considered.

ii) Population characteristics: Number of person/building, classes of building (residential, commercial, public & semi-public and mixed built up), temporal distribution of population and population composition will be considered.

4.3.1.6 Seismic Vulnerability Assessment

For seismic vulnerability assessment, simpler procedure that will help in rapid evaluation of the vulnerability profile of different types of buildings will be adopted. In this procedure vulnerability assessment will be based on 'walking around' the building by a trained evaluator. The evaluation procedure and system will be made compatible with GIS-based city database and also will permit the use of collected building information. Rapid Visual Screening (RVS) method is designed to be implemented without performing any structural calculations and utilizes a scoring system that requires the evaluator to identify the primary structural lateral load-resisting system together with the building attributes. The inspection, data collection and decision-making process typically take place at the building site, and it is expected to take around 30 min for each building. This method will be adopted in the Seismic vulnerability assessment of buildings in all the four study areas. For the actual data collection using the RVS methodology, a modified version of the FEMA-154/ATC-21 based data collection sheet will be used (Annexure V).

Taking note of the temporal variation in occupancy, provision was made to account for peak and lean occupancy of the buildings. In order to take the relief of the area into account broad estimation of the slope into three categories (< 15°, 15°–30° and > 30°) will be included. Parameters like building identification number, ward number, owner's name, roof type, accessibility and comment section will be added for a broader information spectrum and to make the analysis easier. A methodology of correlating RVS scores of the surveyed structures in different seismic zones with probable seismic losses utilizing the damage grades provided by European Macro-seismic Scale13 (EMS-98) was developed by Sinha and Goyal (2004). Seismic vulnerability classification for different structural types is shown in Table 10.

Table 10: Seismic vulnerability classification for different structural types

<table>
<tr><th>Mate-rial</th><th>Type of Load-Bearing Structure</th><th>SubTypes</th><th colspan="6">Vulnerability Class</th></tr>
<tr><th></th><th></th><th></th><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td></td><td>Stone Masonry Walls</td><td>Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)</td><td>O</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Massive stone masonry (in lime/cement cortar)</td><td>|-</td><td>-</td><td>-</td><td>O</td><td>-|</td><td></td></tr>
<tr><td></td><td>Earthen/Mud/Adobe/Rammed Earthen Walls</td><td>Mud Walls</td><td>O</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Mud Walls with horizontal wood elements</td><td>|-</td><td>O</td><td>-|</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Adobe block walls</td><td>O</td><td>-|</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Rammed earth/Pise construction</td><td>O</td><td>-|</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Burnt clay brick/block masonry walls</td><td>Unreinforced brick masonry in mud mortar</td><td>|-</td><td>O</td><td>-|</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Unreinforced brick masonry in mud mortar with vertical posts</td><td>|-</td><td>O</td><td>-</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Unreinforced brick masonry in lime mortar</td><td>|-</td><td>O</td><td>-</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td>MasonRy</td><td></td><td>Unreinforced brick masonry in cement mortar with lintel bands (various floor/roof systems)</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Confined brick/block masonry with concrete posts/tie columns and beams</td><td></td><td></td><td>|-</td><td>O</td><td>-|</td><td></td></tr>
<tr><td></td><td>Concrete block masonry</td><td>Unreinforced, in lime/cement mortar (various floor/roof systems)</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Reinforced, in cement (various floor/roof systems)</td><td></td><td></td><td>|-</td><td>O</td><td>-|</td><td></td></tr>
<tr><td>Structural concrete</td><td>Moment resisting frame</td><td>Designed for gravity loads only (predating seismic codes i.e. no seismic feature)</td><td>|-</td><td>-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Designed with seismic features (various ages)</td><td></td><td></td><td>|-</td><td>-</td><td>O</td><td>-|</td></tr>
<tr><td></td><td></td><td>Frame with unreinforced masonry infill walls</td><td></td><td>|-</td><td>O</td><td>-</td><td>-|</td><td></td></tr>
<tr><td></td><td></td><td>Flat slab structure</td><td></td><td>|-</td><td>O</td><td>-</td><td>-|</td><td></td></tr>
<tr><td></td><td></td><td>Precast frame structure</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Frame with concrete shear walls (dual system)</td><td></td><td></td><td>|-</td><td>-</td><td>O</td><td>-|</td></tr>
<tr><td></td><td>Shear wall structure</td><td>Walls cast in-situ</td><td></td><td></td><td></td><td>|-</td><td>O</td><td>-|</td></tr>
<tr><td></td><td></td><td>Precast wall panel structure</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td>-|Steel</td><td>Moment-resisting frame</td><td>With brick masonry partitions</td><td></td><td></td><td>|-</td><td>O</td><td>-</td><td>-|</td></tr>
<tr><td></td><td></td><td>With cast in-situ concrete</td><td></td><td></td><td>|-</td><td>O</td><td>-</td><td>-|</td></tr>
<tr><td></td><td></td><td>With lightweight partitions</td><td></td><td></td><td></td><td>|-</td><td>O</td><td>-|</td></tr>
<tr><td></td><td>Braced frame</td><td>With carious floor/roof systems</td><td></td><td></td><td></td><td>|-</td><td>O</td><td>-|</td></tr>
<tr><td></td><td>Light metal frame</td><td>Single storey LM frame structure</td><td></td><td></td><td>|-</td><td>-</td><td>O</td><td>-|</td></tr>
<tr><td>Wooden structures</td><td>Load-bearing timber frame</td><td>Thatch roof</td><td>|-</td><td>-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Post and beam frame</td><td></td><td></td><td>|-</td><td>O</td><td>-|</td><td></td></tr>
<tr><td></td><td></td><td>Walls with bamboo/reed mesh and post (Wattle and Daub)</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Frame with (stone/brick) masonry infill</td><td>|-</td><td>-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Frame with plywood/gypsum board sheathing</td><td></td><td>|-</td><td>O</td><td>-|</td><td></td><td></td></tr>
<tr><td></td><td></td><td>Frame with stud walls</td><td></td><td></td><td></td><td>|-</td><td>O</td><td>-|</td></tr>
</table>

O Most likely vulnerability class
|- Most likely lower range
-| Most likely upper range

4.3.2 Risk Assessment

Risk assessment basically depends on the hazard zonation and vulnerability maps. In order to assess the risk of an area in relation to a particular hazard, detailed information is required on the elements at risk, such as buildings, economic and society. The use of detailed building information based on location, building type, number of floors, structure, roof, etc. is necessary for hazard risk assessment. This data will be derived from field data collection in various locations based on the type and density of the building structure/foot print identified from high resolution satellite data with ground truth. Based on the type of hazard and its intensity, the loss of property and lives will be assessed qualitatively.

Analytic hierarchy process will be used to assess the relative weight of hazards and vulnerability criteria for risk rating. Based on the severity of risks different levels of risk will be assign in specific grades. Risk rating with a description of how these ratings should be interpreted is presented in Table 11.

Table 11 – HRVA Risk Rating Interpretation

Colour Codes	Risk Rating
	Very Low Risk
	Low Risk
	Moderate Risk
	High Risk
	Very High Risk

4.4 Final output

1. Building footprints map of the area
2. Mapping unit and grid approach for vulnerability assessment for buildings
3. Building vulnerability map showing the vulnerability conditions of different buildings at different locations at different time
4. Building vulnerability for different hazards
5. Population and Household Density Map
6. Mapping unit and grid approach for vulnerability assessment for population
7. Population vulnerability map showing the vulnerability conditions of population at different locations at different time
8. Temporal distribution of population inside buildings
9. Population vulnerability for different hazards
10. Risk maps

4.5 Conclusion

As per the Disaster Management Act, 2005, one of the measures necessary for managing disaster is the preparedness to deal with any of them. Preparedness means the measures that enable rapid and effective response in disaster situation. Vulnerability assessment and Risk assessment are among the other efforts of preparedness for mitigating disasters. The outputs from Vulnerability and Risk analysis will be the inputs required for reducing the vulnerability to take necessary mitigatory measures there by to reduce risk of the society at large. The risk assessment, which combines information on the nature of hazard with information on vulnerability of the targets, will help to clarify decision making for disaster management and the development of mitigation strategies.

Location (Nearby Village Name)	GPS Reading (Lat/Long/ Elevation)	LITHOLOGY	Major Structures (FAULT/ FOLD/ LINEAMENT)	BEDDING		JOINTS Attitude, Spacing, Aperture-opening, Infilling Material				SOIL		Geomorphology # Dissertation Pattern (L/M/H) # Broad Geomorphic units # Specific Landform	Landuse/ Landcover
				Attitude (Dip Amt. Dip Direction)	Layer Thickness	Set – 1	Set – 2	Set – 3	Set - 4	Type (Sandy, Loamy, Clayey)	Thick-ness 0-25, 25-50, 50-100, >100cm		

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VEGET-ATION (Density, Broad Type)	ROCK MASS STRENGTH				SLOPE			Dip-Slope Relationship		LANDSLIDE					Anthro-Pogenic Factors (Road-Slope Cutting, Mining, Toe Removal)
	Compressive Strength	Rock Weathering (W0 – 0% W1- 0-25%, W2- 25-50%, W3- 50-75%, W4- 75-100%, W5- 100%)	Angle of Friction	Rock Type Alternation	Amt. (Flat/ VL:5-15, L:15-30, M:30-45, H:45-60, VH:>60	Aspect (N/E/ S/W/ NE/ SE/ SW/NW/ FLAT)	Shape (Concave /Convex/ Flat)	Amount (Dip> Slope; OR Dip< Slope)	Aspect (Dip Dir. Vs. Slope Dir.)	Activity (Old/ Active/ Dormant	Material (Rock, Soil, Debris)	Movement [Fall/Topple/Flow/ Slide-(Planar/ Rotational)]	Rel. Size (Small/ Medium/ Big	

Annexure II

Format of data collection regarding Industries for Industrial Hazard Zonation of Guwahati City, Dibrugarh and Silchar Towns and Dhemaji District

1. Large scale Hazardous Installation or establishments (eg. Chemical, refineries, layout of pipelines etc,)

Location	Type of setup	Type of Material	Storage capacity	Diameter (in terms of pipeline) & carrying capacity

2. Past Hazardous incidents- (eg. Fires, explosions etc,)

Location	Date & Time	No. of casualty	No. of fatality	Damaged	Causes

3. Daily wind data (last 10 years) of industrial area

Wind Speed (in knots, m/sec, miles/hr)	Wind Direction

Format of data collection regarding Industries for Industrial Hazard Zonation of Guwahati City, Dibrugarh and Silchar Towns and Dhemaji District

- Questionnaire for socio-economic characteristics and Building type.
- Building Nane & ID:
- Lat/Long:
- Address:
- City/Village:
- Building use type: Residential/Commercial/Institutional/Public Buildings/Industrial/Mixed Built up/Vacant land/open space.
- Building Construction type:-Masonry/RCC/Steel building/Timber building.
- No: of Floors:-
- Building Date:
- Average Population:

M	<14	14-60	60>
F			

- No. Of People:
- Year Built:

Age group	12 AM -2 AM	2 AM -4 AM	4 AM -6 AM	6 AM-8 AM	8 AM-10 PM	10 AM -12 PM	12 PM -2 PM	2 PM-4 PM	4 PM -6 PM	6 PM -8PM	8 PM-10 PM	10 PM -12AM
<14												
14-60												
60>												

- Any other relevant information including field check.

QUESTIONNAIRE FOR BUILDING INVENTORY

Building Name & ID:

Lat/Long:

Address:

Building Age: <5yrs ☐ 5-15yrs ☐ >15yrs ☐

City/Village :

Sl. No	NO. OF FLOOR (Stories)	STRUCTURE 1. Type A* 2. Type B* 3. Type C* 4. Type X*	ROOF CGI=C Cement=cc Tin Sheet=TS Others=O	WALL Brick=BR CGI=C Bamboo=B Wooden=W Stones=S Mixed=M( )	FLOOR Mud=M Cement=C Bamboo=B Wooden=W Mixed=M( )	USE Residential=R Institutional=Inst Industrial-Ind Commercial=C ( ) Public=P ( ) Mixed=M ( )	CRACKS Walls=W Displace-ment/ Tilt=D Drainage-DR Footpath=F Retaining Wall=PW	POPU-LATION
1	2	3	4	5	6	7	8	9
1								
2								

45

*Note

Type A= Rural structures bamboo reinforced biomass wall cladding, thatched/CI sheet roof, Un-burnt brick house, Assam type houses in timber frame

Type B= Brick Masonry Wall 6"*6"to 10"*10" corner columns with lintel bend and tie, timber trussed CI sheet roof, building of large blocks and prefabricated type, half timbered structures, building in natural hewn stone

Type C= Reinforced Concrete Building Engineered & Non-engineered with beam, column & Slab construction, well built wooden structures

Type X= Other types not covered in A, B, C

Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

FEMA-154/ATC-21 Based Data Collection Form (Seismic Zones IV & V)

Address :____

____________________Pin________________________

Other Identifiers ____

GPS Coordinated (if available)______________________________

No. Stories________________ Year Built ________________

Surveyor ________________ Date ____________________

Total Floor Area (sq. ft./sq.m)__________________________

Building Name ______________________________________

Use ____

Current Visual Condition: Excellent ☐ /Good ☐/Damaged ☐ / Distressed ☐

Building on Stilts / Open Ground Floor: Yes ☐ / No☐

Construction Drawings Available: Yes ☐ / No ☐

Plan and Elevation Scale:

PHOTOGRAPH
(OR SPECIFY PHOTOGRAPH NUMBERS)

OCCUPANCY		SOIL TYPE (IS 1893:2002)	FALLING HAZARDS
Assembly Govt. Office Commercial Historic Residential Emer.Service Industrial School	Max. Number of Persons 0-10 11-100 101 – 1000 1000+	Type I Hard Soil Type II Medium Soil Type III Soft Soil	Chimney ☐ Parapets ☐ Cladding ☐ Other ☐

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

BUILDING TYPE	Wood	S1 (FRAME)	S2 (LM)	C1 (MRF)	C2 (SW)	C3 (INF)	URM1 (BAND+RD)	URM2 (BAND+FD)	URM3	URM4
Basic Score	3.8	2.8	3.2	2.5	2.8	2.6	2.8	2.8	1.8	1.4
Mid Rise (4 to 7 stories)	N/A	+0.2	N/A	+0.4	+0.4	+0.2	+0.4	+0.4	-0.2	-0.4
High Rise)> 7 stories	N/A	+0.6	N/AQ	+0.6	+0.8	+0.3	N/A	N/A	N/A	N/A
Vertical Irregularity	-2.0	-1.0	N/A	-1.5	-1.0	-1.0	-1.0	-1.0	-1.0	1.0
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Code Detailing	N/A	+0.4	N/A	+0.2	+1.4	+0.2	N/A	N/A	N/A	N/A
Soil Type II	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Soil Type III	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6
Liquifiable Soil	-0.8	-1.2	-1.0	-1.2	-0.8	-0.8	-0.6	-0.6	-0.8	-0.8
FINAL SCORE, S										

Result interpretation (likely building performance)

S<0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage	Further Evaluation Recommended YES/ NO
0.3<S<0.7	High probability of Grade 4 damage.; Very high probability of Grade 3 damage	
0.7 < S <2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage	
2.0 <S < 3.0	High probability of Grade 2 damage; Very high probability of Grade 1 damage	

*= Estimated, subjective, or unreliable date
DNK = Do Not Know
FRAME =Steel Frame
SW = Shear Wall
URM3 = Unreinforced burnt brick or stone masonry (cem mortar)
INF = Burn Brick Masonry Infill Wall
LM = Light Metal
MRF = Moment-resisting Frame
BAND = Seismic Band
RD = Rigid diagraphram
FD = Flexible Diaphragm
URM4 = Unreinforced masonry (lime mortar)

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