A dissertation submitted on

LANDSLIDE HAZARD ASSESSMENT

Submitted in Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

IN

CIVIL ENGINEERING

(With specialization in Geotechnical Engineering)

Under

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Submitted by

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DECLARATION

I hereby declare that the mini project "**LANDSLIDE HAZARD ASSESSMENT**" in partial fulfillment of the requirement for the award of the degree of " MASTER OF TECHNOLOGY" in Civil Engineering (With specialization in Geotechnical Engineering), submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science & Technology University, is a real record of the work carried out in the said college for six months under the supervision of Dr. Sasanka Borah, Associate Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13.

Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

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CERTIFICATE OF SUPERVISION

This is to certify that the work presented in this report entitled **— LANDSLIDE HAZARD ASSESSMENT** is carried out by Himanjali Bharali, Roll No: PG/C/23/06, a student of MTech 3rd semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

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ABSTRACT

In this study an attempt has been made to develop an integrated approach for landslide hazard zonation for the Kharghuli area using remote sensing GIS technology. This study is based on the executive summary of rapid visual screening for potential landslide areas of Guwahati by Assam State Disaster Management Authority. The study area was finalized based on 37 sites that has been examined previously. All the necessary maps and other raw data have been downloaded from Bhuvan by Indian Space Research Organization, Bhoonidhi ISRO's EO data hub and Earth explorer by United States Geological survey.

Landslides are the most destructive geological hazard in the hilly regions. For systematic landslide mitigation and management, landslide evaluation and hazard zonation is required. Over the past few decades several techniques have been developed that can be used for landslide evaluation and zonation. The selection of appropriate technique for landslide hazard evaluation and zonation is very crucial. The factors that need to be considered to adopt an appropriate approach are; investigation purpose, the extent of the area to be covered, the type of mapping units, the scale of map to be produced, type of data to be used, type of landslides, availability of resources, capability and skill set of an evaluator and the accessibility to the study area. The main aim of this study is to develop a user friendly landslide hazard zonation map for all category of people irrespective of their background of study domain.

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INTRODUCTION

1.1 GENERAL

Landslides are significant natural geologic hazards around the world. Expansion of urban and man-made structures into potentially hazardous areas leads to extensive damage to infrastructure and occasionally results in loss of life every year. Since the early 1970s' many scientists have attempted to assess landslide hazards and produced susceptibility maps portraying their spatial distribution. Landslide susceptibility and hazard maps have become very effective tools for planners and decision makers.

The landslide hazards, in general, cannot be completely prevented; however, the intensity and severity of their impacts can be minimized if the problem is recognized before the development or deforestation begins. Determining the extent of landslide hazard requires identifying those areas of the landslide occurring within some time period. In general, specifying a time frame for the occurrence of a landslide is difficult to determine even under ideal conditions. As a result, landslide hazard is often represented by landslide susceptibility, also referred to as landslide hazard. Through landslide susceptibility mapping, an area can be classified into different susceptibility classes according to the degree of actual or potential hazards from landslides. In other words, the landslide susceptibility map delineates the areas with varying potential for future landslide occurrences. Further, it is always necessary to estimate the consequences of the hazardous phenomena to assess the risk. This deals with the economic, societal and environmental elements at risk. A landslide risk map indicates different degrees of risks involved in different hazard-prone areas.

1.2 LANDSLIDE HAZARD

Landslides are common phenomenon in a technically fragile and sensitive mountainous terrain. Among the various natural hazards, landslides are the most whispered and damaging natural hazards which not only result in the loss of human life but also cause economic burden on society. Therefore, it is essential to develop suitable models to evaluate the susceptibility of slope failures and their zonation. Landslide hazard defines the physical attributes of a potentially damaging landslide in terms of mechanism, volume and frequency and therefore landslide hazard assessment estimates the probability of a landslide occurrence within a certain period in a given area. The intensity and dimension of landslides compared with temporal frequency of slope failures. Landslide hazard assessment is expressed in the term of landslide susceptibility assessment. A hazard map that aims at predicting where slope failures are most likely to occur is more accurately defined as a landslide susceptibility map. The term susceptibility defines the likelihood of occurrence of a landslide if governing factors like rainfall, earthquakes etc. are not considered.

1.3 STUDY AREA

In this study the Kharghuli area has been targeted for a thorough investigation from both geotechnical and seismic perspective to generate a landslide hazard map. Kharghuli is a locality in northern part of Guwahati, Assam, India. Situated on the south bank of the Brahmaputra river, it is a residential area, most of the parts of this locality has hilly terrain. It is connected to rest of the city by means of buses and other modes of transportation.

The study area is of around 1.08 sq. km and the perimeter is 6.08 km. The length of the stretch is about 2.44 km and the width varies from 283 m to 650m.

Fig 1: Study Area

Fig 2: Geotag Photograph taken at the time of site visit

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW OF AVAILABLE LITERATURE

1. **Zheng, L., Fu, G. & Luo, G. (2024). Hazard zonation for potential earthquake-induced landslide in the eastern East Kunlun fault zone. *Open Geosciences, 16*(1), 20220704.**

This study is based on probabilistic seismic hazard analysis, the seismic landslide hazard research considers the spatial and temporal distribution characteristics of seismic peak ground acceleration, which integrates the factors such as seismic intensity, location, and recurrence time. The occurrence of future earthquakes has certain randomness. This article presents the landslide hazard zoning of the eastern Kunlun fault zone and its surrounding faults, which is carried out under the action of horizontal ground motion with certain exceeding probability. According to the geological structure and seismicity characteristics of the study area, the potential source is divided. Based on the seismic hazard analysis and Newmark cumulative displacement evaluation model, the seismic landslide hazard in the study area is analysed. The landslide probability is taken as the risk index. The seismic landslide hazard can be divided into five grades: extremely low-prone area, low-prone area, medium-prone area, high-prone area, and extremely high-prone area. In the results of seismic landslide risk zoning given in this article, the surrounding areas of Tazang fault and Minjiang fault are high-risk areas, which should be paid attention to.

2. **Walling, M. Y., & Mohanty, W. K. (2009). An overview on the seismic zonation and microzonation studies in India. *Earth-Science Reviews, 96*(1-2), 67-91.**

This study presents a review on the progressive development of the seismic zonation map of India both from official agencies and also from independent individual studies. The zonation map have been modified and updated regularly with the occurrence of major destructive earthquakes over the years in the Indian subcontinent with the addition of new data. This study discusses the criteria chosen for the progressive zonation and the major earthquakes that were responsible for retrospection of the earlier published maps. The seismic zonation maps of India have also been prepared by various independent workers by adopting different approaches to achieve the purpose of the zonation. Despite the endeavors from various sources to provide a solution for the problem of earthquake hazards in India, there were many limitations on the zonation map as it gives the picture at a regional scale mostly on the bedrock level without addressing the local site conditions. But nevertheless, the seismic zonation map gives basic guidelines for any region to know the hazard scenario and if any city or urban population is under threat from seismic point of view, further site specific seismic microzonation may be carried out. In the International scenario, the Global Seismic Hazard Assessment Program (GSHAP) in 1999 prepared a hazard map for world in terms of peak ground acceleration (PGA) with a 10% probability of exceedance in 50 years, but it turned out to be an underestimation of the hazard parameter when compared with the observed PGA. To tackle the problem of seismic hazards, there was a need to have a detail study on the local site conditions in terms of its geological, geophysical and geotechnical properties. With the advent of better instrumentation and knowledge on the mechanics of earthquakes, it was possible to identify zones of hazards at a local level and this gives rise to the study of seismic microzonation. Seismic microzonation work has been carried out in India in some of the strategic important mega cities and industrial build up that has the potential of being damaged from future earthquakes, as has been shown in the past. Though the microzonation map is not the final output map, as it can still be updated at later stage with more input data, it does provide a more realistic picture on the site specific seismic hazard.

3. Verma, M., Bansal, B.K. Seismic hazard assessment and mitigation in India: an overview. *Int J Earth Sci (Geol Rundsch)* 102, 1203–1218 (2013).

In this study the Indian subcontinent is characterized by various tectonic units viz., Himalayan collision zone in North, Indo-Burmese arc in north-east, failed rift zones in its interior in Peninsular Indian shield and Andaman Sumatra trench in south-east Indian Territory. During the last about 100 years, the country has witnessed four great and several major earthquakes. Soon after the occurrence of the first great earthquake, the Shillong earthquake (Mw: 8.1) in 1897, efforts were started to assess the seismic hazard in the country. The first such attempt was made by Geological Survey of India in 1898 and since then considerable progress has been made. The current seismic zonation map prepared and published by Bureau of Indian Standards, broadly places seismic risk in different parts of the country in four major zones. However, this map is not sufficient for the assessment of area-specific seismic risks, necessitating detailed seismic zoning, that is, microzonation for earthquake disaster mitigation and management. Recently, seismic microzonation studies are being introduced in India, and the first level seismic microzonation has already been completed for selected urban centres including, Jabalpur, Guwahati, Delhi, Bangalore, Ahmadabad, Dehradun, etc. The maps prepared for these cities are being further refined on larger scales as per the requirements, and a plan has also been firmed up for taking up microzonation of 30 selected cities, which lie in seismic zones V and IV and have a population density of half a million. The paper highlights the efforts made in India so far towards seismic hazard assessment as well as the future road map for such studies.

4. **K.P. Sreejaya, S.T.G. Raghukanth, I.D. Gupta, C.V.R. Murty, D. Srinagesh,Seismic hazard map of India and neighbouring regions,Soil Dynamics and Earthquake Engineering,Volume 163,(2022),107505,ISSN 0267-7261,**

This article presents probabilistic seismic hazard analysis (PSHA) of India and adjoined region, carried out to develop a new national seismic hazard map for India. The hazard map is developed using fault oriented spatially smoothed seismicity approach. A catalog of earthquakes has been compiled for the region (Latitude 50 N − 400 N and Longitude 650 E − 1000 E) from 2600BCE to 2019CE to estimate the seismicity parameters. Eighteen suitable ground motion prediction equations in the logic tree framework are used for the four major geological regions of the country. The hazard is estimated at rock sites (B-C boundary type) conditions in terms of peak ground acceleration (PGA), short-period (0.2 s), and long-period (1s) spectral acceleration maps and uniform hazard spectra, with 2% and 10% probabilities of exceedance in 50 years. Higher hazard values are observed in the Hindukush-Pamir regions and Northeast India, whereas central India and the southern peninsular regions are less prone to seismic threat. The proposed maps find their application in the seismic design of structures, risk assessment, and as an input for updating the existing code provisions.

5. **Gerstenberger, M. C., Marzocchi, W., Allen, T., Pagani, M., Adams, J., Danciu, L., ... & Petersen, M. D. (2020). Probabilistic seismic hazard analysis at regional**

and national scales: State of the art and future challenges. Reviews of Geophysics, 58(2), e2019RG000653.

Seismic hazard modelling is a multidisciplinary science that aims to forecast earthquake occurrence and its resultant ground shaking. Such models consist of a probabilistic framework that quantifies uncertainty across a complex system; typically, this includes at least two model components developed from Earth science: seismic source and ground motion models. Although there is no scientific prescription for the forecast length, the most common probabilistic seismic hazard analyses consider forecasting windows of 30 to 50 years, which are typically an engineering demand for building code purposes. These types of analyses are the topic of this review paper. Although the core methods and assumptions of seismic hazard modelling have largely remained unchanged for more than 50 years, we review the most recent initiatives, which face the difficult task of meeting both the increasingly sophisticated demands of society and keeping pace with advances in scientific understanding. A need for more accurate and spatially precise hazard forecasting must be balanced with increased quantification of uncertainty and new challenges such as moving from time-independent hazard to forecasts that are time dependent and specific to the time period of interest. Meeting these challenges requires the development of science-driven models, which integrate all information available, the adoption of proper mathematical frameworks to quantify the different types of uncertainties in the hazard model, and the development of a proper testing phase of the model to quantify its consistency and skill. We review the state of the art of the National Seismic Hazard Modelling and how the most innovative approaches try to address future challenges.

6. **Nath, S. K., & Thingbaijam, K. K. S. (2009). Seismic hazard assessment–a holistic microzonation approach. *Natural Hazards and Earth System Sciences*, *9*(4), 1445-1459.**

The probable mitigation and management issues of seismic hazard necessitate seismic microzonation for hazard and risk assessment at the local level. Such studies are preceded with those at a regional level. A comprehensive framework, therefore, encompasses several phases from information compilations and data recording to analyses and interpretations. The state-of-the-art methodologies involve multi-disciplinary approaches namely geological, seismological, and geotechnical methods delivering multiple perspectives on the prevailing hazard in terms of geology and geomorphology, strong ground motion, site amplification, site classifications, soil liquefaction potential, landslide susceptibility, and predominant frequency. The composite hazard is assessed accounting for all the potential hazard attributing features with relative rankings in a logic tree, fuzzy set or hierarchical concept.

7. **Mauro Caccavale, Fabio Matano, Marco Sacchi,An integrated approach to earthquake-induced landslide hazard zoning based on probabilistic seismic scenario for Phlegrean Islands (Ischia, Procida and Vivara), Italy, Geomorphology, Volume 295,(2017),Pages 235-259,ISSN 0169-555X**

In this study we present an integrated approach to assess earthquake-induced landslide hazard at the source area of the slope instability process. The method has been applied to the case study of Ischia, Procida and Vivara islands that represent an integral part of the Campi Flegrei, a densely populated, active volcanic area, located at the NW margin of the Naples Bay, Italy. The proposed method follows a stepwise procedure including: 1) Probabilistic Seismic Hazard Analysis (PSHA); 2) assessment of site and topographic effects; 3) input of the PSHA outputs into a classic sliding rigid block analysis for slope instability (Newmark's approach); 4) construction of landslide frequency - magnitude curves for the estimate of the slope failure probability as a function of defined Newmark's threshold values under different probabilistic seismic scenarios; 5) construction of earthquake-induced landslide hazard maps at the source area, based on the integration of the probabilistic approach and the geological, morphological and geotechnical database available for the study area. The Probabilistic Seismic Hazard Analysis (PSHA) is aimed at the definition of the seismic input with different annual exceedance frequency. PSHA results, expressed in terms of Peak Ground Acceleration (PGA) at the bedrock, are calculated for 14 return periods (T) ranging from 10 to 2000 yr. PGA values have been corrected for the site effect associated with geological and morphologic conditions for each selected return period. Secondly, the corrected PGA values have been used as an input for the classic sliding rigid-block Newmark's approach, implemented in a Geographic Information System (GIS) to assess the relative potential for slope failure (landslide susceptibility) both in static (Factor of Safety, FS) and dynamic (Critical acceleration, ac) conditions. The combination of T-dependent, site-corrected PGA with the critical acceleration allowed for the calculation of the expected Newmark's displacements (DN) under different probability of exceeding or return periods (probabilistic seismic scenarios). As a further step, in order to estimate the earthquake-induced landslide hazard, we defined three DN threshold values that have considered capable to trigger shallow seismic-induced landslides in the regional context and mapped the sectors with DN values exceeding such thresholds. On this basis, we constructed frequency-magnitude curves to estimate the probability of slope failures at the source areas, as a function of DN, by correlating the annual probability of landslide occurrence with the number of terrain cells associated with DN values greater than the selected threshold. Finally, based on the estimated annual landslide frequency of the seismic triggering event for each terrain cell, we implemented a 1:5000 scale map of Earthquake-induced Landslide Hazard for Ischia, Procida and Vivara Islands. The map reports the zoning and ranking of study area into sub-zones, on a pixel basis, according to the degree of the potential hazard from landslides derived by the frequency of the triggering event.

8. **Karpouza, M., Chousianitis, K., Bathrellos, G. D., Skilodimou, H. D., Kaviris, G., & Antonarakou, A. (2021). Hazard zonation mapping of earthquake-induced secondary effects using spatial multi-criteria analysis. *Natural Hazards*, *109,* 637-669.**

The present study aims to suggest an approach that allows the simultaneous hazard zonation mapping of earthquake-induced secondary effects. The modelling process of the applied methodology involves an initial separate evaluation of the hazard imposed by seismically induced landslides and soil liquefaction and a subsequent stacking into one single hazard map that refects an integrated assessment of areas exposed to both earthquakes induced phenomena under seismic shaking. To this end, we adopted a spatial multi-criteria method to support the evaluation of the controlling factors that contribute to the occurrence of coseismic landslides and soil liquefaction, and we exploited the potential of Geographic Information Systems to process the various thematic layers and produce hazard zonation maps that can be used to help communities become more resilient to future coseismic hazards. The implemented methodology has the potential to categorize and discriminate regions that are threatened either by coseismic landslides, by soil liquefaction or by their combined occurrence. The results demonstrate the necessity, especially in seismically active regions which consist of mountainous terrain along with coastal plain areas and consequently imply susceptibility to slope destabilization phenomena and soil liquefaction, to jointly evaluate the hazard posed by both of these earthquake-induced secondary effects.

9. **Kundu, P., Das, J., Pain, A. *et al.* Unveiling earthquake hazard in Noida, India: a combined probabilistic and deterministic seismic hazard assessment. *Innov. Infrastruct. Solut.* 9, 93 (2024).**

Noida is a satellite town in the National Capital Region of Delhi which shares a border with Delhi in the West, and Ghaziabad in the North, these are two major cities in India, which are bound by the river Yamuna and Hindon and extending toward Greater Noida in the east. It is known as an Industrial hub of India due to its rapid urbanization and industrialization. It lies approximately 200 and 300 km from Main Boundary Thrust and Main Central Thrust respectively, which are the two most active thrust planes of the Himalayas located on Quaternary sediments, belonging to the Indo-Gangetic alluvium. The city falls under seismic zone IV (According to IS: 1893–2002) (IS1893: Part 1. Indian standard criteria for earthquake-resistant design of structures, Part 1—General provisions and buildings. In Bureau of Indian Standards, New Delhi, India, 2002) which is considered the second most seismically active region in India. Thus, it is indispensable to carry out the seismic hazard assessment of this Noida city and conduct the seismic hazard assessment using both probabilistic (PSHA) and deterministic (DSHA) approaches. An earthquake catalog of the past 300 years has been used with a total number of 2409 events bounded by the latitudes 25.5°–31.5°N and longitudes 74.2°–80.5°E. To address the lack of ground motion prediction equations specific to the region, a logic tree approach is adopted that incorporates four GMPEs. Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) are computed for two different time periods (0.2 and 1.0 s) using CRISIS software. These calculations were used to create hazard maps representing the likelihood of events exceeding 2% and 10% probability within a 50-year timeframe. The mean uniform hazard spectra is prepared and compared with IS1893: Part 1 (2002) (IS1893: Part 1. Indian standard criteria for earthquake-resistant design of structures, Part 1—General provisions and buildings. In Bureau of Indian Standards, New Delhi, India, 2002) for zone IV which reveals overestimation of spectral acceleration at higher time periods. Additionally, disaggregation analysis for Noida City, India, illustrates how different combinations of earthquake magnitude and distance contribute to the hazard. Based on the disaggregation results the controlling seismic sources are identified to perform DSHA in the study region with the same grid spacing using OpenQuake engine with the same GMPEs. Finally, PGA and SA values obtained from PSHA and DSHA were compared to previous studies. Peak Ground Acceleration (PGA) values obtained from PSHA and DSHA were found in close range prescribed in IS: 1893-1 (2002) (IS1893: Part 1. Indian standard criteria for earthquake-resistant design of structures, Part 1—General provisions and buildings. In Bureau of Indian Standards, New Delhi, India, 2002), but the wide disparity is observed for higher time periods i.e., T = 0.2 s and 1 s. The key findings of the current study are Developing PGA map and site-specific hazard spectrum for Noida City, identifying seismic and geological discontinuities in the study area, Prepares hazard maps and for different return periods. The current study makes an attempt to develop an updated PGA map and site-specific hazard spectrum for Noida City which plays a vital role in earthquake-induced disaster mitigation efforts. We anticipate that this study will make a significant contribution to the revision of regional building codes, aimed at enhancing the earthquake-resistant design and construction of structures within this highly seismic area for reducing building vulnerability and protecting lives and property.

10. **Jena, R., Pradhan, B., Beydoun, G., Al-Amri, A., & Sofyan, H. (2020). Seismic hazard and risk assessment: a review of state-of-the-art traditional and GIS models. *Arabian Journal of Geosciences*, *13*(2), 50.**

The historical records of earthquakes play a vital role in seismic hazard and risk assessment. During the last decade, geophysical, geotechnical, geochemical, topographical, geomorphological, geological data, and various satellite images have been collected, processed, and well-integrated into qualitative and quantitative spatial databases using geographical information systems (GIS). Various types of modelling approaches, such as traditional and GIS-based models, are used. Progressively, seismic studies can improve and modify systematic models and standardize the inventory map of earthquake-susceptible regions. Therefore, this paper reviews different approaches, which are organized and discussed on various models primarily used to create an earthquake scenario focusing on hazard and risk assessment. The reviews are divided into two major parts. The first part is the basic principles, data, and the methodology of various models used for seismic hazard and risk assessment. In the second part, a comparative analysis in terms of the limitations and strengths of the models, as well as application variability is presented. Furthermore, the paper includes the descriptions of software, data resources, and major conclusions. The main findings of this review explain that the capability of machine learning techniques regularly enhances the state of earthquake research, which will provide research opportunities in the future. The model suitability depends on the improvement of parameters, data, and methods that could help to prevent future risk. This paper will help researchers further understand the models based on their strengths, limitations, and applicability.

11. Saha, A. K., Gupta, R. P., & Arora, M. K. (2002). GIS-based Landslide Hazard Zonation in the Bhagirathi (Ganga) Valley, Himalayas. International Journal of Remote Sensing, 23(2), 357–369. https://doi.org/10.1080/01431160010014260

Landslides cause widespread damage in the Himalayas. Landslide Hazard Zonation is important to take quick and safe mitigation measures and make strategic planning for the future. A part of the Bhagirathi Valley in the Garhwal Himalaya was selected for landslide hazard zonation. The study utilized different types of data including Survey of India topographic maps, geological (lithological and structural) maps, IRS-1B and-1D multispectral and PAN satellite sensor data and field observations. The processing of multi-geodatasets was carried out in a raster GIS environment. The various data layers generated and co-registered were: landuse/landcover, buffer map of thrusts, buffer map of photo-lineaments, lithology, buffer map of drainage, slope angle and relative relief. Data integration was carried out using the ordinal scale (qualitative) relative weighting rating technique to give a Landslide Hazard Index (LHI) value. The breaks in the LHI frequency diagram were used to delineate various landslide hazard zones, namely, very low, low, moderate, high and very high. Field data on landslides were employed to evaluate and validate landslide hazard zonation map. It is interpreted that the distribution of landslides is largely governed by a combination of geoenvironmental conditions like proximity (>500 m) to the thrust zone, presence of Munsiari Formation (Higher Himalayan Crystalline) and barren or less-vegetated areas.

12. Shano, L., Raghuvanshi, T. K., & Meten, M. (2020). Landslide susceptibility evaluation and hazard zonation techniques–a review. Geoenvironmental Disasters, 7, 1-19.

Landslides are the most destructive geological hazard in the hilly regions. For systematic landslide mitigation and management, landslide evaluation and hazard zonation is required. Over the past few decades several techniques have been developed that can be used for landslide evaluation and zonation. These techniques can broadly be classified into qualitative and quantitative approaches. Qualitative approaches include geomorphological analysis and heuristic techniques whereas quantitative approaches include statistical, artificial intelligence and deterministic techniques. In quantitative techniques prediction for landslide susceptibility is based on the actual realistic data and interpretations. Further, the quantitative techniques also overcome the subjectivity of qualitative approaches. Each of these techniques may consider different causative factors and utilizes various means for factor evaluation and analysis. When compared, each of these techniques has its own advantage and disadvantage over other techniques. The selection of appropriate technique for landslide hazard evaluation and zonation is very crucial. The factors that need to be considered to adopt an appropriate approach are; investigation purpose, the extent of the area to be covered, the type of mapping units, the scale of map to be produced, type of data to be used, type of landslides, availability of resources, capability and skill set of an evaluator and the accessibility to the study area. The main aim of this article is to present a comprehensive review on various techniques and approaches available for landslide susceptibility and hazard zonation mapping. Further, an attempt is also made to assess the effectiveness of these techniques in landslide hazard zonation studies.

13. Vahidnia, M. H., ALE, S. A., ALI, M. A., & Hosseinali, F. (2009). Landslide hazard zonation using quantitative methods in GIS.

Landslides are major natural hazards which not only result in the loss of human life but also cause economic burden on the society. Therefore, it is essential to develop suitable models to evaluate the susceptibility of slope failure and their zonation. This paper scientifically assesses various methods of landslide susceptibility zonation in GIS environment. A comparative study of Weights of Evidence (WOE), Analytical Hierarchy Process (AHP), Artificial Neural Network (ANN), and Generalized Linear Regression (GLR) procedures for landslide susceptibility zonation is presented. Controlling factors such as lithology, landuse, slope angle, slope aspect, curvature, distance to fault, and distance to drainage were considered as explanatory variables. Data of 151 sample points of observed landslides in Mazandaran Province, Iran, were used to train and test the approaches. Small scale maps (1:1,000,000) were used in this study. The estimated accuracy ranges from 80 to 88 percent. It is then referred that the application of WOE in rating maps categories and ANN to weight effective factors result in the maximum accuracy.

14. **Pareta, K., Kumar, J., & Pareta, U. (2012). Landslide hazard zonation using quantitative methods in GIS. Int J Geospatial Eng Technol, 1(1), 1-9.**

Landslides are one of the critical geological processes, which cause not only enormous damage to civil engineering structures i.e. roads, railways, bridges, dams, bio-engineering structures, and houses but also lead to loss of life. Hence, there is a need for landslide hazard zonation for identification of potential landslide areas. The present study is an attempt towards development of a landslide model by using multi-criteria decision analysis in GIS and remote sensing techniques for landslide hazard zonation. Giri river watershed of Yamuna basin was selected for the model implementation. WorldView-02-MS and ResourceSAT-2 LISS4-Mx satellite imageries, SoI topographical maps, and field data were used as inputs to the study. These data layers represent the soil, land use, geological, topographical, and hydrological conditions of the terrain. A numerical rating scheme for the factors was developed for spatial data analysis in a GIS. The resulting landslide hazard zonation map delineates the area into different zones of four relative HZ-classes: very high, high, moderate, and low. The very high HZ-class has located in the Rawana, Jabyana, Gusan, Chandesh and Parar villages. The LHZ-map was corroborated by correlating the landslide frequencies of different classes. This has shown close agreement with the existing field variability condition.

2.2 KEY POINTS OF LITERATURES REVIEW

Sl no.	Title with year of publication	Author	Remark
1	Probabilistic seismic hazard analysis at regional and national scales: State of the art and future challenges. (2020)	Gerstenberger, M. C., Marzocchi, W., Allen, T., Pagani, M., Adams, J., Danciu, L., ... & Petersen, M. D.	➢ National Seismic Hazard Models (NSHMs) are regional models that take our understanding of earthquake occurrence and their consequent shaking intensities and make this information useful for decision makers and society ➢ Key goals in modern probabilistic NSHMs are the improved quantification of uncertainty and research to understand the skill and usefulness of the forecasts ➢ Current PSHA-based methods used by NSHMs from diverse tectonic

			settings around the world are reviewed
2	Seismic hazard and risk assessment: a review of state-of-the-art traditional and GIS models. (2020)	Jena, R., Pradhan, B., Beydoun, G., Al-Amri, A., & Sofyan, H.	➢ modify systematic models and standardize the inventory map of earthquake-susceptible regions ➢ integrated into qualitative and quantitative spatial databases using geographical information systems
3	Seismic hazard map of India and neighbouring regions, Soil Dynamics and Earthquake Engineering (2022)	K.P. Sreejaya, S.T.G. Raghukanth, I.D. Gupta, C.V.R. Murty, D. Srinagesh	➢ The study is carried out with the motivation to update the Indian seismic code zone map of IS 1893. ➢ A careful Investigation of several source models reveals that the fault-oriented spatially smoothed model is more effective for the analysis. ➢ A well-established ranking scheme is used to rank the candidate GMPEs and obtain the logic tree weights. ➢ A higher hazard is observed in the western Himalaya and Northeast India and lower hazard at Central and southern India.
4	Hazard zonation mapping of earthquake-induced secondary effects using spatial multicriteria analysis (2021)	Karpouza, M., Chousianitis, K., Bathrellos, G. D., Skilodimou, H. D., Kaviris, G., & Antonarakou	➢ Implemented methodology has the potential to categorize and discriminate regions that are threatened either by coseismic landslides, by soil liquefaction or by their combined occurrence. ➢ Hazard imposed by seismically induced landslides and soil liquefaction
5	Unveiling earthquake hazard in Noida, India: a combined probabilistic and deterministic seismic hazard assessment (2024)	Kundu, P., Das, J., Pain	➢ Urban area (satellite town) based ➢ Probabilistic seismic hazard ➢ Deterministic seismic hazard ➢ Seismic zone IV
6	An integrated approach to earthquake-induced landslide hazard zoning based on probabilistic seismic scenario for Phlegrean Islands (Ischia, Procida and Vivara), Italy (2017)	Mauro Caccavale, Fabio Matano, Marco Sacchi	➢ An integrated approach allows to assess earthquake-induced landslide hazard at source area of slope instability process. ➢ Probabilistic Seismic Hazard Analysis allows the definition of seismic input with different annual exceedance frequency. ➢ Site corrected PGA values have been used as input for classical sliding

			rigid-block Newmark's approach, implemented in GIS. ➢ Frequency-magnitude curves was used to estimate probability of slope failures as a function of Newmark's displacements.
7	Seismic hazard assessment–a holistic microzonation Approach (2009)	Nath, S. K., & Thingbaijam, K. K. S.	➢ Prevailing hazard in terms of geology and geomorphology, strong ground motion, site amplification, site classifications, soil liquefaction potential, landslide susceptibility, and predominant frequency.
8	Landslide hazard zonation using quantitative methods in GIS(2012)	Pareta, K., Kumar, J., & Pareta, U	➢ Landslide model by using multi-criteria decision analysis in GIS and remote sensing techniques for landslide hazard zonation.
9	GIS-based Landslide Hazard Zonation in the Bhagirathi (Ganga) Valley, Himalayas (2002)	Saha, A. K., Gupta, R. P., & Arora, M. K.	➢ The processing of multi-geodatasets was carried out in a raster GIS environment. ➢ Data used includs Survey of India topographic maps, geological (lithological and structural) maps, IRS-1B and-1D multispectral and PAN satellite sensor data.
10	Landslide susceptibility evaluation and hazard zonation techniques–a review (2020)	Shano, L., Raghuvanshi, T. K., & Meten, M	➢ Quantitative techniques prediction for landslide susceptibility. ➢ Quantitative techniques to overcome the subjectivity of qualitative approaches.
11	Landslide hazard zonation using quantitative methods in GIS (2009)	Vahidnia, M. H., ALE, S. A., ALI, M. A., & Hosseinali, F.	➢ Scientifically assesses various methods of landslide susceptibility zonation in GIS environment. ➢ Comparative study of Weights of Evidence (WOE), Analytical Hierarchy Process (AHP), Artificial Neural Network (ANN), and Generalized Linear Regression (GLR) procedures for landslide susceptibility zonation.
12	Seismic hazard assessment and mitigation in India: an overview (2013)	Verma, M., Bansal, B.K.	➢ Seismicity monitoring ➢ Maps prepared on Indian subcontinent
13	An overview on the seismic zonation and microzonation studies in India (2009)	Walling, M. Y., & Mohanty, W. K.	➢ Seismic microzonation of India based on peak ground acceleration ➢ provide a more realistic picture on the site-specific seismic hazard.

14	Hazard zonation for potential earthquake-induced landslide in the eastern East Kunlun fault zone (2024)	Zheng, L., Fu, G. & Luo, G	➢ Probabilistic seismic hazard analysis ➢ Newmark model
15	GIS-based landslide hazard assessment: an overview(2005)	Wang Huabin, Liu Gangjun	➢ integrated system for effective landslide hazard assessment and zonation incorporating artificial intelligence and data mining technology in a GIS-based framework of knowledge discovery.
16	Landslide hazard assessment: recent trends and techniques(2013)	Sudhakar D Pardeshi	➢ Methods of Landslide Hazard Zonation (LHZ) viz. heuristic, semi quantitative, quantitative, probabilistic and multi-criteria decision-making process.
17	Probabilistic landslide hazard assessment at the basin scale(2005)	Fausto Guzzetti	➢ probabilistic model to determine landslide hazard at the basin scale. ➢ Probability of spatial occurrence of landslides by discriminant analysis of thematic variables, including morphological, lithological, structural and land use
18	Regional coseismal landslide hazard assessment without historical landslide inventories: A new approach(2015)	Theodosios Kritikos	➢ Tectonics and topography control coseismic landslide occurrence. ➢ The modeling approach incorporates fuzzy set theory in GIS ➢ The model requires no site-specific data inputs to perform the assessment

2.3 SUMMARY OF LITERATURE REVIEW

Landslide Hazard Zonation is important to take quick and safe mitigation measures and make strategic planning for the future. In probabilistic seismic hazard analysis, the seismic landslide hazard research considers the spatial and temporal distribution characteristics of seismic peak ground acceleration, which integrates the factors such as seismic intensity, location, and recurrence time. Despite the endeavors from various sources to provide a solution for the problem of earthquake hazards in India, there were many limitations on the zonation map as it gives the picture at a regional scale mostly on the bedrock level without addressing the local site conditions. The probable mitigation and management issues of seismic hazard necessitate seismic microzonation for hazard and risk assessment at the local level. Such studies are preceded with those at a regional level. A comprehensive framework, therefore, encompasses several phases from information compilations and data recording to analyses and interpretations**.** The breaks in the Landslide Hazard Index frequency diagram were used to delineate various landslide hazard zones, namely, very low, low, moderate, high and very high. Field data on landslides were employed to evaluate and validate landslide hazard zonation map. Moreover, the factors that need to be considered to adopt an appropriate approach are; investigation purpose, the extent of the area to be covered, the type of mapping units, the scale of map to be produced, type of data to be used, type of landslides, availability of resources, capability and skill set of an evaluator and the accessibility to the study area.

CHAPTER 3

THEORITICAL CONSIDERATION

3.1 TERMINOLOGY

3.1.1 Digital Elevation Modal

A digital elevation model (DEM) is a 3D computer model of the Earth's surface, excluding any buildings, trees, or other objects. DEMs are often used in geographic information systems (GIS) and to create relief maps.

Fig 3: Digital Elevation Modal

The availability of DEMs is crucial for performing geometric and radiometric corrections for terrain on remotely sensed imagery and allows the generation of contour lines and terrain models, does providing another source of information for analysis. Present mapping programs are rarely implemented with only planimetric consideration. The demand for DEMs is growing with increasing use of GIS and with increasing evidence of improvement in information extraction using elevation data. The incorporation of elevation and terrain data is crucial to many applications to compensate for foreshortening N layover effects N slope induced radiometric effects. Elevation data are used in the production of popular topographic maps.

Elevation data, integrated with imagery are also used for generating perspective views, useful for tourism, route planning, to optimize views for developments and even golf course planning and development. Elevation models are integrated into the programming of missiles to guide them over the terrain. Resource management telecommunications planning and military mapping are some of the applications associated with DEMS.

3.1.2 RVS (Rapid Visual Screening)

Rapid visual screening (RVS) is a method for evaluating the potential seismic risk of buildings in earthquake-prone areas. It can also be used to assess the potential risk of landslides, avalanches, and floods. RVS is used to screen large numbers of buildings quickly and without the need for structural calculations. RVS can be used before or after a catastrophic earthquake. RVS can help identify buildings that are unsafe and may need to be repaired or demolished. Computer algorithms like machine learning, fuzzy logic, and neural networks can be used to improve the accuracy of RVS.

3.2.3 Hazard Zonation

Landslide Hazard Zonation (LHZ) refers to the process of identifying and mapping areas that are prone to landslides based on their susceptibility to such hazards. It involves categorizing regions into different zones according to the probability, intensity, and potential impact of landslide occurrences. This zoning helps in risk assessment, planning, and implementing mitigation measures.

Key Objectives of Landslide Hazard Zonation

1. Identify Susceptible Areas: Pinpoint areas with varying levels of landslide risk (low, moderate, high, or very high).
2. Support Planning: Assist in land-use planning, infrastructure development, and urban expansion by avoiding high-risk zones.
3. Aid Disaster Management: Help in preparedness, evacuation planning, and resource allocation.
4. Minimize Loss: Reduce human, environmental, and economic losses by targeting mitigation measures.

Techniques Used in Landslide Hazard Zonation

1. Qualitative Methods
2. Quantitative Methods
3. Advanced Methods

Applications of Landslide Hazard Zonation

1. Urban and Infrastructure Planning: Avoid constructing buildings, roads, and dams in high-risk zones.
2. Disaster Risk Reduction: Guide government policies and emergency response strategies.
3. Environmental Conservation: Protect natural ecosystems from erosion and degradation.

3.2 LANDSLIDE

Geologists, engineers, and other professionals often rely on unique and slightly differing definitions of landslides. This diversity in definitions reflects the complex nature of the many disciplines associated with studying landslide phenomena. For our purposes, landslide is a general term used to describe the downslope movement of soil, rock, and organic materials under the effects of gravity and also the landform that results from such movement. Regardless of the exact definition used or the type of landslide under discussion, understanding the basic parts of a typical landslide is helpful. The figure bellow shows the position, and the most common terms used to describe the unique parts of a landslide.

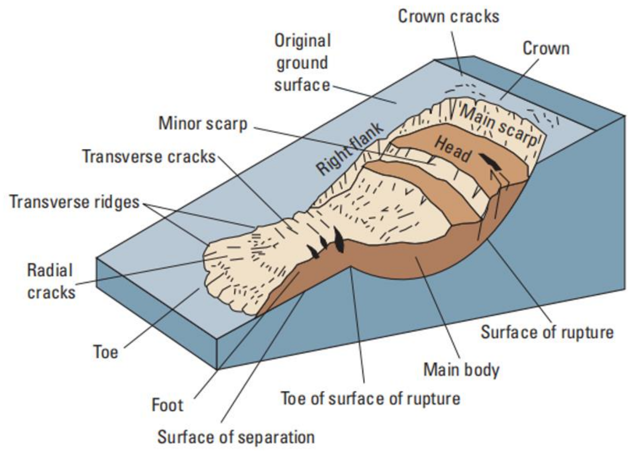


Fig 4: Different Parts of landslide (Source : Landslide Handbook by USGS)

Classification of landslide

Varying classifications of landslides are associated with specific mechanics of slope failure and the properties and characteristics of failure types; these will be discussed briefly herein.

3.2.1 Fall

A fall begins with the detachment of soil or rock, or both, from a steep slope along a surface on which little or no shear displacement has occurred. The material subsequently descends mainly by falling, bouncing, or rolling.

Rockfalls are abrupt, downward movements of rock or earth, or both, that detach from steep slopes or cliffs. The falling material usually strikes the lower slope at angles less than the angle of fall, causing bouncing. The falling mass may break on impact, may begin rolling on steeper slopes, and may continue until the terrain flattens.

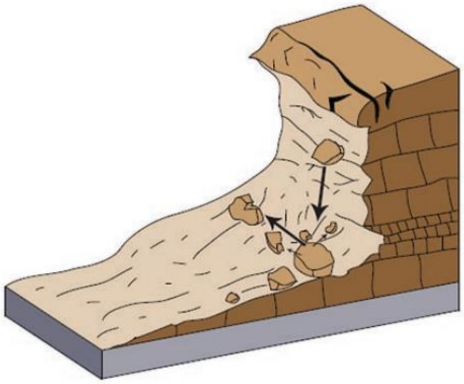


Fig 5 : Schematic of Rockfall

(Source : Landslide Handbook by USGS)

Fig 6 : A rockfall that occurred in Colorado, USA

(Source : Landslide Handbook by USGS)

3.2.2 Topple

A topple is recognized as the forward rotation out of a slope of a mass of soil or rock around a point or axis below the centre of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by the weight of material upslope from the displaced mass. Sometimes toppling is due to water or ice in cracks in the mass. Topples can consist of rock, debris (coarse material), or earth materials (fine-grained material). Topples can be complex and composite.

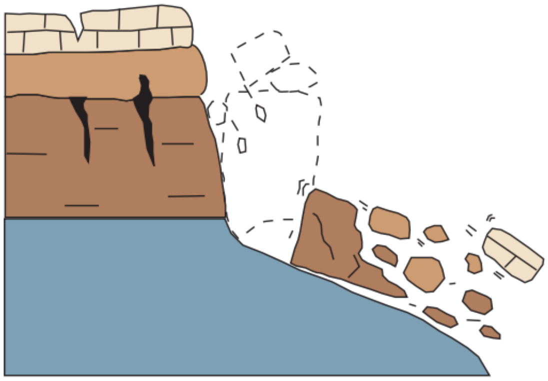


Fig 7: Schematic of a Topple

(Source : Landslide Handbook by USGS)

Fig 8: Block Toppling at British Columbia, Canada

(Source : Landslide Handbook by USGS)

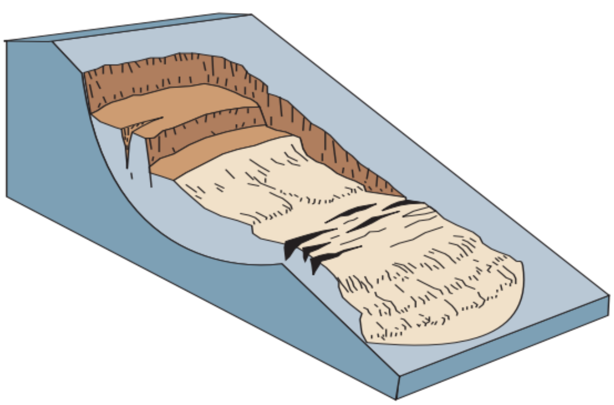
3.2.3 Slide

A slide is a downslope movement of a soil or rock mass occurring on surfaces of rupture or on relatively thin zones of intense shear strain. Movement does not initially occur simultaneously over the whole of what eventually becomes the surface of rupture; the volume of displacing material enlarges from an area of local failure.

Slides are of two types a) Rotational Landslide b) Translational Landslide

Rotational Landslide

A landslide on which the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope. The displaced mass may, under certain circumstances, move as a relatively coherent mass along the rupture surface with little internal deformation. The head of the displaced material may move almost vertically downward, and the upper surface of the displaced material may tilt backwards toward the scarp. If the slide is rotational and has several parallel curved planes of movement, it is called a slump.



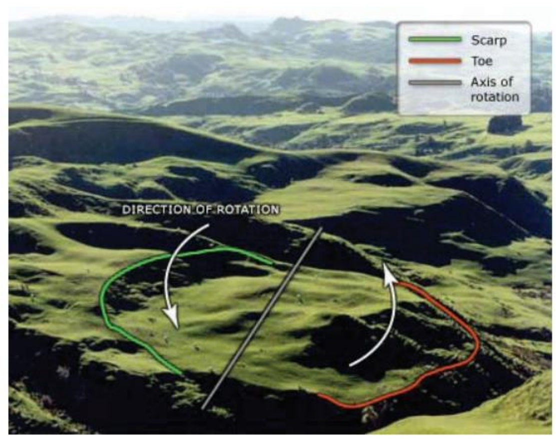


Fig 9: Schematic of Rotational Landslide **Fig10: Rotational Landslide occurred in New Zealand**

(Source : Landslide Handbook by USGS) **(Source : Landslide Handbook by USGS)**

Translational Landslide

The mass in a translational landslide moves out, or down and outward, along a relatively planar surface with little rotational movement or backward tilting. This type of slide may progress over considerable distances if the surface of rupture is sufficiently inclined, in contrast to rotational slides, which tend to restore the slide equilibrium. The material in the slide may range from loose, unconsolidated soils to extensive slabs of rock, or both. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil. In northern environments the slide may also move along the permafrost layer.

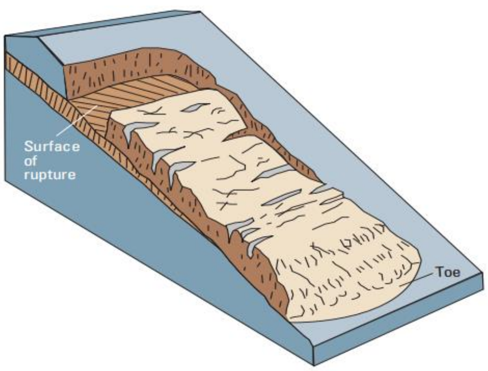


Fig 11: Schematic of translational landslide

(Source : Landslide Handbook by USGS)

Fig 12: A translational landslide in British Columbia, Canada.

(Source : Landslide Handbook by USGS)

3.2.4 Spread

An extension of a cohesive soil or rock mass combined with the general subsidence of the fractured mass of cohesive material into softer underlying material. Spreads may result from liquefaction or flow (and extrusion) of the softer underlying material. Types of spreads include block spreads, liquefaction spreads, and lateral spreads.

Lateral spreads usually occur on very gentle slopes or essentially flat terrain, especially where a stronger upper layer of rock or soil undergoes extension and moves above an underlying softer, weaker layer. Such failures commonly are accompanied by some general subsidence into the weaker underlying unit. In rock spreads, solid ground extends and fractures, pulling away slowly from stable ground and moving over the weaker layer without necessarily forming a recognizable surface of rupture. The softer, weaker unit may, under certain conditions, squeeze upward into fractures that divide the extending layer into blocks. In earth spreads, the upper stable layer extends along a weaker underlying unit that has flowed following liquefaction or plastic deformation. If the weaker unit is relatively thick, the overriding fractured blocks may subside into it, translate, rotate, disintegrate, liquefy, or even flow.

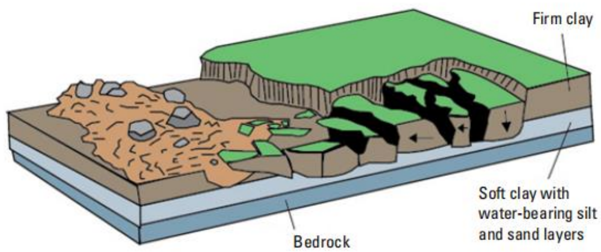


Fig13: Schematic of a lateral spread
(Source : Landslide Handbook by USGS)

Fig 14: Lateral spread damage in California, USA
(Source : Landslide Handbook by USGS)

3.2.5 Flow

A flow is a spatially continuous movement in which the surfaces of shear are short-lived, closely spaced, and usually not preserved. The component velocities the displacing mass of a flow resemble those in a viscous liquid. Often, there is a gradation of change from slides to flows, depending on the water content, mobility, and evolution of the movement.

Debris Flows is a form of rapid mass movement in which loose soil, rock and sometimes organic matter combine with water to form a slurry that flows downslope. They have been informally and inappropriately called “mudslides” due to the large quantity of fine material that may be present in the flow. Occasionally, as a rotational or translational slide gains velocity and the internal mass loses cohesion or gains water, it may evolve into a debris flow. Dry flows can sometimes occur in cohesionless sand (sand flows). Debris flows can be deadly as they can be extremely rapid and may occur without any warning.

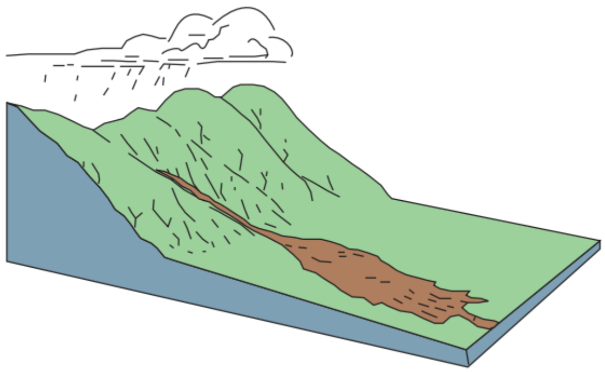


Fig 15: Schematic of Debris Flow

(Source : Landslide Handbook by USGS)

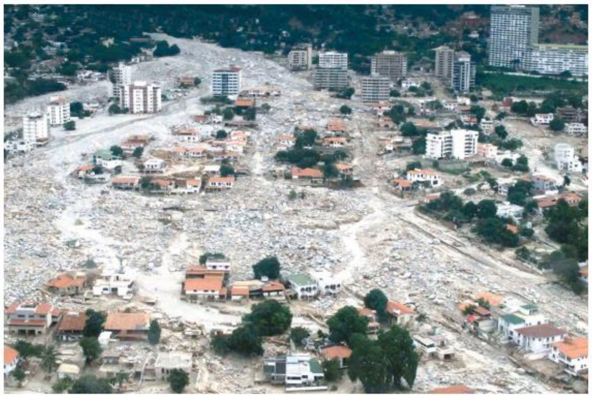


Fig 16: Debris-flow damage in Venezuela

(Source : Landslide Handbook by USGS)

3.2.6 Lahars (Volcanic Debris Flow)

The word “lahar” is an Indonesian term. Lahars are also known as volcanic mudflows. These are flows that originate on the slopes of volcanoes and are a type of debris flow. A lahar mobilizes the loose accumulations of tephra (the airborne solids erupted from the volcano) and related debris.

Fig 17: Schematic of Lahars

(Source : Landslide Handbook by USGS)

Fig 18: Lahar in Washington, USA

(Source : Landslide Handbook by USGS)

3.2.7 Debris Avalanche

Debris avalanches are essentially large, extremely rapid, often open-slope flows formed when an unstable slope collapses and the resulting fragmented debris is rapidly transported away from the slope. In some cases, snow and ice will contribute to the movement if sufficient water is present, and the flow may become a debris flow and (or) a lahar.

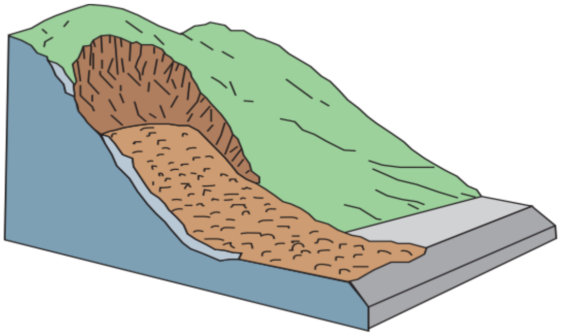


Fig 19: Schematic of Debris Avalanche

(Source: Landslide Handbook by USGS)

Fig 20: Debris Avalanche in Philippines

(Source : Landslide Handbook by USGS)

3.2.8 Earthflow

Earthflows can occur on gentle to moderate slopes, generally in fine-grained soil, commonly clay or silt, but also in very weathered, clay-bearing bedrock. The mass in an earthflow moves as a plastic or viscous flow with strong internal deformation. Susceptible marine clay (quick clay) when disturbed is very vulnerable and may lose all shear strength with a change in its natural moisture content and suddenly liquefy, potentially destroying large areas and flowing for several kilometres. Size commonly increases through headscarp retrogression. Slides or lateral spreads may also evolve downslope into earthflows. Earthflows can range from very slow (creep) to rapid and catastrophic. Very slow flows and specialized forms of earthflow restricted to northern permafrost environments are discussed elsewhere.

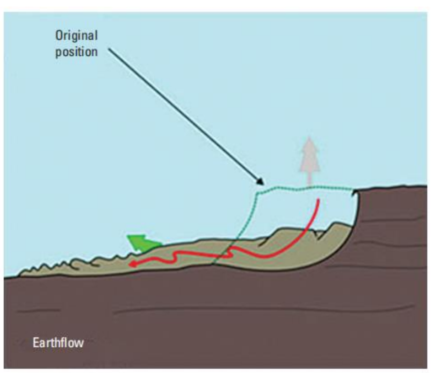


Fig 21: Schematic of an earthflow

(**Source : Landslide Handbook by USGS)**

Fig 22: Earthflow in Ottawa, Canada

(Source : Landslide Handbook by USGS)

3.2.9 Snow Earthflow (Creep)

Creep is the informal name for a slow earthflow and consists of the imperceptibly slow, steady downward movement of slope-forming soil or rock. Movement is caused by internal shear stress sufficient to cause deformation but insufficient to cause failure. Generally, the three types of creep are: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure for other types of mass movements.

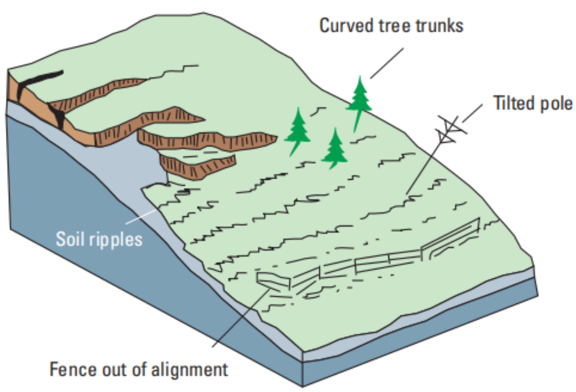


Fig 23: Schematic of Snow Earthflow

(Source : Landslide Handbook by USGS)

Fig 24: Creep in East Sussex, United Kingdom

(Source : Landslide Handbook by USGS)

3.2.10 Flows in Permafrost

Failures in permafrost conditions involve the movement of fine-grained, previously ice-rich soil and can occur on gentle slopes. Seasonal thaw of the upper meter of frozen ground melts ground ice and results in oversaturation of the soil, which in turn loses shear strength and initiates flows. Solifluction, a form of cold environment creep, involves very slow deformation of the surface and forms shallow lobes elongated downslope. Active layer detachments, also known as skin flows, involve rapid flow of a shallow layer of saturated soil and vegetation, forming long, narrow flows moving on the surface but over the underlying permanently frozen soil. This type of movement may expose buried ice lenses, which when thawed may develop into retrogressive thaw flows or possibly debris flows. Retrogressive thaw flows are larger features with a bimodal shape of a steep headwall and low-angle tongue of saturated soil. This type of feature will continue to expand through headscarp retrogression until displaced vegetation buries and insulates the ice-rich scarp.

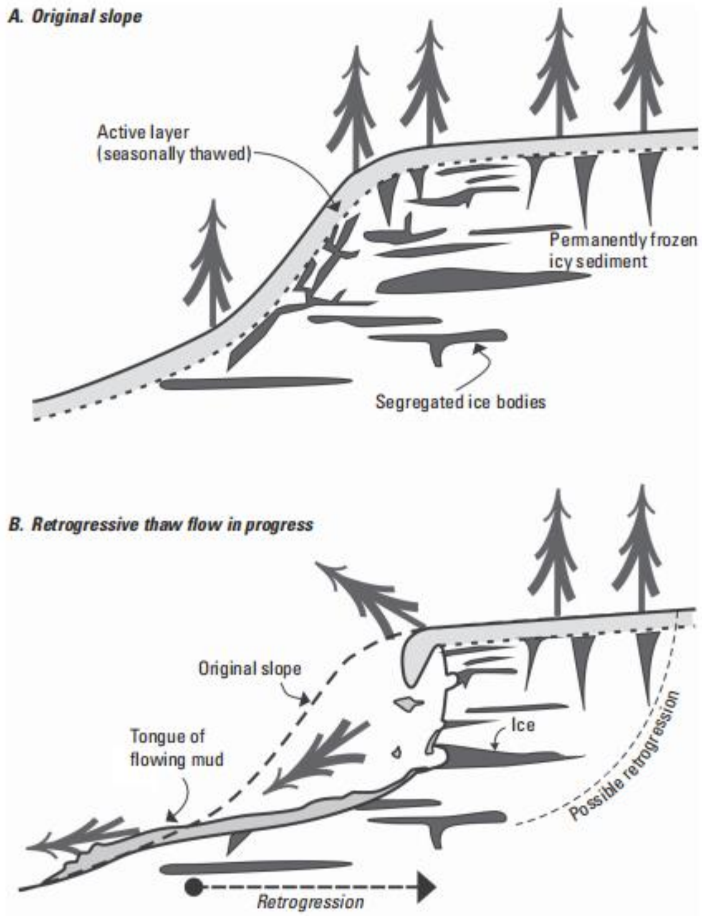


Fig 25: Schematic of a retrogressive thaw flow slide(Source : Landslide Handbook by USGS)

Fig 26: Photograph of a retrogressive thaw flow in the Northwest Territories, Canada

(Source : Landslide Handbook by USGS)

3.3 GUIDELINE

3.3.1 Assam State Disaster Management Plan by ASDMA

The Assam State Disaster Management Authority was notified in the year 2007 with the adoption of the Disaster Management Act in the year 2006.

The aim of State Disaster Management Plan is to ensure that all components of Disaster Management are addressed to facilitate planning, preparedness, operational, coordination and community participation.

The purpose of Assam State Disaster Management Plan is to set out Government of Assam's approach to disaster management in accordance with the operational and legislative responsibilities of the Disaster Management Act 2005 and Assam Disaster Management Rules 2010.

Assam State Disaster Management Plan will stand as a high level document outlining the approach to disaster management by Assam State Disaster Management Authority , Department of Revenue and Disaster Management and allied State Departments. The plan is in alignment of the framework overseeing the following sections: operational, administrative, financial, legal aspects and process. All hazard events, whether natural or man-made the state is vulnerable to, will be managed in accordance with the Assam State Disaster Management Plan. This Plan will be further supported by hazard specific plans; department wise preparedness, mitigation and emergency response plan; state disaster management guidelines (SDMG).

3.3.2 National Landslide Risk Management Strategy by NDMA

India is vulnerable to different types of landslides which cause significant destruction in terms of loss of lives and property. As per Geological Survey of India, about 0.42 million km^2 covering nearly 12.6% of land area of our country is prone to landslide hazards. Mountainous region of the North-Western Himalayas, the Sub-Himalayan terrain of the North-East, the Western and Eastern Ghats are prone to landslides covering 22 States and 2 Union Territories.

During the monsoon, areas witness frequent landslides. Some of the major recent incidents are Kerala (2018), Himachal Pradesh (2018), Uttarakhand (2018), Tamenglong-Manipur (2018), Kalikhola, Manipur (June, 2017); Laptap, Pampare-Arunachal Pradesh (July, 2017); Malpa, Uttarakhand (August, 2017); Kotropi, Himachal Pradesh (August, 2017); Malin, Pune (July, 2014); Mirik, West Bengal (June, 2015) etc. causing huge loss to life and property. Most of the landslides occur due to heavy rainfall. Majority of landslide prone areas are located in the earthquake prone seismic Zone-IV and V. Thus these areas are also prone to earthquake-triggered landslides e.g. Sikkim Earthquake (2011), Kashmir Earthquake (2005), Chamoli Earthquake (1999), Uttarkashi Earthquake (1991) etc. In recent years, the incidences of landslides have increased due to extreme weather events, environmental degradation due to human interference and other anthropogenic activities resulting in heavy losses of human lives, livestock and property.

Thus, a need for formulation of National Landslide Risk Management Strategy was felt. National Disaster Management Authority constituted a Task Force for the formulation of national and local level strategy for landslide risk reduction. Strategy document addresses all the components of landslide disaster risk reduction and management such as hazard mapping, monitoring and early warning system, awareness programmes, capacity building and training, regulations and policies, stabilization and mitigation of landslide etc. This strategy document envisages specific recommendations for the concerned nodal Agency, Ministries / Departments, States and other stakeholders, so as to avert or reduce the impact of future landslide calamities.

3.3.3 Landslide Handbook- A Guide to Understanding Landslides by USGS

This handbook is intended to be a resource for people affected by landslides to acquire further knowledge, especially about the conditions that are unique to their neighbourhoods and communities. Considerable literature and research are available concerning landslides, but unfortunately little of it is synthesized and integrated to address the geographically unique geologic and climatic conditions around the globe. Landslides occur throughout the world, under all climatic conditions and terrains, cost billions in monetary losses, and are responsible for thousands of deaths and injuries each year. Often, they cause long-term economic disruption, population displacement, and negative effects on the natural environment.

Outdated land-use policies may not always reflect the best planning for use of land that is vulnerable to landslides. The reasons for poor or non-existent land-use policies that minimize the perceived or actual danger and damage potential from geologic hazards are many and encompass the political, cultural, and financial complexities and intricacies of communities. Landslides often are characterized as local problems, but their effects and costs frequently cross local jurisdictions and may become State or Provincial or national problems.

Growing populations may be limited in their geographic expansion, except to occupy unstable, steep, or remote areas. Often, stabilizing landslide-scarred areas is too costly, and some inhabitants have no other places to relocate. Fortunately, simple, “low-tech” precautions and actions can be adopted to at least ensure an individual’s immediate safety, and this handbook gives a brief overview of many of these options. We strongly suggest that, where possible, the assistance of professional engineers/geologists or those experienced in the successful mitigation of unstable slopes be consulted before actions are taken. This handbook helps homeowners, community and emergency managers, and decisionmakers to take the positive step of encouraging awareness of available options and recourse in regard to landslide hazard.

3.4 SOFTWARE

3.4.1 ArcGIS

ArcGIS is a comprehensive geospatial platform for professionals and organizations, and the leading geographic information system (GIS) technology. GIS is a proven IT technology that helps users understand patterns, relationships, and geographic context, providing a foundation for mapping and analysis that is used for business, operational, and scientific workflows in almost every industry. It is the leading geographic information system (GIS) technology. Built by Esri, ArcGIS integrates and connects data through the context of geography. It provides world-leading capabilities for creating, managing, analyzing, mapping, and sharing all types of data.

ArcGIS connects maps, apps, data, and people in ways that help empower organizations to make data-driven decisions more efficiently. ArcGIS accomplishes this by making it easy for everyone in an organization to discover, use, make, and share maps from any device, anywhere, at any time. ArcGIS is designed to be flexible, offering these capabilities through multiple implementation patterns and approaches.

What ArcGIS can do

- Create maps: Build maps to visualize geographic data, such as climate data or trade flows
- Analyze data: Use spatial analytics to understand how location affects challenges like climate change or resource allocation
- Share data: Share maps and data with others, or keep them private
- Collaborate: Work with colleagues to build maps, apps, and notebooks

How ArcGIS works

- ArcGIS connects data through geography, making it easy to discover, use, and share data
- ArcGIS allows users to create geographical information that can be accessed across an organization or on the internet

ArcGIS components

- ArcGIS Online: A cloud-based mapping and analysis solution that allows users to access maps, data, and apps from around the world
- ArcMap: A program that allows users to view, edit, create, and analyze geospatial data
- ArcGIS Knowledge: An entity-centric approach to data modeling and analysis

3.4.2 Google Earth

Google Earth Pro is a free software that, albeit not a true GIS, allows visualization, assessment, overlay, and creation of geospatial data. This user-friendly resource is often a useful intermediary for learners who are interested in learning more about GIS and want to start with more basic processes and tools.

Features:

- High-resolution satellite imagery: View the Earth in high resolution using satellite and airplane images
- Geospatial data: Import, export, and create geospatial data in KML format
- Historical imagery: View historical imagery to go back in time
- Add-on software: Use add-on software for movie making, advanced printing, and precise measurements
- Search capabilities: Search for specific coordinates
- Tools for creating data layers: Create new data layers
- Polygon tool: Draw polygons to mark areas, give them titles and descriptions, and change the color of the fill and outline

Use cases:

- Learning about GIS: A useful tool for beginners who want to learn more about GIS
- Scientific research: Used by students and scientists around the world
- Casual use: Basic enough for casual users to pick up

3.4.3 HYRCAN

HYRCAN offers a stand-alone windows system that is very simple to use, yet complex models can be created and analyzed quickly and easily. The graphical user interface enables quick generation of advanced models, and the enhanced output facilities provide a detailed presentation of computational results.

Features:

- Graphical user interface (GUI): Allows users to quickly create advanced models
- Output facilities: Provides detailed results of computations
- Analysis procedures: Fully automated and based on numerical procedures
- Embedded scripting languages: Allows users to interact with and manipulate models
- Project management facilities: Allows users to manage projects
- Plotting capabilities: Allows users to plot results
- Run-time monitoring: Allows users to monitor results in real time

How to use:

1. Enter geometry, material properties, and analysis constraints
2. Specify boundaries and support elements
3. Add external loading, groundwater, and support
4. View results in the GUI

Availability:

- HYRCAN is available for Windows 7, 8, and 10
- It's available in multiple languages, including English, Portuguese, Chinese, Italian, Turkish, Russian, and Polish

Developer:

- Roozbeh Geraili Mikola is the developer of HYRCAN

3.4.4 MACCAFERRI

Maccaferri is an international provider of solutions for the civil, geotechnical, and environmental construction markets. They have been in business for over 140 years.

Features

- User-friendly: The software is designed to be easy to use
- Cost-effective: The software is designed to be economical
- Improved buildability: The software is designed to improve the buildability of projects
- BIM integration: Some Maccaferri software can be integrated with Building Information Modelling (BIM) to improve design accuracy and collaboration Software products
- eDesign: An online software that doesn't require a download
- MACS-Design: A software suite that helps users determine suitable facing systems for pinned drapery solutions
- MacTube Design: A software for tubular geotextile containers
- MacBars Design: A software for stabilizing embankments
- REQUALIFE: A web application that allows technicians and designers to carry out eco-morphological quality assessments

3.4.5 GeoStudio

GeoStudio is a software suite that helps engineers model and analyze geotechnical conditions. It's used in civil and mining engineering projects to analyze slope stability, groundwater flow, and environmental challenges.

Features:

- Limit equilibrium analysis: Analyses the stability of soil and rock slopes
- Finite element stress-based stability analysis: Analyses the stability of a system based on stress
- Automated strength reduction stability analysis: Analyses the stability of a system by reducing its strength
- Rapid drawdown analysis: Analyses the effect of rapid drawdown on a system

- Complex seepage analysis: Analyses the effect of seepage on a system
- Dewatering and settlement assessment: Analyses the effect of dewatering and settlement on a system
- Construction sequence organization: Organizes complex construction sequences
- Graphing and visualization tools: Helps interpret results and compare them to the physical system

Uses:

- Designing embankments, levees, and dams
- Understanding how ground conditions impact excavations
- Predicting soil settlement and structures' displacement
- Modelling heat transfer with phase change

CHAPTER 4
METHODOLOGY

4.1 GENERAL

A methodology refers to a system of methods, principles, and rules used to guide a specific process or achieve a particular goal. In geotechnics, methodology plays a crucial role as it provides a systematic approach to investigating, analyzing, and solving problems related to the behavior of soil, rock, and other materials.

Methodology for Landslide Hazard Mapping involves a systematic approach to identify, assess, and map areas prone to landslides. It includes data collection, field surveys, identification of causative factors, selection of mapping technique, mapping and zonation, validation and accuracy assessment and application of mitigation planning. This is crucial for understanding risks, planning mitigation strategies, and guiding development.

4.2 LANDSLIDE RISK MANAGEMENT FRAMEWORK

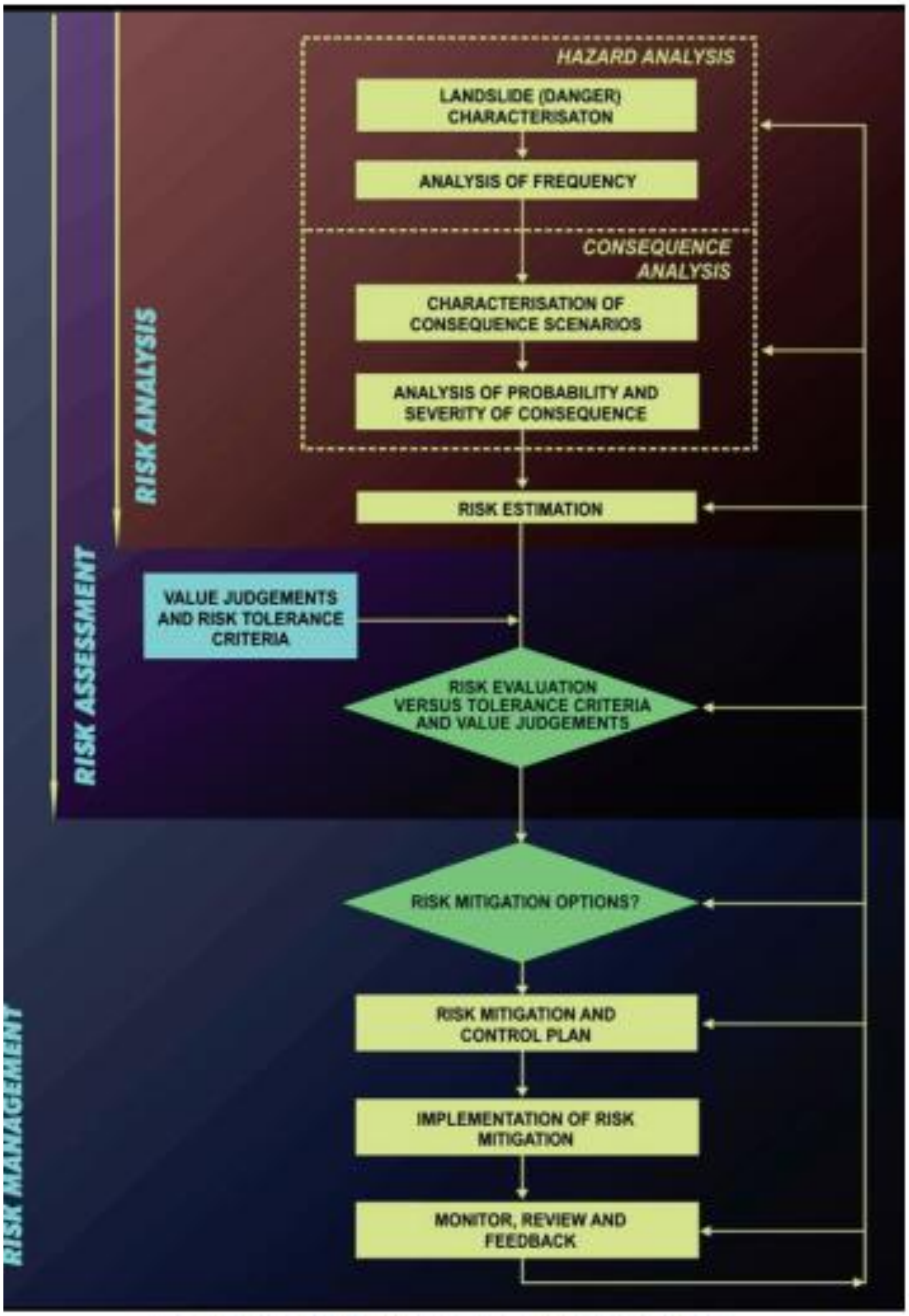
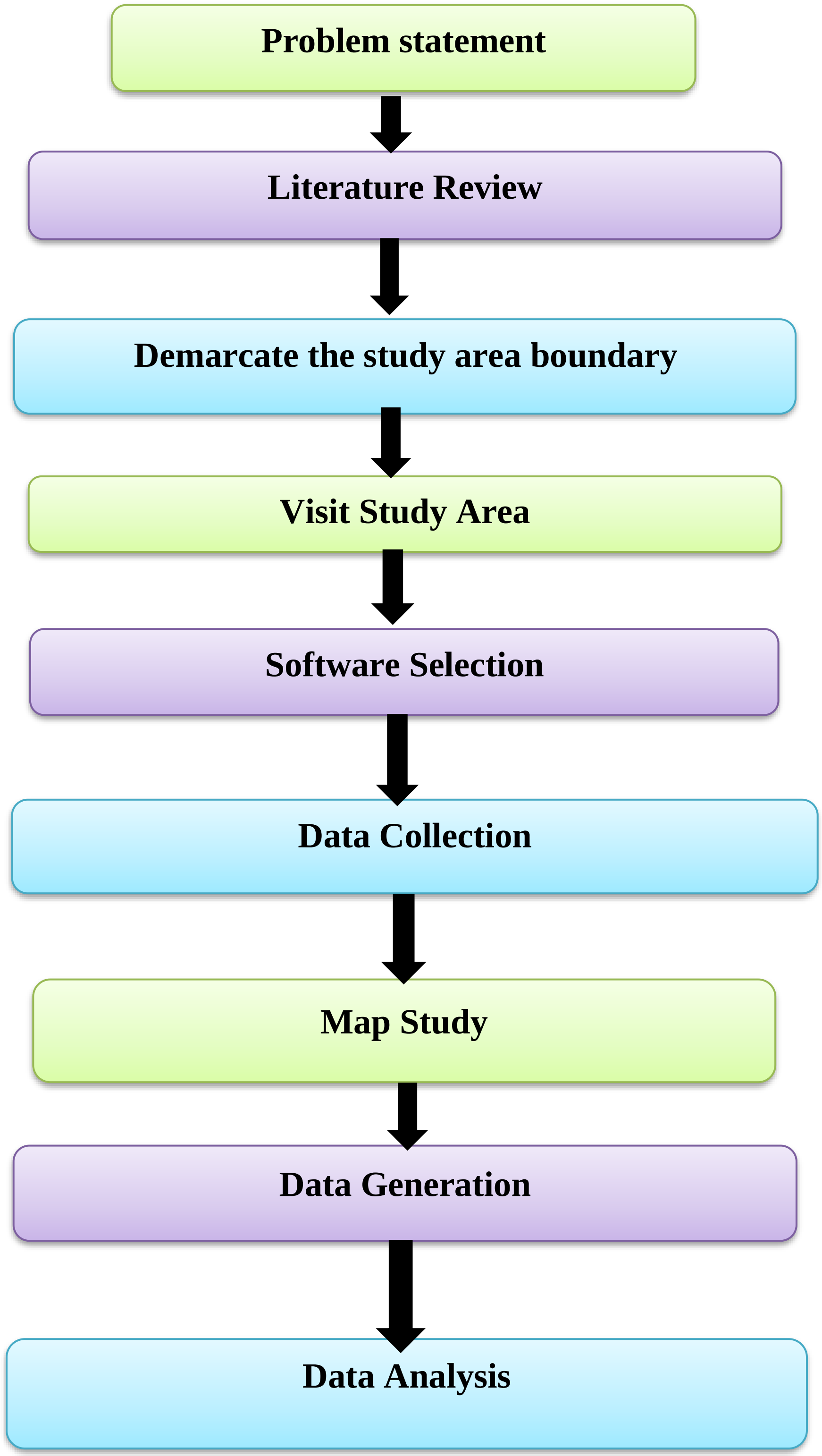


Figure. 2: Landslide Risk Management Framework (Fell et al., 2005)

4.3 FLOW OF WORK



CHAPTER 5

RESULTS AND DISCISSION

5.1 GENERAL

The preliminary map study of the Kharghuli area was performed in the Google Earth Pro platform. The boundary was marked aligning with the previous "Rapid Visual Screening of Potential Landslide Prone Areas of Guwahati City". The longitudinal and cross-sectional elevation profiles at 12 sections have been generated. The digital elevation model of the study area was processed in ArcGIS platform to generate contours and 3D visuals of the Kharghuli area.

5.2 MAPS

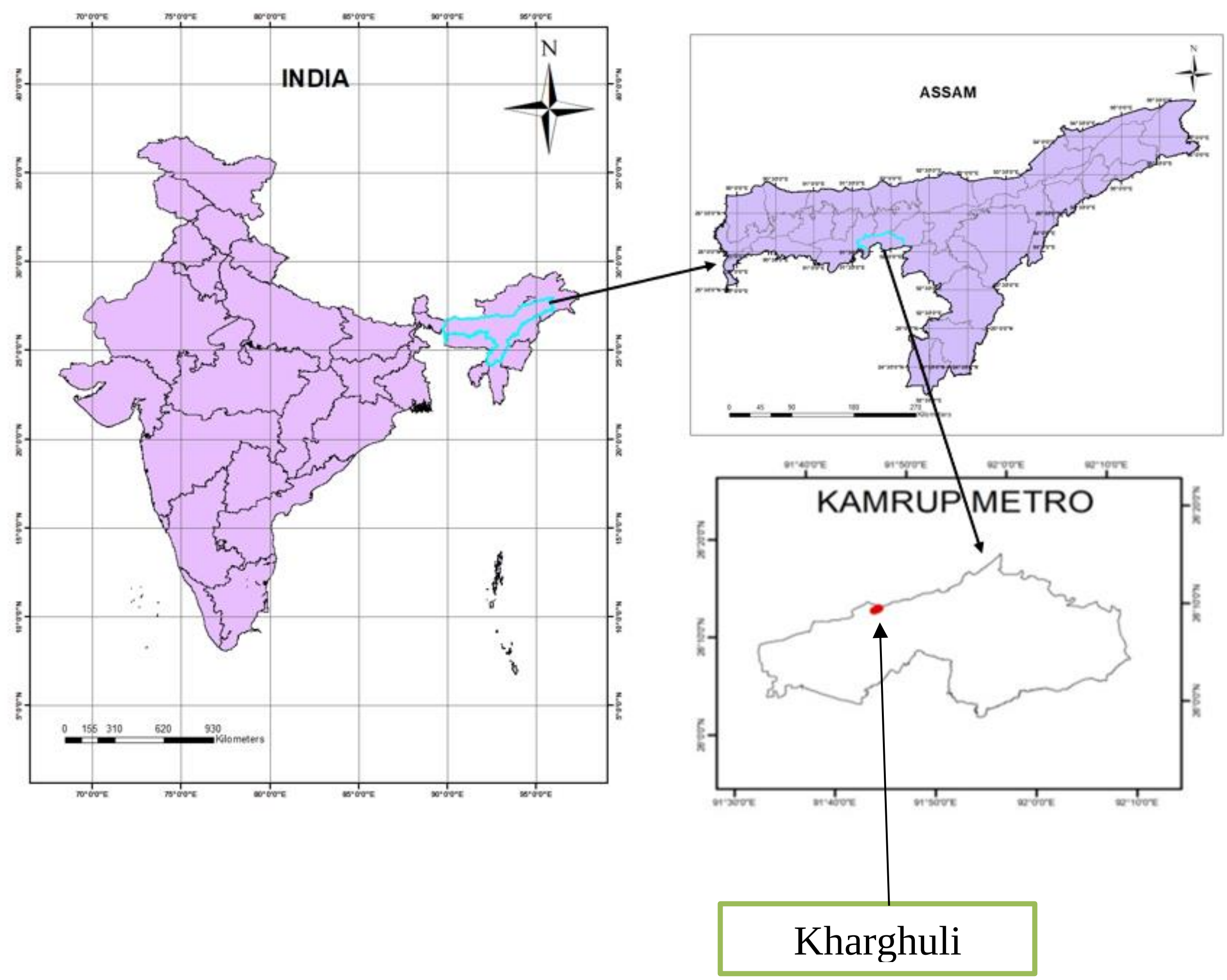


Fig 27: Study Area - Kharghuli

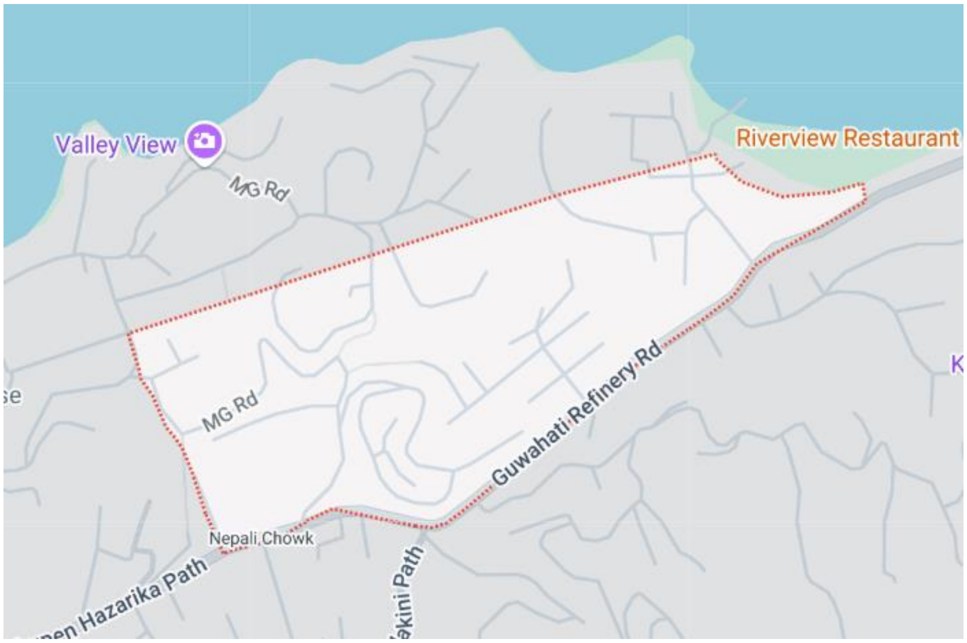


Fig 28: Google image of Kharghuli

Fig 29: Boundary of study area

Fig 30: Location of study sites for the RVS for Potential Landslide Area

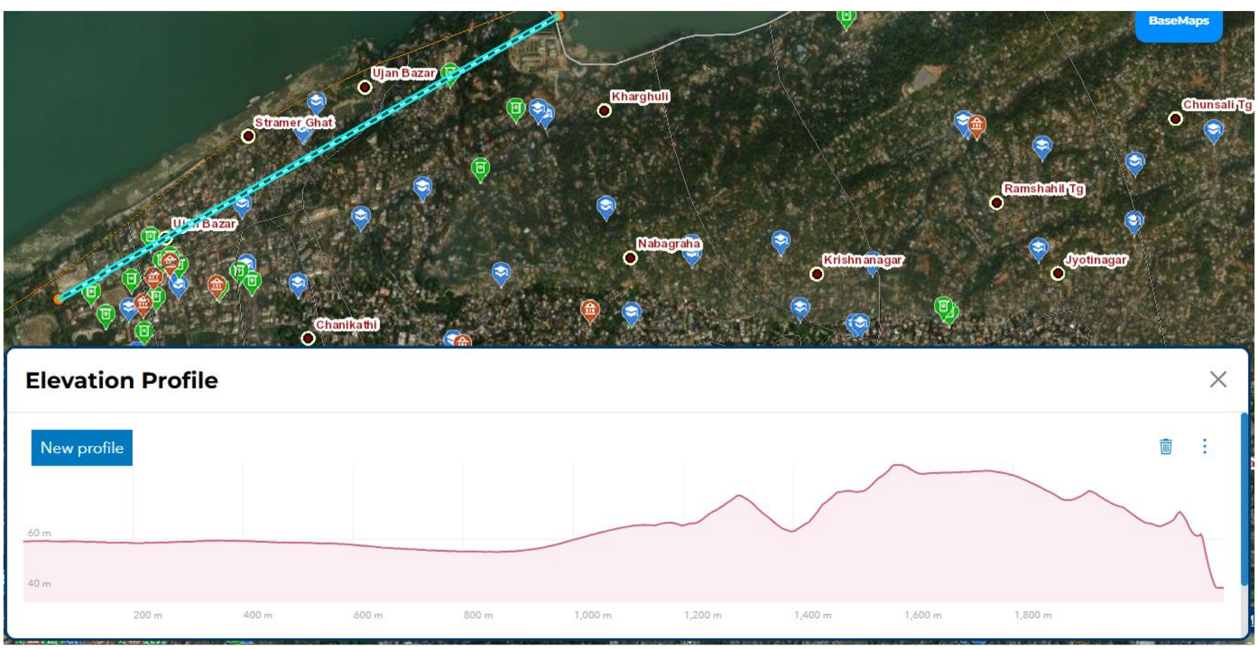


Fig 31: Longitudinal Profile of study area

Fig 32: Sections at an interval of 200 m

Fig 33: Elevation profile at section 1

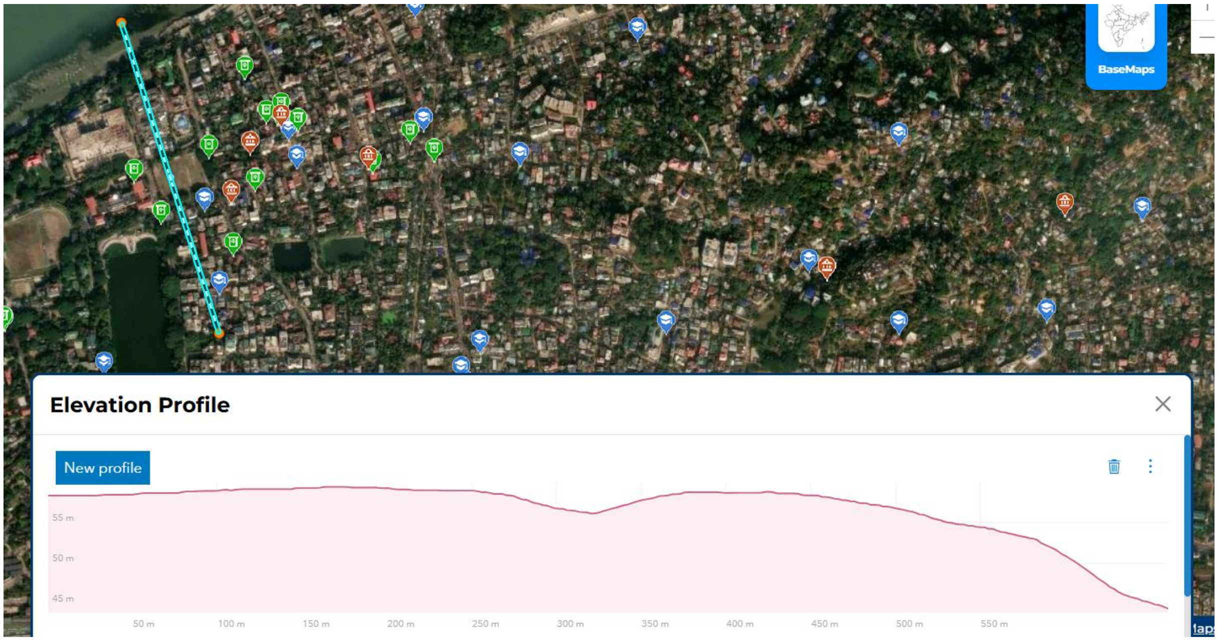


Fig 34: Elevation profile at section 2

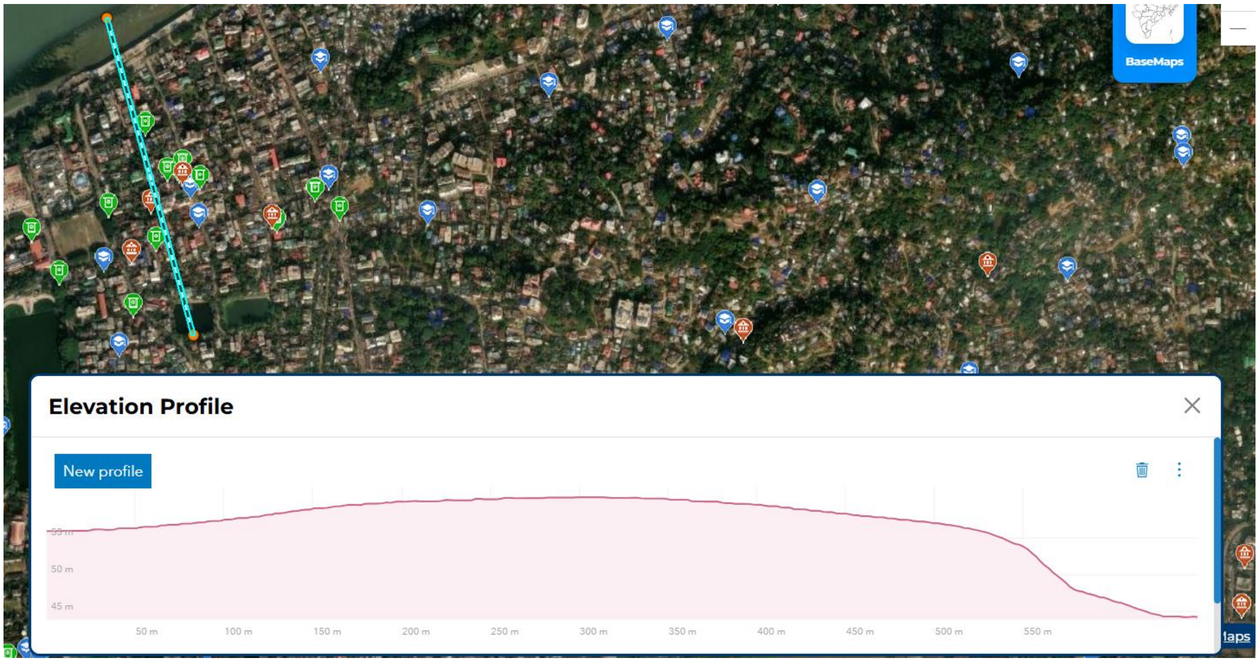


Fig 35: Elevation profile at section 3

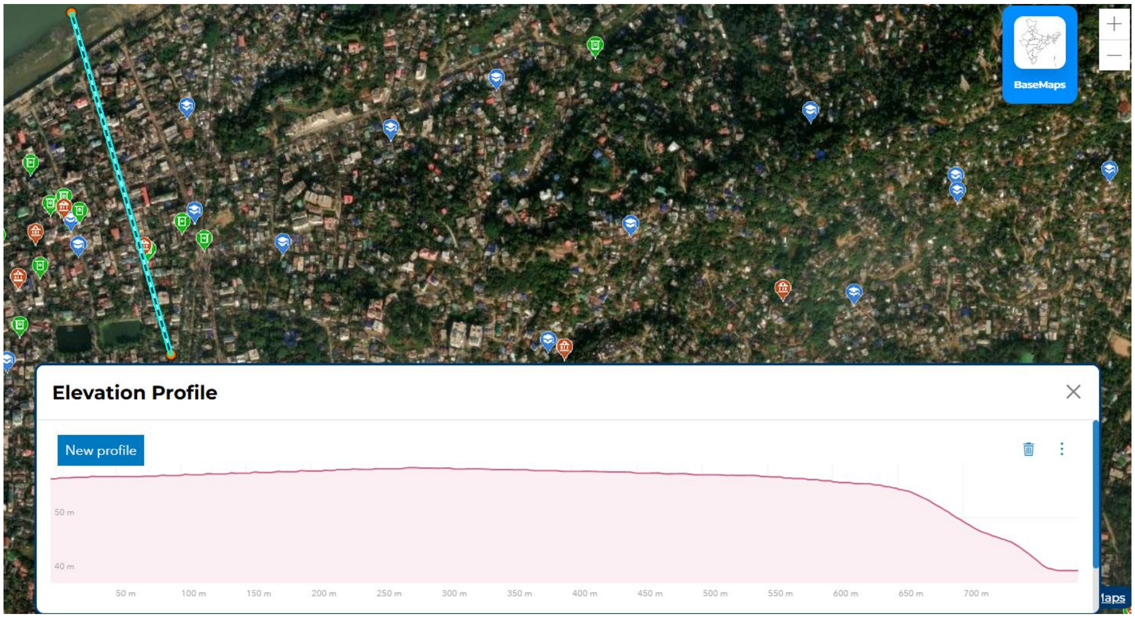


Fig 36: Elevation profile at section 4

Fig 37: Elevation profile at section 5

Fig 38: Elevation profile at section 6

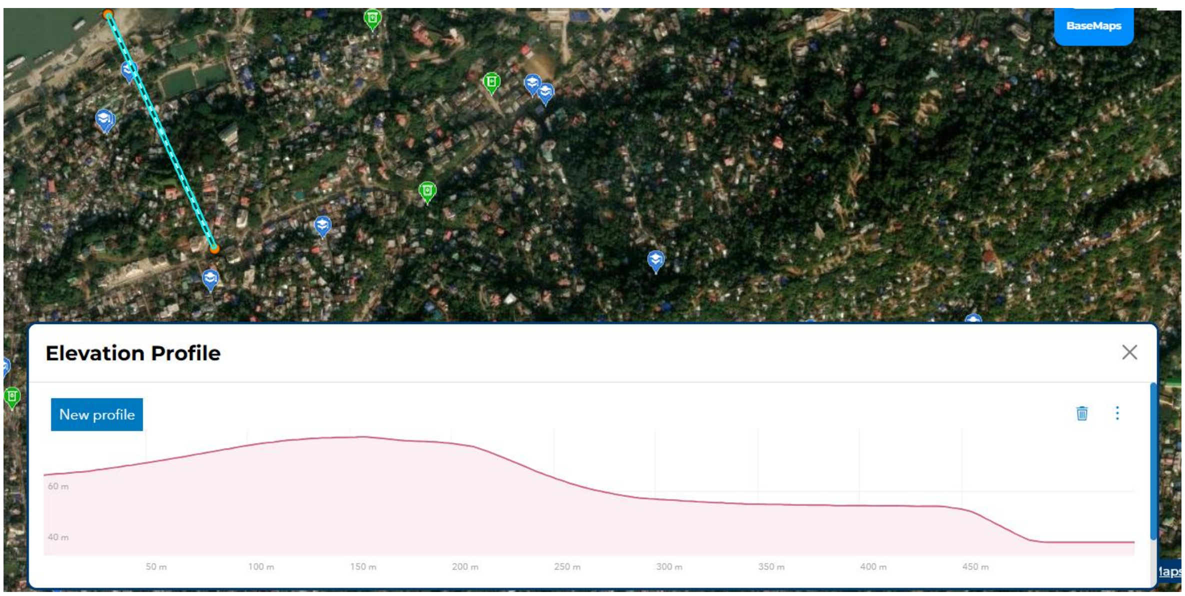


Fig 39: Elevation profile at section 7

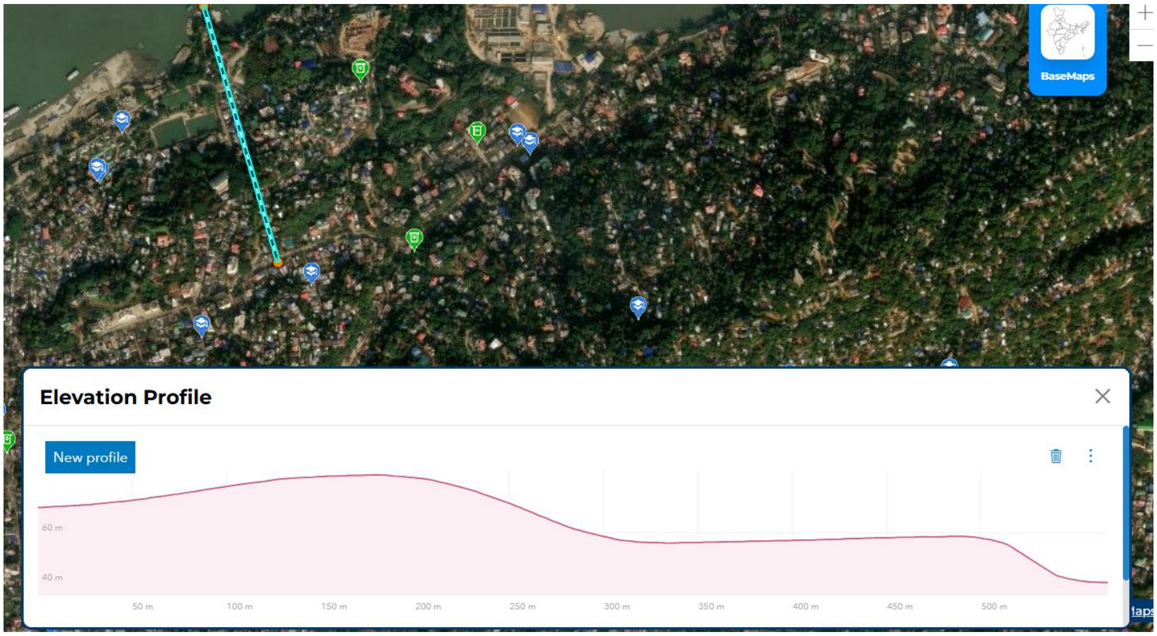


Fig 40: Elevation profile at section 8

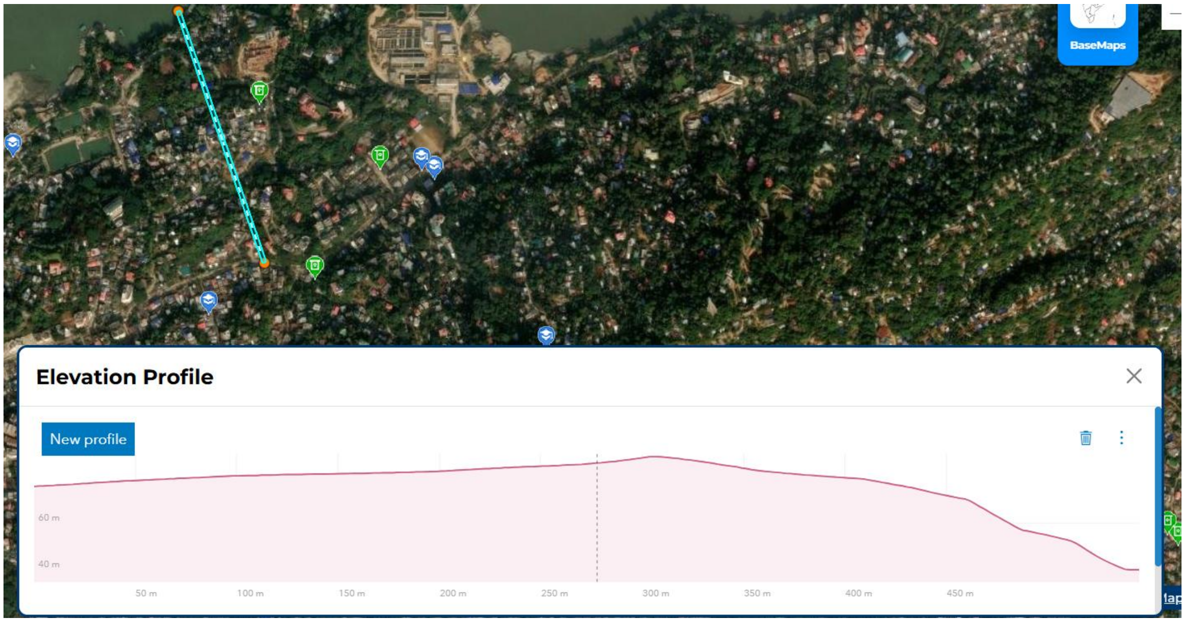


Fig 41: Elevation profile at section 9

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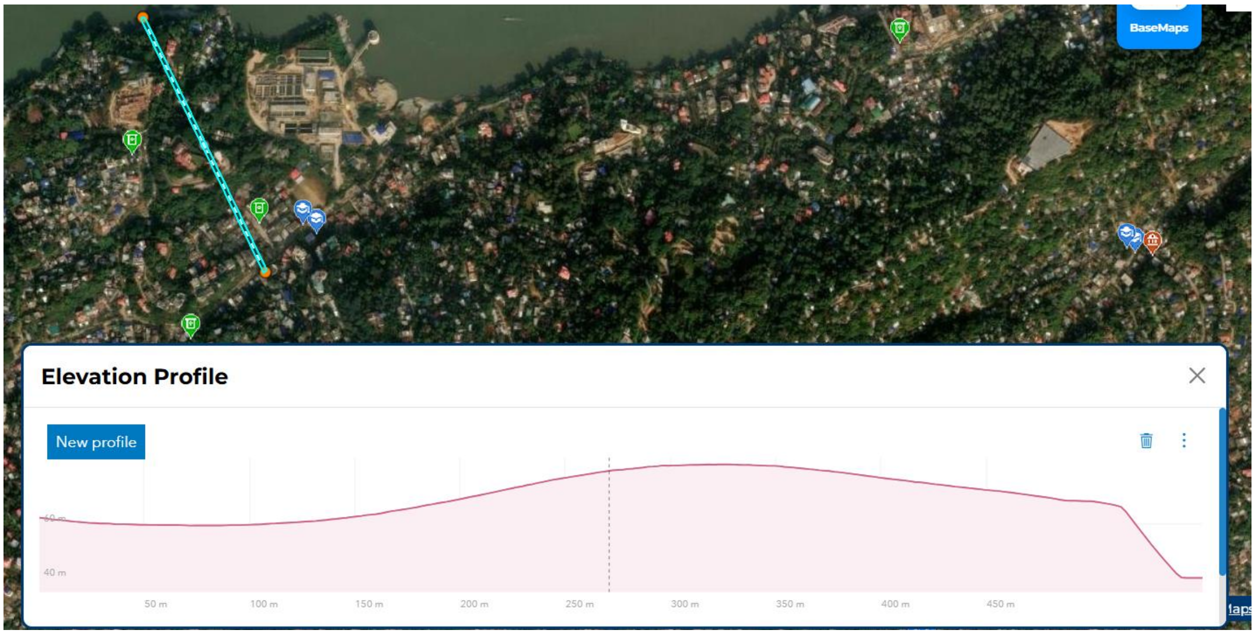

Fig 42: Elevation profile at section 10

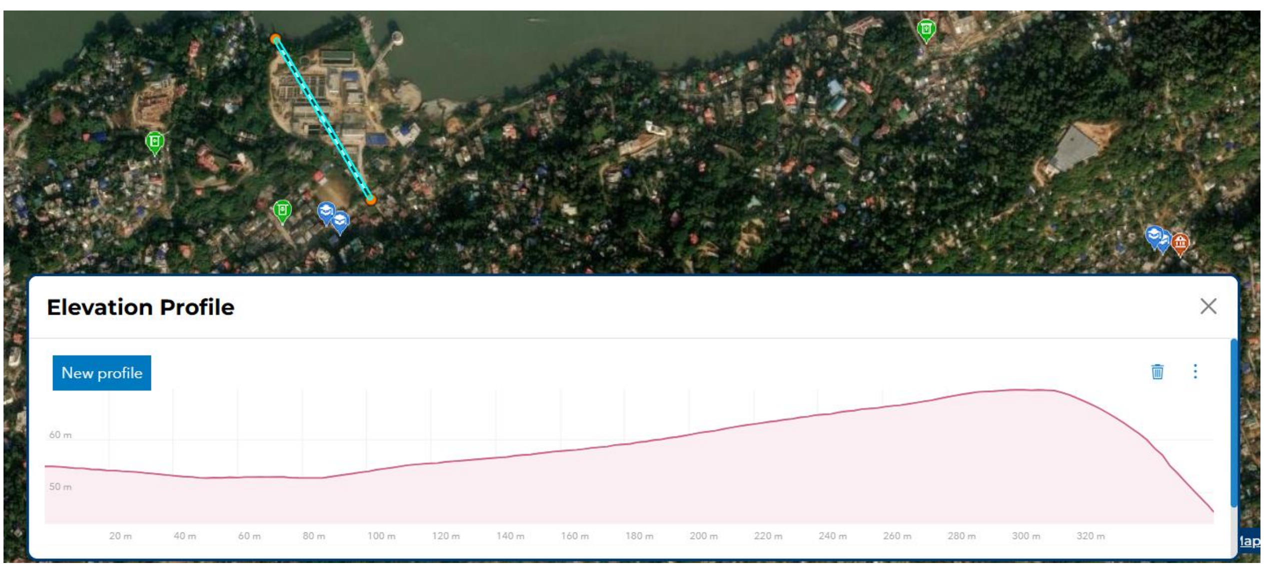

Fig 43: Elevation profile at section 11

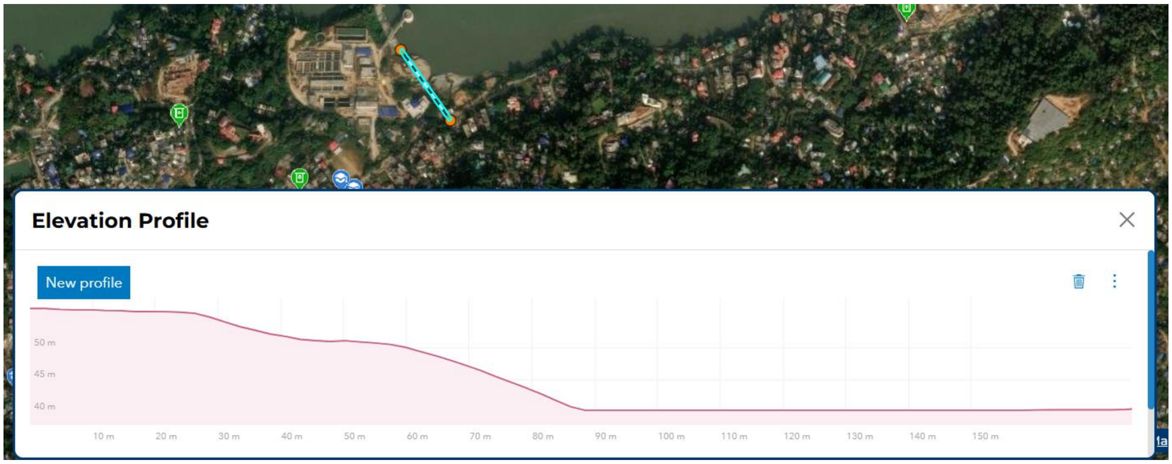

Fig 44: Elevation profile at section 12

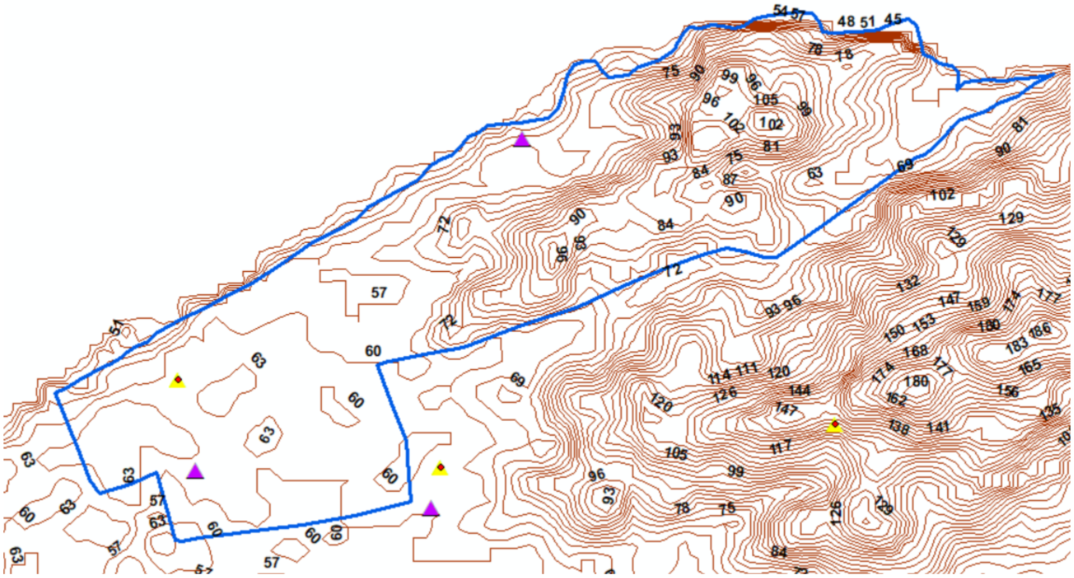

Fig 45: Contour Map

Fig 46: Contour Map overlapping on Base Map

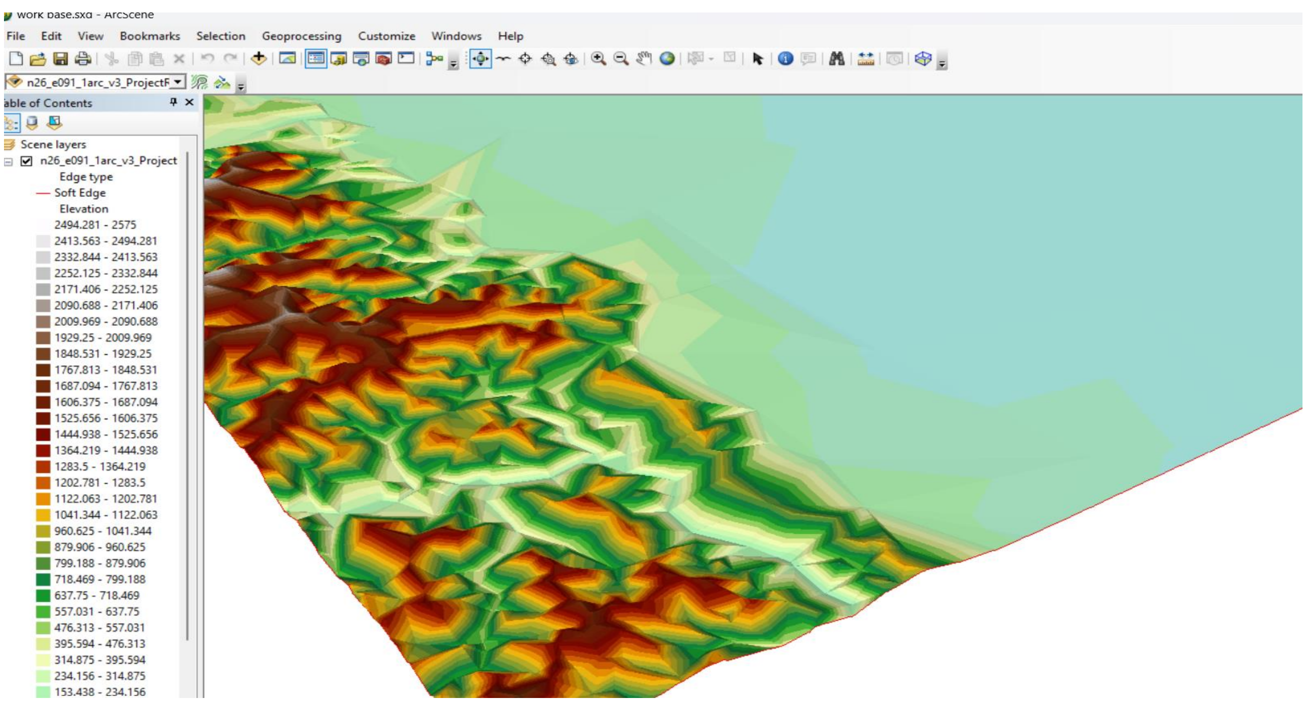

Fig 47: Processed DEM

CHAPTER 6

CONCLUSION

7.1 CONCLUSION

The Kharghuli is mostly a residential area of Guwahati city. The study area is around 1.08 sq. km and the perimeter is 6.08 km. The length of the stretch is about 2.44 km and the width varies from 283 m to 650m. From the longitudinal and 12 cross sectional elevation profile, it has been seen that the area is having a ridge line at approximately one third of the width from the opposite side of the river and the slope is steeper towards the river side. From the historical images of this area, it has been observed that there were very few multistoried buildings but nowadays its increasing and numbers of apartments is also there. Necessity of facilities like road, drainage is also increasing because of urbanization and population growth. Therefore, it is very important to have a hazard zonation map for the planner and designer to make sustainable development in this area.

7.2 FUTURE SCOPE

- Detail Geotechnical investigation
- Critical slope determination
- Determination of slope stability
- Generation of LULC
- Seismic Landslide Hazard Zonation
- Gound Improvement

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