Building Vulnerability Assessment for Hazards Management: A Case Study of a Hilly Town in North East India

F. Phibawanlang Kharpran

Research Scholar, Department of Geography, North Eastern Hill University, Shillong-793022, India

Abstract: ***Vulnerability from the perspective of disaster management means assessing the threats from potential hazards to the population and to infrastructure. A vulnerability assessment is the process of identifying, quantifying, and prioritizing (or ranking) the vulnerabilities in a system. It may be conducted in the political, social, economic or environmental fields. The elements mention above for analyzing or accessing vulnerability is taken as the parameters for conducting the study on "Building Vulnerability Assessment for Hazards Management: A Case Study of a hilly town in North East India". The present study attempts to make an analysis of vulnerability of types of houses and the building structures of (one locality) residential area, by studying the natural features of the area of study using modern technologies such as Remote Sensing and GIS thus checking the level of preparation of a locality towards natural hazards.***

Keywords: vulnerability, assessment, hazard, urban, management

1. Introduction

The earth we live in is an unstable one, events of destruction and reconstruction is a natural phenomenon but when this natural phenomenon occurs in a populated area it turns into a hazardous event. Since natural hazards cannot be prevented and human keeps on increasing the risk, what is needed is *Vulnerability Assessment* which will aid in reducing the risk of disasters and helps in disaster management. The term vulnerability has been used by different sectors and disciplines in a relative sense. The word vulnerability has an intrinsic value when we talk about disaster management it is the foremost step or an important key which drives the cycle for managing disaster. Very few studies have been done on a micro level i.e. of a locality regarding vulnerability assessment. Shillong being a city falling under the high zone of seismic intensity is very much vulnerable to earth quake keeping a risk of loss to life and property. Riatsamthiah a residential ward of Shillong is located in the steep slopes or ridge in the south bank of a stream called Wah Umkhrah. In this ward the manners in which the houses are being constructed at the top of the sliding plates of hills and at the edges near the stream are indeed, beckoning for catastrophe to happen with worst outcome. Haphazard high rise structures with very few narrow exits, surrounded by strong and reinforced cement and fabricated steel will hardly allow few people to escape, if and when disaster strikes. Electrical wiring connections are faulty. Many constructions have encroached into public roads and footpaths. A simple glance at all these features justifies the area selected making it vulnerable to various types of natural hazards such as landslides earthquakes and also to floods.

Natural Hazard is a naturally occurring event that might have a negative effect on people or the environment. World Meteorological Organization (WMO) states that "Natural hazards are severe and extreme weather and climate events that occur naturally in all parts of the world, although some regions are more vulnerable to certain hazards than others. Natural hazards become natural disasters when people's lives and livelihoods are destroyed." Every year natural hazards such as cyclones, floods, volcanoes, earthquakes, landslides and tsunamis claim thousands of lives devastate homes and destroy livelihoods. Natural Disaster is the aftermath or the consequence of the natural hazard that took place. Natural Hazards are natural phenomenon that are afeature of our planet and cannot be prevented however a natural disaster can be controlled by proper management. Its intensity is measured by the number of lives loss and amount of property damage [1]**.** Savindra Singh in his book *Environmental Geography* highlights many factors and elements for assessing vulnerability. These can be group as the type or nature of hazards such as cyclones, earthquakes, landslides, tsunami, floods etc. Spatial unit or area of vulnerability which can be a particular locality, region or a country, or community. Speed of hazards and duration of hazards e.g. rapid onset but long-term impacts such as landslides [2]. Another important element which is the main theme of the present study is resistibility of materials of physical structures **s**uch as different types of buildings in varying locations e.g. hill slopes or river valleys. **Disaster risk reduction** is the concept and practices of reducing disaster risks through systematic efforts to analyze and reduce the causal factors of disasters. Reducing exposure to hazards, lessening vulnerability of people and property, wise management of land and the environment, and improving preparedness and early warning for adverse events are all examples of disaster risk reduction. Disaster risk reduction includes disciplines like disaster management, disaster mitigation and disaster preparedness, but DRR is also part of sustainable development. In order for development activities to be sustainable they must also reduce disaster risk. On the other hand, unsound development policies will increase disaster risk and disaster losses. Thus, DRR involves every part of society, every part of government, and every part of the professional and private sector. The present work undertaken, thus deals mainly with the mitigation phase of the Disaster management cycle. Since natural hazards cannot be prevented and human keeps on increasing the risk, what is needed is *Vulnerability Assessment* which will aid in reducing the risk of disasters and helps in disaster management.

A report of the Turkey-US Geotechnical Reconnaissance Team September 3, 1999 of the Marmara earthquake which shook Turkey on 18 August 1999, give a clear insight on the performance of buildings in the urban area[3]. It show that 120,000 poorly engineered houses were damaged beyond repair, 30,000 houses were heavily damaged, 2,000 other buildings collapsed and 4,000 other buildings were heavily damaged. In one of the area surveyed in Adapazari some old wood structures with masonry brick infill performed remarkably well during the earthquake, whereas nearby more modern reinforced concrete buildings collapsed. Each time, the Turkish public, known for its patience and ability to put up with shortcomings and injustices, was prepared to offer as much as they could to alleviate the suffering caused by these earthquakes. However, this time, the establishment in the capital city of Ankara got a slightly different reaction. After the 1998 earthquake in Ceyhan, some people sued their building contractors but these demands for justice were probably not strong and visible enough to affect the "business as usual" attitude towards building safety in Turkey. All of those involved in the building process – from contractors and civil engineers to council inspectors and clients – have played a role in turning a natural hazard into a disaster. It is impossible to identify any one group of professionals as the guilty ones. However, some immediate lessons can be derived from this tragedy, highlighting the main shortcomings of disaster management in turkey – a lack of mitigation, preparedness and professional ethics [4]. A number of Asia-Pacific countries have been looking at housing resilience. In the Islamic Republic of Iran, for example, the building code for unreinforced masonrybuildings now limits these to two storeys and a height of 8 metres and includes provisions for seismic design.

Bangladesh, with the support of the Climate Investment Fund, is planning to develop low-cost, storm and cyclone proof housing. For Myanmar, there are now illustrated practical guidelines for retrofitting rural houses. While codes and guidelines are essential, national and local authorities also have to ensure that builders and homeowners comply with these. It should also be noted that good building practices can be fostered even without a code, as shown in the rebuilding after the 2005 earthquake in a remote and mountainous region of Pakistan [5].

North-East India is afflicted by three main natural hazards: floods, earthquakes and landslides. The earthquakes occurring in 1897 and in 1950 were very severe, the first one measuring 8.7 and the second one 8.5 on the Richter scale. The earthquake of 1950 not only caused tremendous loss of property and life, but even changed the course of many rivers including the morphology, especially depth profile of Brahmaputra. Landslide is another dominant hazard in the North-east region, especially in the populated hill slopes in and around the urban centres and along the hill sections of highways. The principal factors are-heavy and prolonged rainfall, destabilization of hill slopes due to deforestation, impact of earthquake tremors, and occurrence of massive cloudbursts. Floods are a recurring annual feature of Assam during monsoon period. In very severe floods, three to four million hectares of land are affected. The floods affect the crops, because erosion, breach embankments, washes away cattle, destroy houses, uproot trees and even affect the wildlife sanctuaries [6].

2. Objectives

The main objectives of this present work are: to study the vulnerability of the locality to natural hazards and to assess the vulnerability of these houses and buildings to any natural hazard by classifying them into different vulnerability class.

3. Database and Methodology

Necessary information has been compiled from a number of sources like Survey of India topographical map 1:50000 sheet 78 O/14; Land sat imagery 2015 downloaded from Google earth; for primary data, field observation was used to gather empirical information about different layers required for analysis using GIS software MapInfo. A number of books, articles, journals were used as reference for a clear understanding of the concepts and methodology for carrying out the present work.

The tools used for analysis includes Cartography which is the most obvious example of a geographic technique and Geographic Information system(GIS) an outgrowth of digital cartography, which provide a set of tools for storing, retrieving, analysing and displaying spatial data from real world. Using MapInfo software, maps are prepared having all the attributes required for building vulnerability assessment.

The work was made using an orthophoto downloaded from Google earth software. This is used as a base map on which all land parcels and roads, within the study area and its direct surroundings were digitized using spatial entities of point line and polygon. This result in a digital parcel map or land use map for which a number of physical attributes were collected in the field. Apart from the parcel map the following information was collected and generated Digital contour lines, digitized from 1:50,000 scale topographic maps, which was then used to generate a Digital Elevation Model (DEM) and a slope steepness map. Field observation was used to gather empirical information about the types of house buildings by studying the composition of building materials. Their number of floors is also identified for classifying them into assign groups. Hence maps showing distribution of building types and number of floors are prepared respectively. After preparing all the required layers and maps tables all the layers are then overlay for vulnerability assessment.

4. Study Area

Shillong city is the capital of Meghalaya, one of the smallest states in India it has an area of about 181.51 Sq. Km and extends from 25° 31' North Latitude and 91° 47' East Longitude to 25° 39' North Latitude and 92° 00' East Longitude. Altitude of the area varies between 942 metres to 1927 metres above mean sea level, an average altitude of 1,496 m above sea level, with the highest point being Shillong Peak at 1,966 m. Shillong falls on the deeply dissected central upland zone of the Meghalaya Plateau. Wah Umkhrah, Wah Umkhen and Umshyrpi are the three main streams draining the area through a number of second order and third order tributaries. Geologically Shillong lies on the low grade metamorphic rocks of Shillong group, predominantly of quartzite with subordinate phylites and slates no major fault or thrust occur within the Shillong urban area but a major sheer zone (Tyrsad-Barapani sheer) occur in the vicinity (about 15km NW of Shillong), fault of Dawki system exists 40km in the south and extension of Halflong Thrust run up to about 45km SSE of Shillong. The city's location to the north of the tropic of cancer and in the central part of the Meghalaya plateau has made its climate mild and equable. Under Koppen's climate classification Shillong features a subtropical highland climate. Its climate is pleasant with warm wet summers and dry cold winters having temperature varying from 23°C in summer and 4 °C in winter. Lying close to the area receiving world's heaviest rainfall Shillong is also affected by monsoon rains for months. Its relative humidity is always more than 50%.

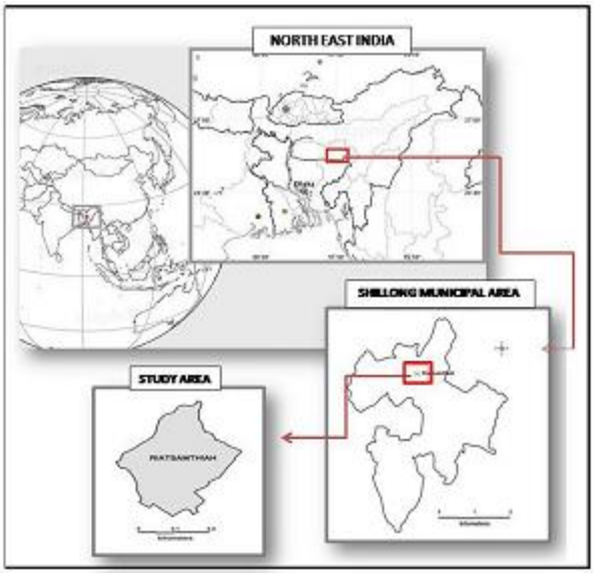


Figure 1: Location Map of the Study Area.

Like any other urban areas of Northeast India Shillong has a humble beginning way back in the 18th century A.D. at present Shillong has grown tremendously with 7 towns forming the Shillong Urban Agglomeration\ Shillong Metropolitan Region (Shillong Municipality, Shillong Cantonment, Mawlai, Pynthorumkhrah, Nongthymmai, Madanriting, Nongmynsong). Shillong city means the area governed by the Municipal Corporation. Shillong was constituted into a municipal station in the year 1878. In early 1910, Laban, European ward, Police Bazar and Mawkhar were the four wards of the Shillong municipality, in the same year Mawkhar was split into Jaiaw ,Mission compound, Goalapatti and Southern Mawkhar. Later Laitumkhrah, Malki and Mawprem were three new wards included in Shillong municipality [7].

As recorded by Census of India, population of Shillong in 2011 is 143,007; of which male and female are 70,028 and 72,979 respectively. Although Shillong city has population of 143,007; its urban/metropolitan population is 354,325 of which 176,591 are males and 177,734 are females. Shillong is an important city in North East India having had a glorious past as the summer capital of British East India and administrative importance as capital of undivided Assam and presently as the capital of the state of Meghalaya. The city is an educational hub of the entire region which is blessed withgood schools and colleges set up by the Christian Missionaries before independence, after independence important institutes like North Eastern Hill University, Indian Institute of Management, North East Indira Gandhi Regional Institute of Health and Medical Sciences, National Institute of Fashion Technology Further aggravate its importance.

Shillong City is highly vulnerable to earthquake as it falls under the high risk seismic Zone V. Apart from Earthquake, Shillong is also vulnerable to natural and man-made hazards such as Flash Flood, Landslides, Cyclone and Fire Accidents. The city is growing at a fast rate with settlements extending beyond the municipal limits. The need for housing for the increasing population number have led to the trend of growth along transportation networks, on the banks of streams, steep slopes, etc. making the city more vulnerable to natural hazards. Five decades before the cultural landscape of Shillong is clearly depicted by Assam type buildings which is a reaction of the British rule which made sure that the town is safe from disaster like the 1897 earthquake but this is slowly forgotten by those residing in the city as most earthquake friendly houses are replaced by modern RCC buildings which sadly are mostly not earthquake proof.

5. Analysis

GIS is a rapidly growing technological field that incorporates graphical features with tabular data in order to assess real world problems. GIS operates on many levels. On the most basic level, GIS is used as computer cartography, i.e. mapping. There is a wide range of functions for data analysis available in most GIS packages, including measurement techniques attribute queries, proximity analysis, overlay operations and the analysis of models of surfaces and networks. GIS forms and important tool in Disaster Management it is not only an analytical tool but also a problem solving and decision making tool. In the present study which deals with *Building Vulnerability Assessment for Hazards Management*, several GIS packages as offered by MapInfo software were used. The following paragraphs shows the analytical framework of the study where every data layer prepared is analysed and overlay for a clear understanding of every aspect of building vulnerability.

5.1. Slope Analysis

The term slope denotes inclination of some small portion of the land surface from the horizontal one. The study of slope is the most important aspects of geomorphology. The representation and analysis of slope have great significance in landform studies. The degree of slope controls the amount of runoff, velocity of river, erosion, transportation and deposition. Slope is influence by structure, lithology, climate, soil, vegetation, altitude, relief, tectonic disturbances etc.

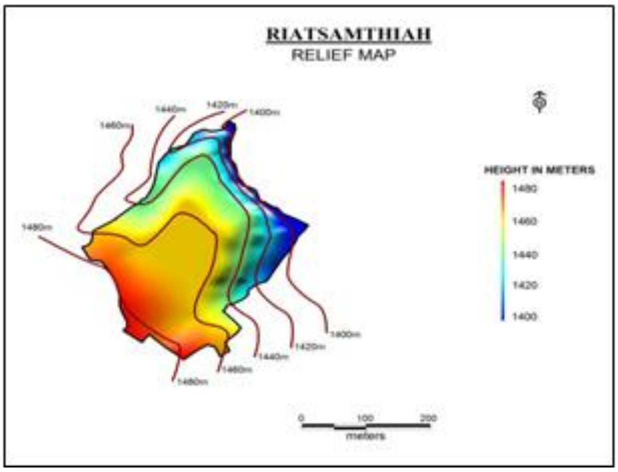


Figure 2: 3 Dimensional representation of the study area.

The general slope of the study area can be distinct into the flat land or terrace of the southern part and the steep slope of the north which drops abruptly towards Wah Umkhrah. The name Riatsamthiah which is a Khasi word literally meaning 'sleepy cliff', as the name suggests Riatsamthiah is part of a cliff along the south bank of Wah Umkhrah. The southern part of the study area has a height of 1480m. A large part of the central flat land have a general height of 1460m, the steepest parts of the north shows a decrease in height which drops from 1440m to less than 1400m.

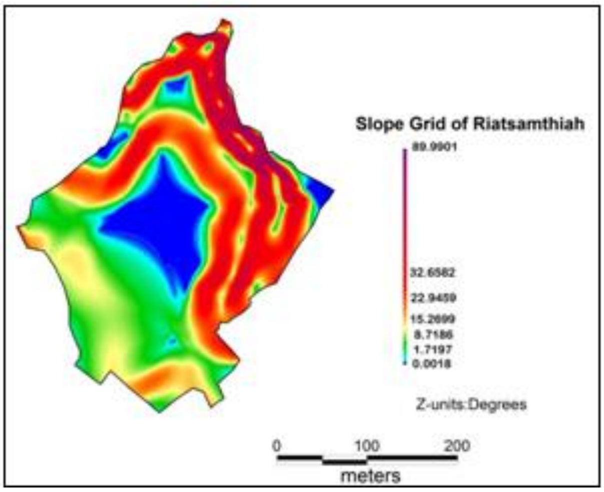


Figure 3: Slope Map

Slope is defined by a plane tangent to a topographic surface, as modelled by the DEM at a point. Slope is classified as a *vector*; as such it has a quantity (gradient) and a direction (aspect). The slope of the area of study shows a very gentle gradient ranging from 1º to 15º in the south-western and southern part of the study area. Moving to the central part the area, a gradient of 0o can be found in the centre which then slopes to a higher degree towards the north-west, north and towards the east which is more than 30º. As we move towards the northern most part of the study area the slope of the area is at its maximum angle of 90o this area is the steepest part which is the rocky cliff of the south bank of Wah Umkhrah. The steep slope in the western and eastern part falls in a high risk area for earthquake induced landslides.

5.2. Geology and Seismicity

Shillong city is situated in the almost elliptically shaped Shillong Plateau. The Shillong Plateau (SP) with an Archaean gneissic basement and late Cretaceous-Tertiary sediments along its southern margin is bounded by the Brahmaputra River to the north and by the Dauki fault to the south .The study area is marked by Shillong series of parametamorphites, which include mostly quartzite and sandstones, followed by schist, phyllites, slates, and so forth. Prominently, a conglomerate bed containing cobbles and boulders of earlier rocks, that is, Archaean crystalline, remains as main constituent of the Shillong series, which formed the basement over which the Shillong series of rocks were originally laid down as sedimentary deposits in Precambrian, probably in shallow marine conditions . The Shillong groups of rocks are intruded by epidiorite rocks, known as Khasi Greenstone. The Khasi Greenstone is a group of basic intrusive in the form of linear to curvilinear shapes occurring as concordant and discordant bodies within the Shillong group of rocks and had suffered metamorphism.

These rocks are widely weathered and the degree of weathering is found to be more in the topographic depressions than in other areas. The metabasic rocks are more prone to weathering than the quartzite rocks.

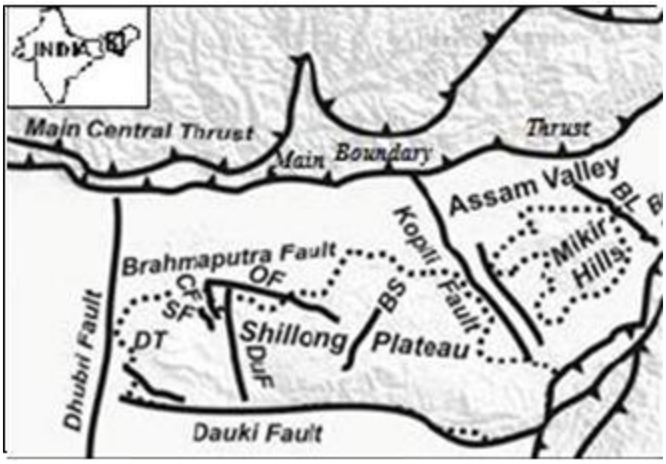


Figure 4: Tectonic sketch map showing the major features around Shillong Plateau (as modified after Baruah and Hazarika).

As portrayed in Figure 4, some prominent faults are Chedrang fault, Dudhnoi fault, and the Barapani lineament/shear zone. Numerous lineaments trend in NE-SW, N-S, and source area for the 1897 great Shillong earthquake Ms 8.7 that caused severe damage and more than 1500 casualties. Another significant earthquake of June 1, 1969, with a magnitude 5.0 and epicentral distance of 20 km from Shillong was also strongly felt. As reported by Gupta and Singh, there has been a gradual decrease in P-wave velocity yielding a speculation that the region is experiencing a dilatancy stress precursory to a large earthquake. According to Khattri et al. 1992, the Shillong Massif shows a pertinent seismic activity with an average of 10–15 small magnitude Earthquakes per day. Over the past hundred years, there were instrumental records of 20 large earthquakes. In the recent past, there has been a noticeable rise in the number of felt earthquakes whose epicentres lie within the vicinity of Shillong city. One event occurred on August, 2009, that generated significant ground acceleration. Besides, the September, 2011, earthquake caused heavy causalities in northern India whose strong tremors were felt in this study region. It is worthy to mention that damage associated with the occurrence of earth tremors has been found not only due to magnitude of the earthquake of earth tremors and its epicentre distance, but also due to local site effects which are essentially frequency dependent caused by the topography and geology of the site. With installation of adequate digital seismic networks set up by NEIST-J (North East Institute of Science & Technology, Jorhat), National Geophysical Research Institute (NGRI), and India Meteorological Department (IMD), there has been a remarkable improvement in recording and locating the lower magnitude earthquakes. During the past few months, there have been a few felt earthquakes in Shillong city that occurred within 100–150 km radius. This populous city of Shillong is not far from the source zone of the great earthquake of 1897 (8.7). Intense seismicity beneath the Plateau is conjectured to be caused by pop-up tectonics of the Plateau between Dapsi thrust and Oldham/Brahmaputra fault. Further, to the far east of SP, Kopili fault is active that caused two recent felt earthquakes (Mw 5.1 and 6.2) in August and September, 2009, respectively. Considering this recent rise of felt tremors and its surrounding active tectonic settings, there is a need to systematically investigate the overburden thickness pertinent to Shillong city which is regarded as the root cause for severe damage as observed by Cara et al., 2008, and many others [8].

5.3. Vulnerability Assessment

A vulnerability assessment is the process of identifying, quantifying, and prioritizing (or ranking) the vulnerabilities in a system. Vulnerability from the perspective of disaster management means assessing the threats from potential hazards to the population and to infrastructure. The table below shows the level of vulnerability by classifying the types of structures into different classes of vulnerabilities. They are classified into four classes of vulnerability i.e. Class A which is the highest vulnerability, Class B for high vulnerability, Class C which is the moderate vulnerability and Class D which is the lowest vulnerability.

Table 1: Vulnerability Assessment: types of structures.

Types of Structures		*Vulnerability Class*				*Number of Buildings in Each Blocks in the Locality*					
		A	B	C	D	1	2	3	4	5	6
Assam type	Timber structure with Ikra walls			/	0	10	9	15	20	23	17
	Unreinforced R/R masonry for basement enclosure	/	0			5	3	2	7	5	8
	Dilapidated condition	0				3	2	1	11	9	8
Masonry	Simple stone or Random rubble.	0								1	3
	Manufactured stones/bricks		_				2	2	2	3	2
Reinforce Concrete Cement (RCC)	Frame with moderate ERD(Earthquake Resistance Design)			/	_		2	3	3		2
	Frame without ERD	0	_			6	9	6	10	3	9
	Wall without ERD beam/column depth	0				1	2	1	2		1
SYMBOLS INDICATING RANGE OF OCCURENCE											
0 Most likely to occur				_ Probable range of occurrence				/ Range of less probability			
VULNERABILITY CLASS											
A-Highest Vulnerability				B-High Vulnerability		C-Moderate Vulnerability			D-Low Vulnerability		

The structures falling in the ***Class D*** are the timber structure with Ikra walls of the Assam Type; this is mainly because of their inherent earthquake resisting features which most likely can be classified to the lowest vulnerability class. Another structure falling in class D is the RCC buildings with moderate earthquake resistance which is probable range. Moving to the ***Class C*** or the class of moderate vulnerability the type of structure in this class is RCC buildings with moderate earthquake resistance design with a range of less probability. Moving to the high vulnerability class or the ***Class B*** vulnerability the types of structures in this category are the Assam type structures having unreinforced random-rubble (R/R) masonry for basement enclosure are most likely to be in the high vulnerability class. The masonry structures in the study area are not independent structures but they are either in combination with Assam type structure or are part of RCC frames which are extended outwards. This masonry structures fall in the most probable range of the class B. Other structure in this class with the most probable range is the RCC structures with low earthquake resistance design. Most of the structures in the study area falls in the highest vulnerability class or the ***Class A*** vulnerability. The structures with the most likely vulnerability in class A is the Assam type dilapidated condition, masonry with Simple stone or Random rubble, RCC structure frame without ERD and RCC structure having wall without ERD beam/column depth the structures, with a less range of probability in the Class A vulnerability is the Assam type with unreinforced random-rubble (R/R) masonry for basement enclosure.

5.4. Vulnerability Assessment

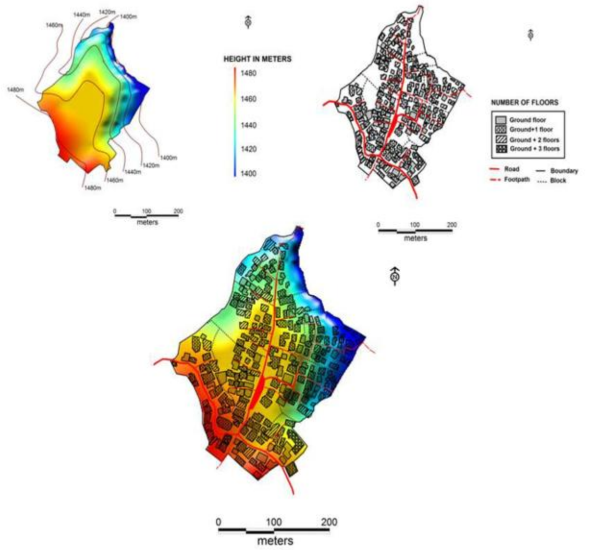
For assessing the vulnerability of buildings with regard to the number of floors/storey, the aspect of slope was taken into account. GIS as a tool provides us with an important analyzing technique i.e. map overlay which is a combination of several spatial data sets (points, lines, or polygons) and creates a new output vector dataset, visually similar to stacking several maps of the same region. In the present work two maps are overlay the first map is the 3D relief map and the second map overlay on top of it is the map showing buildings with their number of floors. The vulnerability of the buildings having different number of floors are analyze in relation to their location along the slopes of the relief map

Figure 5: *the figure above shows the overlay of two maps i) distribution number of floors and ii) relief map of the study area. Vulnerability of buildings with regard to the number of floors/storey is analysing in relation to their location along the slope.*

and their relief height. The area with a high relief height of 1480 is in the south and south western part, the slope of the area is gentle less than 10°. The buildings in this part which are more noticeable are the buildings which have a Ground+3 storey building; these buildings are the most vulnerable buildings. Most buildings in Vulnerability of buildings with regard to the number of floors/storey are analyzed in relation to their location along the slope**.** The area located in a relief height of 1460m is least vulnerable as the degree of slope is very low as it is a flat terrace, hence making it stable for buildings which have 1 or 2 storey. The buildings which are most vulnerable are those located in the lower elevation of the area of less than 1420m this northern and eastern part of the study area have very steep slope of more than 40o and most of the slopes are unstable and have a high probability of triggering landslides if a high intensity earthquake occurs since this is the zone of high vulnerability identified by CDMP. The building here ranges from single storey buildings to three storey buildings. The most likely buildings to collapse due to their location are the G+2 buildings falling in the block1 area of the steep slopes and those locating in block 6 areas in the lower reaches or the foot of a slope. Other buildings which are likely to be vulnerable to earthquakes are the two storey buildings located at the edge of a cliff.

6. Conclusion

As mention in the earlier paragraphs, Natural Hazards are natural phenomenon that are a feature of our planet and cannot be prevented however a natural disaster can be controlled by proper management. This present paper *gives* us a clear understanding of the different buildings which are present in the study area and their vulnerability towards natural hazards. Since the mitigation stage of hazards management is the main focus of the study, the objectives are: to study the vulnerability of the locality to natural hazards, to identify and classify the types of houses and building according to the building materials and their number of floors; and to assess the vulnerability of these houses and buildings to any disaster. Fulfilling all the objectives of the study we can consider that, the locality of Riatsamthiah has a high risk of disaster if it is struck by a seismic hazard. In response to this there is a strong need for checking the construction of buildings on vulnerable locations and put a restriction on the heights of these buildings. The houses in dilapidated conditions need to be reconstructed and retrofitted to avoid any future mishaps.



In this locality the manners in which the houses are being constructed at the top of the sliding plates of hills and at the edges near the stream are indeed, beckoning for catastrophe to happen with worst outcome. Haphazard multi storey structures with very few narrow exits, surrounded by strong and reinforced cement and fabricated steel will hardly allow few people to escape, if and when disaster strikes. Electrical wiring connections are faulty. Many constructions have encroached into public roads and footpaths. A simple glance at all these features, will land us in a similar situation with Nepal when a high intensity earthquake strikes. The mistake in which Nepal has committed by not enforcing strict laws for hazards management needs to be a lesson for all other places located in high seismicity zone. They need to be more aware and to take a serious note for complying with the building laws and regulations as a safety measure against natural hazards. Although the present scene of the locality gives us a sense of helplessness as there seems to be no room for improving the condition of building constructions. But the least we can do is to follow the cycle of disaster management and be prepared and plan for a better response strategy. Thus the need of the hour is to immediately organize training and awareness program for the residents of the locality on how to response when a disaster strikes.

7. Acknowledgment

I would like to thank my Supervisor Dr. Phibankhamti Ryngnga assistant professor of Geography, and other faculty members of the Department of Geography, North Eastern Hill University. The above article is the product of their untiring efforts toward my Dissertation in my Master‘s Program.

References

[1] C. J. Barrow, "Environmental and social impact assessment—An introduction", Arnold, London, 1997.
[2] Savindra Singh, "Environmental Geography", revised ed. 2010, Prayag Pustak Bhavan, Allahabad 2012.
[3] Ansal (1999): "Initial Geotechnical Observations of the August 17, 1999, Izmit Earthquake" A report of the Turkey-US geotechnical reconnaissance team, September 3, 1999 (http://nisee.berkeley.edu/turkey/report.html)
[4] A Ozerdem, "Tiles, taps and earthquake-proofing: lessons for disaster management in Turkey", Environment & Urbanization Volume 11 No 2 October 1999, SAGE. (http://eau.sagepub.com/content/11/2/177)
[5] United Nations, Economic and Social Commission for Asia and the Pacific (ESCAP), "Building resilience to natural disasters and major economic crisis", 2013. (http://www.drrgateway.net/sites/default/files/ThemeStudy2013-full.pdf)
[6] Sandhya Goswami, "Natural Disasters, Social Vulnerability and Conflict in North East India"NTS-Asia, 2009 (http://www.rsis-ntsasia.org/activities/conventions/2009-singapore/Sandhya%20Goswami.pdf)
[7] JP Singh, "Shillong: An urban survey", Morphology of towns: Perspective In Urban Geography volume X , Ed. C.S Yadav, Concept publishing company, New Delhi 1987.
[8] Rajib Biswas, Saurabh Baruah and Dipak K. Bora, "Mapping Sediment Thickness in Shillong City of Northeast India through Empirical Relationship" in Journal of earthquake, volume 2015,article ID 572619. (http://dx.doi.org/10.1155/2015/572619)
[9] J. Albretch, "Key concepts and techniques in GIS"; SAGE, New Delhi, 2007.
[10] Bureau of Indian Standards, National Building Code 2005, Bureau of Indian Standards New Delhi, 2005.
[11] Kang-tsung Chang, "Introduction to geographic information systems", 3rd. Ed. McGraw Hill, Boston, 2006.
[12] S Danielson, "Risk and Vulnerability", Overview of human geography,Debitage.net (2009) (http://debitage.net/humangeography/index.html)
[13] District Disaster Management Authority (DDMA), "Shillong city disaster management plan", 2013. (http://eastkhasihills.gov.in/disaster/Cit_Disaster%20%202013.pdf)
[14] I Heywood, S Cornelius, S Carver and S Raju, "An introduction to geographical information systems", 2nd Ed. Pearson's Education, New Delhi, 2007
[15] D.R Khullar, "India a comprehensive geography", Kalyani, Guwahati 2012.
[16] Living With Risk: A Global Review of Disaster Reduction Initiatives, UNISDR, 2004;
[17] Meghalaya Urban Development Authority (MUDA), "Meghalaya building-bye laws, 2011". (http://meghalaya.nic.in/MBBL2011.pdf) on 2.6.2015
[18] A.S Sahu, "A geographical study on vulnerability pockets of the selected embankments in Purba Medinipur District, West Bengal": Indian Journal Of Regional Science, 2014 – volume XLVI, number 1, Regional Science Association, India.
[19] C.J Van Westen, "Remote sensing and GIS for natural disaster management", IIRS , Dehradun, India, 2000.
[20] Corina Warfield, "The Disaster Management Cycle", 2008. (http://www.gdrc.org/uem/disasters/1-dm_cycle.html)
[21] National Information Centre of Earthquake Engineering (NICEE), IIT Kanpur, INDIA: EERI Newsletter, November 2011 Volume 45, Number 11.(http://www.nicee.org/Sikkim2011.php)