# SITE AMPLIFICATION BEHAVIOUR IN SEISMIC HAZARD ASSESSMENT IN AND AROUND KOHIMA TOWN, NAGALAND

**WANTHANG RENGMA**

**DEPARTMENT OF GEOLOGY**

**NAGALAND UNIVERSITY**

**KOHIMA CAMPUS, MERIEMA - 797004**

**NAGALAND UNIVERSITY**

December 2022

# DECLARATION

I, Mr. Wanthang Rengma, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University / Institute.

This is being submitted to the Nagaland University for the degree of Doctor of Philosophy in Geology.

Candidate

Head

Supervisor

NAGALAND UNIVERSITY

*Glenn T. Thong*
*Professor of Geology*

*Kohima Campus, Meriema - 797004*

☎ *0370 - 2240515*
*Mobile 09436000479*
*E-mail glen2t03@yahoo.com*
*glennthong@nagalanduniversity.ac.in*

# CERTIFICATE

The thesis presented by Mr. Wanthang Rengma, M.Sc., bearing Registration No. 577/2014 (20$^{th}$ May 2014) embodies the results of investigations carried out by him under my supervision and guidance.

I certify that this work has not been presented for any degree elsewhere and that the candidate has fulfilled all conditions laid down by the University.

Place :

Date :

G.T. THONG
Supervisor

# PLAGIARISM-FREE UNDERTAKING

| | |
|---|---|
| Name of Research Scholar | Mr. Wanthang Rengma |
| Ph.D. Registration Number | 577/2014 of 20th May, 2014 |
| Title of Ph.D. thesis | Site amplification behavior in seismic hazard assessment in and around Kohima Town, Nagaland |
| Name & Institutional Address of the Supervisor / Co-Supervisor | Prof. G.T. Thong, Department of Geology, Nagaland University, Kohima Campus, Meriema - 797004<br><br>Dr. R. Duarah, Scientist (Retd.), NEIST, Jorhat |
| Name of the Department & School | Department of Geology / School of Sciences |
| Date of submission | 19.12.2022 |
| Date of plagiarism check | 16.12.2022 |
| Percentage of similarity detected by the URKUND software | 7 |

Inbox

Search GT

1 - 1 Files uploaded by me

| Name | Similarity | Submission ID | Date Uploaded |
|---|---|---|---|
| Thesis.doc<br>Glenn T Thong | 7% | D153595885 | today at 1:26 PM |

Receiver address Uploads

Select an item to get more information.

You can receive documents using the following receiver addresses:

glen2t03.naga@analysis.urkund.com
Nagaland University, Kohima

# ACKNOWLEDGEMENT

During the course of my research work and preparation of my thesis several people have extended their support and helped me in many ways. In the first place, I would like to express my heartfelt gratitude to my guide Dr. G.T. Thong, Professor of Geology, Nagaland University for his invaluable advice and relentless supervision.

My sincere thanks goes to my Co-Supervisor Dr. R. Duarah, Scientist (Retd.), NEIST, Jorhat under whose support the GPR surveys were made available. I also want to thank Dr. Manoj Phukan of NEIST, Jorhat and Mr. David Lhoupenyi, Geologist, Directorate of Geology and Mining, Nagaland for their assistance in providing useful information for my work. It would be incomplete without thanking Mr. Mehilo Apon, Research Scholar and all the faculty members of the Department of Geology, Nagaland University for being so kind to me and extending their help whenever I needed.

I am also greatly indebted to my family especially my two daughters, Haile and Hanah for always being positive at times when I felt discouraged and not letting me give up. I am thankful to my near and dear ones including my wife for their moral support, affection and prayers. Above all, I owe all my gratitude to God who took care of all my problems and gave me good health so that I could complete my work successfully.

(WANTHANG RENGMA)

# PREFACE

Kohima, the capital of Nagaland, lies in the north-eastern part of India. It falls within a zone of very high seismic activity. The region occupies a distinct position in the world seismicity map. It is evident from the past two earthquakes of magnitude >8.7 that occurred in 1897 (the Great Shillong Earthquake) and 1950 (the Great Assam Earthquake). These two great earthquakes caused large-scale destruction throughout the region. The alluvial plains suffered extensive damage in the form of ground failure and liquefaction. However, the death toll due to these great earthquakes was small due to low developed during that period of time. Today, the rapidly growing human habitat and developmental activities continuously increases the risk due to large earthquakes.

The persistent rise of the Himalayas and continuous tectonic activity along the Indo-Myanmar Ranges testify to intense continental collision, which in turn continues to produce large earthquakes, marking the region with high seismicity. The Naga Hills forms part of the Indo-Myanmar orogenic belt and constitute an important element in the dynamic framework of SE Asia. It is especially important in that it lies within the boundary zone of plate collision characterized by shallow to upper crustal depth earthquakes. Thus, the Naga Hills segment has a complex yet very interesting geological setup. Therefore, the highly populated state capital of Nagaland, Kohima, is at risk of earthquake site amplification of ground motion and landslides. The present study therefore, has been taken up to assess the site amplification behaviour of the geological materials. Site amplification behaviour in seismic hazard assessment is related to earthquake effects on the built environment. Site amplification of ground motion causes destruction to the built environment. Several studies conducted during the recent past demonstrated that local geology and ground conditions can highly amplify seismic ground motion. It is also well documented that increasing site amplification is associated with weak lithological conditions that may lead to local density increments as much as 2 to 3 degrees in the MM scale. The extensive damage caused by the 1989 Loma Prieta earthquake was due to enhanced ground shaking. The Mexico earthquake (1988) and Bhuj earthquake (2001) were due to enhanced site amplification. Most of the destructive earthquakes that the country experienced in recent years amply demonstrate the earthquake damage and destruction were mostly due to site dependent factors. The local geology, rock types and land-use pattern play a major role in exaggerating earthquake damage and loss. Thus, site amplification study of Kohima town is important for assessing seismic hazards, adopt proper land use and urban planning and creating public awareness.

The present study on site amplification hazards assessment focuses on identification of site amplification potentials in the area and their impact on the built environment. The study taken up involved detailed study of the local geology, soil profiles, topography, depth of groundwater table, in addition to laboratory tests for determination of soil stability conditions. The data generated can be used for effective urban planning, to adopt improved land use and regulation, to enforce building bylaws and for sustainable development.

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF PLATES

# PARTICULARS OF CANDIDATE

| | |
|---|---|
| NAME OF THE CANDIDATE | : Mr. Wanthang Rengma |
| DEGREE | : Ph.D. |
| DEPARTMENT | : Geology |
| TITLE OF DISSERTATION | : Site amplification behavior in seismic hazard assessment in and around Kohima Town, Nagaland |
| DATE OF ADMISSION | : 30th August, 2013 |
| APPROVAL OF RESEARCH PROPOSAL | : 16th June, 2014 |
| REGISTRATION No. & DATE | : 577/2014 (20-05-2014) |

Head of Department

# BIODATA OF THE CANDIDATE

## 1. Research papers published

- Wanthang Rengma and G.T. Thong, 2022. ***Seismic Site Amplification Hazard Impact on Kohima Urban Town***, Nagaland, India. Hill Geographer (Journal of Geological Society of the Northeastern Hill region), vol. 38, No. 1, December, 2022.

## 2. Seminar / Conference / Workshop Attended / Presentation of paper

- Presented paper in State Geological Programming Board at Directorate of Geology and Mining, Nagaland, Dimapur ($7^{th}$ August, 2015) on ***"Landslide Hazard Zonation and Disaster Management/Mitigation using Remote Sensing and Geographic Information System - A case study of National Highway 29 between Dimapur and Kohima".***

- Presented paper in National Seminar on Geology, Geochemistry, Tectonics, Energy and Mineral Resources of Northeast India (9-11 Nonmember, 2016) at Department of Geology, Nagaland University, Kohima Campus, Meriema on ***"Influence of Lithology on Site Amplification in Kohima Town".***

# CONTENTS

# CHAPTER 1

## INTRODUCTION

Nagaland is a tiny, hilly, tribal-belt state situated in the northeastern part of India bordering Myanmar in the east, Assam in the west, Arunachal in the north and Manipur in the south. It is bounded by geographical coordinates of 25°26' and 27°02'N latitudes and 93°20' and 95°15'E longitudes. It has a population of 19,78,502 (Census 2011). The total land area of the state is 16,579 sq km. The density of population is 199 per sq km. Nagaland attained statehood of the Indian Union in1963.

Geologically, the Naga Hills forms part of the Assam-Arakan Yoma Basin. The sediments, which accumulated during the Cenozoic and Mesozoic, are broadly categorized into two distinct facies - the Shelf and the Basin (Mathur and Evans, 1964). The basinal facies of Cenozoic sediments forms part of the Naga Hills and is represented by the Disang Group (Upper Cretaceous-Upper Eocene), Barail Group (Upper Eocene-Oligocene), Surma Group (Lower Miocene), Tipam Group (Middle to Late Miocene), Namsang Beds (Upper Miocene-Pliocene), Dihing Group (Plio-Pleistocene) and the Naga Hills Ophiolite (NHO) of probable Upper Jurassic-Upper Eocene/Oligocene age. The basinal facies is marked by strong folding and overthrusting (Ghose and Singh, 1981), which is encountered in the Inner Fold Belt (IFB).

Nagaland is therefore, a relatively young mountainous region of the Tertiary mobile belt marked by irregular, varying topography, with high undulating hills and valleys, steep slopes and deep gorges. The state constitutes 95% of Tertiary formations that were subjected to intense tectonic stresses resulting to folding, jointing, faulting, fracturing and shearing. This region is therefore, highly vulnerable to natural hazards like landslides, site amplification of ground motion due to earthquakes, etc.

Site amplification behavior in seismic hazard assessment is related to earthquake effects on the built environment. Site amplification of ground motion causes large-scale destruction to the built environment. Ground conditions amplify the effects of earthquakes in soils and destabilize slopes in hilly terrain. Therefore, it is important to identify the factors responsible for site amplification and to assess its impact on the built environment.

The collapse of buildings, structures or any part of the built environment and ground failure due to earthquakes cause loss to lives, property and development assets. The greatest challenge is to reduce loss of human lives and property. The 2011 Sikkim earthquake (M 6.8) caused the collapse of several buildings in Mangam, Jorethang and lower Zongoe, located 50 km away from the epicenter, due to ground motion. The intensive damage due to the 1989 Loma Prieta earthquake was due to enhanced ground shaking (Holzer, 1994).Most damage during an earthquake is caused by ground motion. Strong ground motion can induce secondary hazards like liquefaction and landslides under geologically weak, local site conditions. The destruction due to the Bhuj earthquake (2001)has been attributed to site condition. As liquefaction occurs, the overlying soil stratum ruptures, leading to the loss of shear strength, and ultimately, ground failure (Obermeier et al., 1986).

During the Alaska earthquake of 1984, the liquefaction of a layer of soft clay beneath the Turnagain Heights, a suburb of Anchorage, caused a landslide that destroyed approximately 75 homes and disrupted utilities. Most damage of Maysville during the Sharsburg earthquake of July 29, 1980 was caused by ground motion. Kohima being located on a very highly folded, faulted and fractured terrain lies in a seismically high-risk zone. It is expected that the area will be impacted by ground motion amplification during strong earthquakes. Strong motion in a city built on seismically active zones can destroy 10% or more of existing buildings (Asuzen, 2008).

The seismic vulnerability of highly populated cities can be assessed through quantification of site amplification behavior, shaking intensity and the resonance pattern of ground vibration and their impact on the built environment, life-line structures and the population as a whole. The site response parameters can be used to identify areas of higher amplification based on surface geology, and may be correlated to the natural frequency of the soil. The mapping of soil behavior in general provides an overview of the possible damage to an individual structure or a set of buildings. The North Ridge earthquake of 1994 left several pockets of severely damaged buildings. Thus, the frequency-dependent amplification forms an important factor for seismic hazard analysis. Local site amplification of seismic ground waves is often controlled by the upper soft sedimentary sequence, which leads to the trapping of seismic energy due to impedance contrast between the soft surface soils and the underlying bedrocks.

In the present study, the Kohima urban area has been selected for assessment of site amplification of seismic hazards in view of the seismic scenario in the region. Kohima town located within the Kohima Synclinorium, lies near the tectonically active Belt of Schuppen (BoS). This region forms part of the Naga Hills segment and lies near the subduction zone along the Indo-Myanmar Ranges (IMR). Kohima, being the capital and administrative headquarter of the state of Nagaland, attracts people from various districts of the state. It also serves as the business center for many of the small towns and villages in and around the district. The concentration of good educational institutions in the town also attracts students from all over the state. The master plan has included Jotsoma, Kohima, Meriema and Thizama villages as part of Kohima. The rapid growth of the township in recent decades has exerted enormous pressure for construction of houses and development activities. Therefore, Kohima town and its suburbs has a high level of seismic risk due the complex geological structure, soft argillaceous rocks and multi-storied concrete buildings on steep, landslide-prone slopes, rapid growth of human population and lack of proper awareness among the common masses.

The present study is a first order assessment of site amplification of hazards and focuses on the geology, geomorphology, tectonic lineaments and faults, groundwater and rainfall conditions, climate change, built environment, regulatory measures for landuse and settlement and enforcement of building byelaws. Site amplification studies are part of earthquake damage reduction measures. As surface ground motions are strongly amplified by geological conditions during earthquakes, they cause severe damage to the built environment. Site amplification effects are therefore, important for assessment of seismic hazards in urban towns. Local geology has a strong influence on severity of damage (Narayan and Sharma, 2001).

The factors responsible for site amplification in the study area include the complex geological formations, site conditions, faults located near the seismically active subduction zone, varying topography, steep slopes with thick colluviums in the valleys made up dominantly of the argillaceous Disang shale, litho-contacts, joints, fractures, paleoslides and several lineaments and active faults near each other. The presence of shallow water table conditions is indicated by the occurrence of springs and fracture zones beneath. These adverse geological conditions have been compounded by development in the township along the narrow, linear ridges, steep-sided slopes riddled with joints, fractures and faults, soft argillaceous shale that are expansive and plastic in nature, etc. All these factors have made the study area highly vulnerable to liquefaction and site amplification. Guttenberg (1957) observed that strong shaking lasts relatively longer at sites of alluvial deposits than on crystalline rocks. Unconsolidated soil deposits aggravate seismic hazards by site amplification of rock-level ground motion. These geologically unfavorable site conditions, rapid growth of population and urbanization and rampant development activities in the study area are considered ideal conditions for seismic site amplification of ground motion.

The built environment and other regulatory issues also play an important role in site amplification of hazard assessment. Construction of multistoried concrete buildings on steep slopes and landslide prone areas due to lack of regulation or enforcement on land use and settlement are major hurdles. Climate change, environmental degradation and lack of preparedness have also contributed to the risk in the face of landslides and site amplification hazards. Many theoretical and analytical approaches have indicated that in irregular alluvial valleys, the resultant ground motion can be very complex and chaotic (Bard and Gabriel, 1986).

The damage and loss of lives due to earthquakes and ground failure has been directly related to site conditions of local geology, topography, structural features, rock types, soil types and groundwater conditions. It is widely accepted that local geological conditions have pronounced impact on seismic ground motion of the site (Aki, 1988; Finn, 1991).The irregular damage patterns of the Jabalpur earthquake (1997) and Bhuj earthquake (2001) have been attributed to local site conditions.

It is well known that earthquakes can have dramatic effects on local communities and the built environment. Moreover, it is evident that earthquake-induced ground motion amplified by superficial materials can exacerbate the situation, often causing major damage. Evaluation of potential ground shaking provides an estimate of response to potentially fatal levels of ground shaking. The contribution of surface geology, particularly soft sediments, to the amplification of ground shaking is an important component in predicting earthquake damage.

Considering the complex geotectonic framework of the Naga Hills, its active seismic history, associated natural hazards, the present scenario of developmental activities in the township, the site amplification behavior in seismic hazard assessment of the Kohima urban township and its suburbs is highly relevant and imperative. The role of geological and geotechnical studies is becoming very important in the planning of city urban infrastructure, which can recognize, control and prevent natural hazards (Bell etal., 1987; Legget, 1987; Hake, 1987;Rau,1984; Dai et al.,1994,2001; Van Rooy and Stiff,2001). Study of seismic hazards and preparation of seismic-amplified hazard maps are thus, very important.

The seismic site response of soil data from Ground Penetration Radar (GPR) studies, inventory of earthquakes, landslides, geology, lithology, groundwater, built environment including socio-economic and other relevant information were generated or obtained to improve urban town planning and management, as well as for better hazard prediction and sustainable development.

### 1.1 Location of the study area

The study area includes Kohima town and its surroundings (Fig.1.1). It is situated at an altitude of 1444 m above msl. It is bounded within 94°3'0" and 94°9'0" E longitudes and 25°37'30"and 25°46'30" N latitudes. It is part of the Survey of India (SoI) toposheet no. 83K/2. It is about 50 sq km in area, and extends from Phesama in the south, Thizama in the north, Jotsoma in the east and Chedema in the west. The National Highway (NH) 29 passing through this area connects Dimapur and Imphal, while the NH 61 links Mokokchung to Kohima.

### 1.2 Accessibility

Dimapur, the commercial complex of Nagaland, is connected by road, railway and air. Kohima, the capital of Nagaland is accessible only by road.

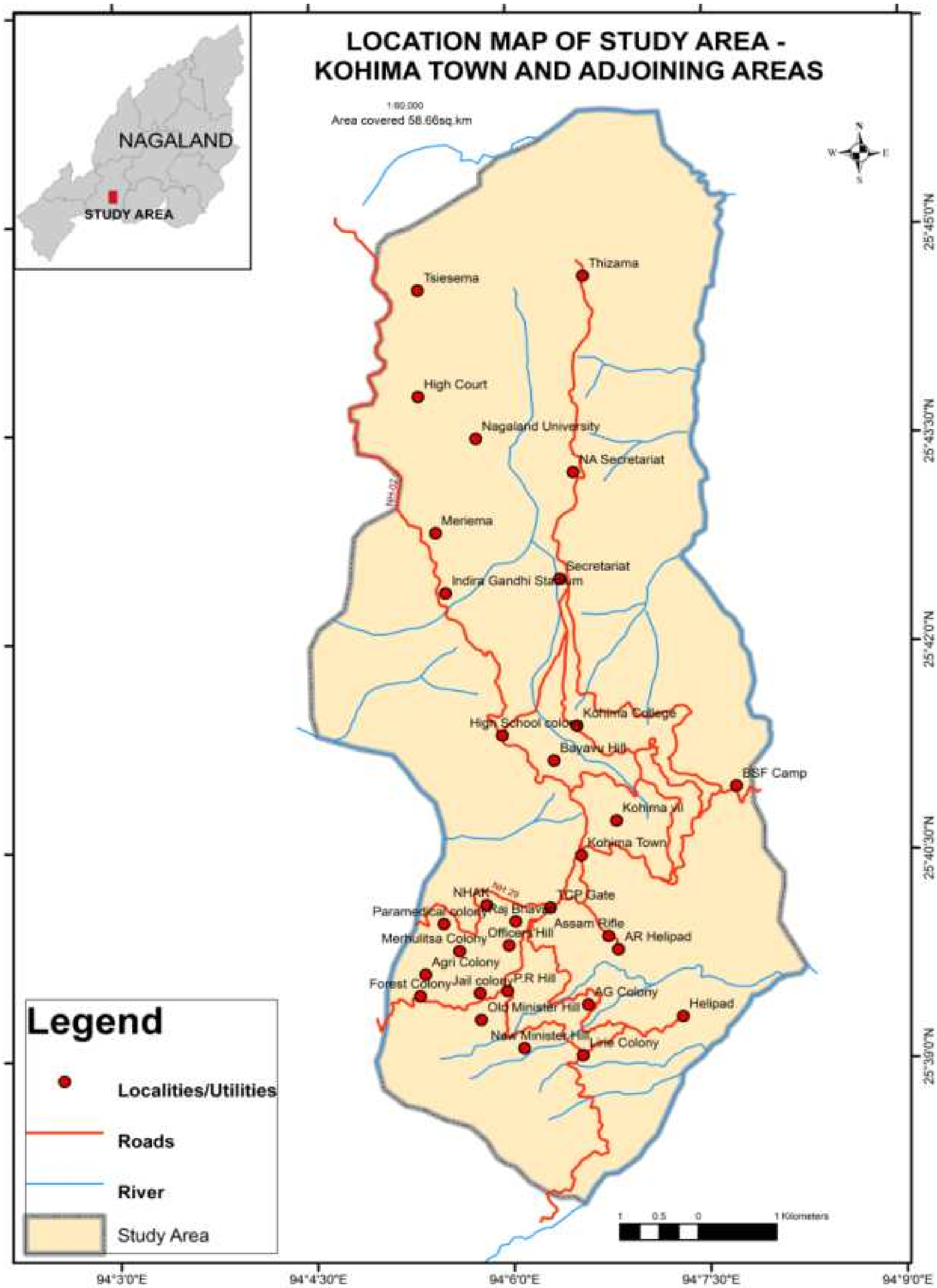



**Fig.1.1:** Location map of the study area

## 1.3 Objectives

In view of the complex geotectonic framework of the Naga Hills, active seismic history and associated natural hazards the present study aims at improved land use and settlement in urban planning, and more importantly, the safety of lives and property, and sustainable development. Seismic site amplification and geological data provide input on earthquake resistant designs in construction of building sand effective urban planning, management and settlement, which benefits the community from loss of lives and damage to assets due to earthquakes and landslides. The objective of the study may be summarized as below:

- To improve seismic safety performance in built-up environment, particularly in highly vulnerable urban areas;
- To identify vulnerable areas and delineate seismic risk zones;
- To make recommendations relating to reduction of earthquake losses;
- To provide scientific and technical information and site amplification map to the policy makers, town planners, etc. for enforcement of seismic designs in building construction and regulation of land use and settlement in urban planning.

### 1.4 Limitations

Studies on the geology, petrology, landslides, groundwater, etc. of Nagaland have been carried out by the Nagaland University, Directorate of Geology and Mining, Nagaland (DGM), Central Ground Water Board, Geological Survey of India, etc., but no earthquake related studies on site amplification were carried out. The present research work is therefore, the first of its kind and is a first-order assessment. Thus, relevant data is very scanty.

### 1.5 Statement of the research problem

Cities built on soft sediments are vulnerable to damage caused by site amplification of ground motion during an earthquake. Townships and cities, and the related socio-economic developmental activities are threatened as the unconsolidated sediments and alluvial soils amplify ground motion, which damages structures. Soft sediments are more prone to earthquakes than hard rocks. The study area is dominantly made up of soft sediments.

The study area is located in a seismically active region; the geological formations that constitute the area are thus, very fragile, fractured and jointed by tectonic activities. These could lead to severe consequences, such as collapse of buildings and other structures during earthquakes. The contributory factors that could cause site amplification of ground motion in the study area maybe categorized as under:

### *1.5.1 Geological and meteorological problems*

- This area is located near the subduction boundary of tectonic collision between the Indian Plate and Eurasian Plate (Burma microplate) in the east, which is the cause of the extensive structural deformation.
- The abundance of several active faults in the vicinity of each other is a major concern for ground failure by site amplification.
- Paleoslides in the area indicate the potential of liquefaction and amplification of ground motion.
- The high altitudes of the hilly terrain with fractured rock constituents are more vulnerable to collapse during earthquakes.
- The abundance of springs in the area point to subsurface fracture zones, which causes fluctuation of the groundwater table during the rainy season, thereby enhancing the risk of site amplification of ground motion.
- The study area receives heavy rainfall during the monsoon, part of which infiltrates into the subsurface and the remainder flows as surface runoff rain. These weaken the soil structure, thereby leading to frequent landslides and subsidence.

### *1.5.2 Built environment problems*

Suzen (2008) opines that strong motion can destroy 10 percent or more of existing buildings. Pressure on land for settlements in the township due to better facilities, education, employment, etc. has led to construction of buildings on high and steep slopes, geologically weak zones, landslide prone areas, etc. This can be seen below in the context of the study area where even moderate-intensity motion may be destructive.

- Multi-storied buildings/structures constructed on steep slopes, landslide prone areas and weak zones pose high risk to urban dwellers.

- Random settlements create congestion and space problem.
- Non-regulated landuse and lack of enforcement of building bylaws has allowed rampant settlement, which poses hazards to structures.

### *1.5.3 Socio-economic problems*

Rapid urbanization and population growth has created a resource crunch and lack of facilities in the township.

- There is an acute shortage of suitable land for settlement and development.
- Traffic congestion is a daily affair.
- Water crisis is now a reality.
- Pollution and sanitary problems are common.
- Unemployment is at its peak.
- There exists economic and social imbalance.

### *1.5.4 Enforcement and regulatory problems*

Due to lack of regulatory measures and will to enforce rules for land use and settlement, haphazard development in the township as taken place. A strong political will is required for successful implementation of building byelaws. The State Government needs to frame an Act as per the provisions of Article 371(A) of the Constitution of India to regulate landuse and construction.

## 1.6 Previous literature

The structure and tectonics of the Naga Hills ranges is described in numerous geological literature and the memoirs of the Geological Survey of India. The geology of the Naga Hills is important in that it lies within the boundary of a zone of plate collision characterized by frequent occurrence of shallow and intermediate earthquakes. Notable works relevant to the geology of the Naga Hills include that of Pascoe (1912), Chhibber (1932, 1934), Evans and Crompton (1946), Krishnan (1953), Wilson and Metre (1953) and Brunnschweiler (1966).Several workers(Santo,1969; Hutchinson, 1975; Mitchell and McKerrow, 1975; Graham et al., 1975; Saikia et al., 1981; Le Dain et al., 1984) correlate the development of the orogen with the interaction of the Indian and Eurasian plates. Hutchinson (1975) and Duarah et al. (1983) identified two ophiolite belts in the Indo-Myanmar Ranges (IMR) and discussed their significance. Dutta and Saikia (1976) and Saikia et al.(1981) discussed seismicity and tectonic development of the region in terms of plate tectonics. Fitch (1970), Chandra (1975), Verma et al. (1976), Rastogi et al. (1973) and others used fault plane solutions to decipher plate movements.

The gravity anomaly maps of NE India (Evans and Crompton, 1946) aid the identification of distinct belts of negative and positive anomalies along the mountain ranges. Verma et al. (1976) studied the relationship between gravity and seismicity in the region and observed that the seismic zone underlying Myanmar (Burma) is characterized by negative isostatic anomalies, which indicates the possible existence of a subduction zone beneath the Arakan-Yoma and Myanmar plains. The high seismicity in the Naga Hills region indicates that movements are still continuing. It is believed that the BoS zone has not attained isostatic equilibrium. However, no detailed studies on the associated seismic hazards, and specifically vulnerability, are available in current literature.

# CHAPTER 2

## REGIONAL GEOLOGICAL SETTING

### 2.1 Introduction

The regional geology of the IMR has a great influence on the geology of Nagaland. Past geotectonic activities in the region has created numerous folds, faults, thrusts, valleys and mountain ranges, which have contributed to the present landscape. Past tectonism has not only created the undulating topography, but also contributed to the mineral deposits of the region. The regional geology (Fig. 2.1) and tectonic setup (Fig. 2.2) of the IMR are depicted in the maps below.

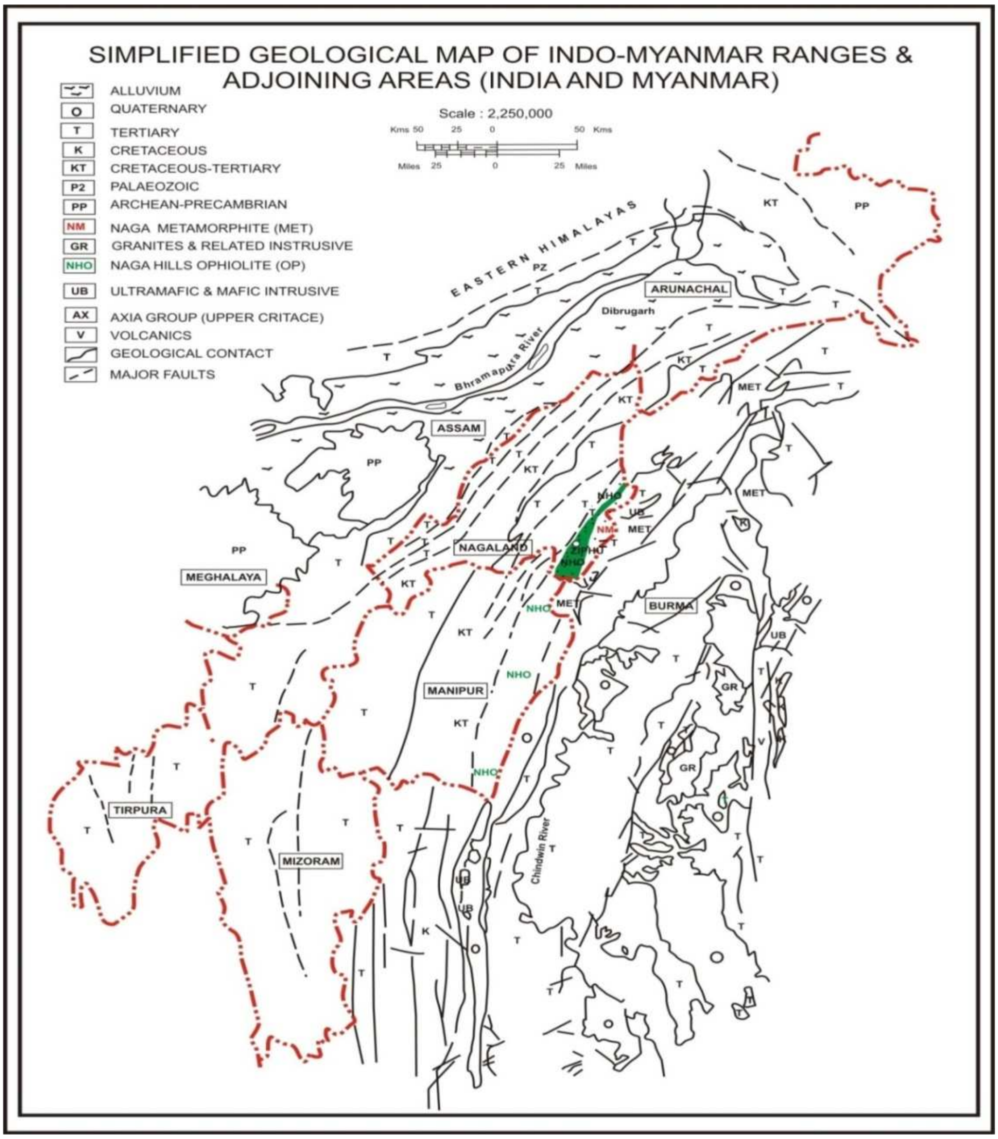



**Fig. 2.1:** Geological map of the Indo-Myanmar Ranges and adjoining areas (After Brunnschweiler, 1974)

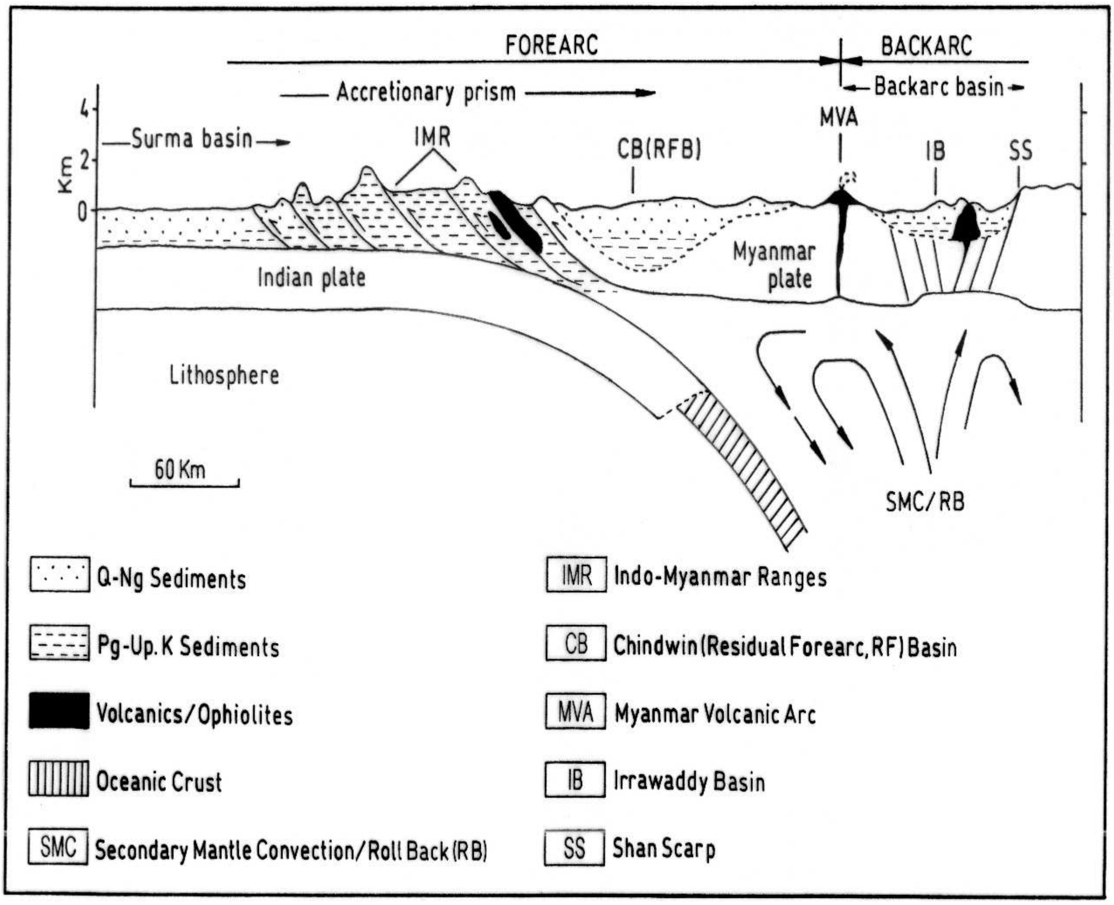



**Fig.2.2:** Tectonic map of NE India and adjoining region (afterNandy,2001)

The IMR represents an arcuate tectonic belt, which is convex towards the west and thought to be a prolongation of the Indonesian Island Arc. This arc connects with the eastern end of the Himalayas along the Tidding Suture Zone. The IMR is longitudinally divided into three segments (Brunnschweiler, 1974).

From north to south they are represented as the Naga Hills, Chin Hills and Arakan-Yoma Hills. The Naga Hills trends approximately NE-SW and represents the northernmost segment of the IMR. It terminates against the continental mass of the Mishmi Block (Soibam, 1998). The Naga-Patkai Hills of Nagaland and the northern part of Manipur constitute this segment. Brunnschweiler (1974) divided this segment into three major stratigraphic units, such as the Naga Metamorphic Complex, Naga Hills flysch and Upper Chindwin molasse of the Chindwin Basin. Acharya (1986) described the geological and tectonic setting of this segment of the IMR into two longitudinal belts, such as the Central Naga Hills Paleogene flysch sediments and the Naga-Chin Hills Ophiolite belt.

The Chin Hills consists of flysch sediments with minor igneous and metamorphic rocks. It occupies the area between the Naga Hills in the north and the Arakan-Yoma segment in the south. A group of schistose rocks occurring in the south is thrust over Lower Tertiary unmetamorphosed shales and sandstones with conglomerate layers to the west. Brunnschweiler (1974) described this segment of the IMR as without ophiolite but with exotics in the flysch sediments. This could be the basis of separation of the Naga and Chindwin hills. The Chindwin Hills lies on the south of the Arakan-Yoma Range. These are relatively low hills that comprise the coastal arcs of Myanmar. Tectonically, this segment is more or less similar to the other two segments, except that the tectonic lineaments trend NNW-SSE. Several small outcrops of ophiolite are found on the eastern side.

Part of the northern extension of the IMR mobile belt constitutes the geology of Nagaland, which is represented by about 95 percent of Tertiary sediments and about 5 percent of igneous and crystalline metamorphic rocks of Mesozoic-Cenozoic age. The Cenozoic sequence of this region consists of shelf and basinal sediments, such as flysch and molasse. These rocks strike NNE-SSW with moderate to steep dips towards NW and SE. The western part of Nagaland is made up dominantly of the Barail Group of rocks consisting of well-bedded sandstones and shale intercalations in the IFB and BoS.

The central part of Nagaland is dominantly occupied by the Disang Group of rocks consisting of shales with thin intercalations of sandstones, siltstone and clay stone. The eastern part of Nagaland comprises the Naga Metamorphics and NHO. The former is made up of phyllite, quartzite, marble, etc. while the latter consists of suites of mafic, ultramafic, pelagic sediments, conglomerate, felsic dykes, etc. The Dimapur plains are made up of Quaternary formations consisting of boulder, sand and gravel beds, and recent alluvium.

### *2.1.1 Naga Metamorphics*

The low to medium grade metamorphic rocks of Nagaland has been dated at about Pre-Mesozoic. These rocks have been thrusted over the Naga ophiolites. The westward translation along the thrusts is considerable. The ophiolites and Disang crop out as tectonic windows (Chattopadhyay et al., 1983). Brunnschweiler (1966) reported in a window exposing Upper Cretaceous rocks under a Naga Metamorphic cover. The Naga Metamorphics lie on the east of the NHO.

### *2.1.2 Nimi Formation*

The Nimi Formation is a totally obliterated, thick sequence of low-grade metasediments in the Naga Metamorphics, which has mostly retained its relict sedimentary clastic texture. The dominant rocks in this formation are phyllite, quartzite, marble, limestone, mica-schist, quartz-sericite shist, etc. No fossil remains are seen in the Nimi Formation, which are lithologically and homotaxially similar to the Pansat Beds (Brunnschweiler, 1996).

### *2.1.3 Naga Hills Ophiolite*

The NHO is an arcuate linear belt lying between the Nimi Formation in the east and Disang flysch sediments in the west. It is unconformably overlain by the Jopi Formation in the Phek and Kiphire districts. The NHO, extending about 90 km in length and 2-15 km in breadth, occupies an area of about 100 sq km in Nagaland. It displays highly dismembered litho-units, such as peridotites (tectonites, mafic-ultramafic cumulates, mafic volcanics, metabasics, etc.) mixed with rare dikes, minor felsic intrusive and oceanic sediments such as chert, greywacke and limestone. The presence of radiolarian assemblages and foraminifers in chert and limestone has enabled the dating of the rocks to Upper Jurassic-Cretaceous.

## 2.2 Seismicity

### *2.2.1 Regional seismicity*

The high seismicity of NE India (Fig. 2.3) has been attributed to a complex tectonic setup that has resulted from an ancient plate margin. The major tectonic background includes the eastern Himalayas, the Mishmi Massif, the Indo-Burmese Arc, the Brahmaputra Valley and the Shillong Plateau. The major Himalayan structures include the Main Central Thrust, Main Boundary Thrust and Main Crystalline Thrust, besides several transverse faults (Krishnan, 1964).

NE India has been placed in Zone-V, the highest level of seismic hazard potential. The region has experienced large earthquakes in the past, which include the Great Shillong Earthquake of 1897, with a magnitude of 8.2 on the Richter Scale and the

Great Assam Earthquake (M 8.7) of 1950. The latter changed the course of the mighty Brahmaputra River. Between 1897 and 1950, two other major earthquakes (M>8) occurred, the Kangra earthquake of 1905 and the Bihar-Nepal earthquake of 1934, which caused much devastation in the Himalayan region. Since 1950, no such earthquakes have occurred. However, studies indicate that enough strain has accumulated to generate earthquakes of M≥8 in the region in the near future.

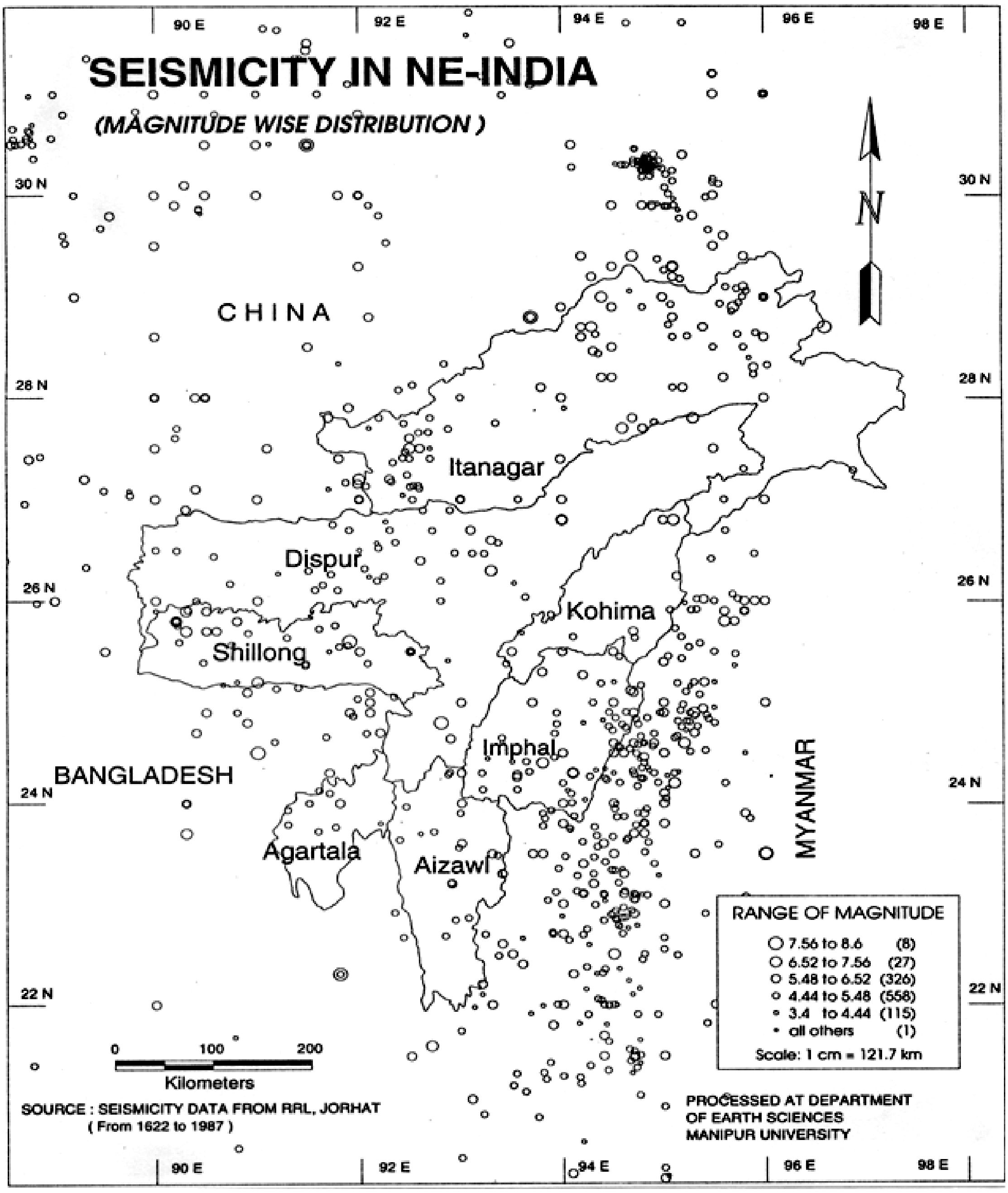



**Fig. 2.3:** Seismicity of the northeast region of India (after CSIR-NEIST, 1987)

The Global Seismic Hazard Assessment Program (GSHAP) has classified the region in the zone of high seismic risk with peak ground acceleration rising to the tune of 0.35-0.4g (Bhatia et al., 1999). Rapid urbanization in the region has led to the construction of multi-storied buildings and large structures. Adding to all the above, significant population explosion has increased the vulnerability due to earthquakes. As the entire north-eastern region of India falls under seismic Zone-V, the region is considered highly vulnerable to earthquake hazards (Table 2.1).Chen and Monohar (1990) suggest that earthquakes may have occurred within the subducting Indian Plate.

**Table 2.1:** Seismic data of NE India showing major earthquakes in the recent past

| Place | Year | Magnitude | Effect/Damage |
|---|---|---|---|
| Cachar | March 21, 1869 | 7.8 | Numerous earth fissures and sand craters |
| Shillong Plateau | June 12, 1897 | 8.7 | ~1542 people died |
| Sibsagar | August 31, 1906 | 7.0 | Property damaged |
| Myanmar | December 12, 1908 | 7.5 | Property damaged |
| Srimangal | July 8, 1918 | 7.6 | 4500 $km^2$ area suffered damage |
| SW Assam | September 9, 1923 | 7.1 | Property damaged |
| Dhubri3 | July 2, 1930 | 7.1 | Railway lines, culverts and bridges cracked |
| Assam | January 27, 1931 | 7.6 | Destruction of property |
| Nagaland | 1932 | 7.0 | Destruction of property |
| NE Assam | October 23, 1943 | 7.2 | Destruction of property |
| Arunachal Pradesh | July 7, 1947 | 7.5 | Destruction of property |
| Upper Assam | July 29, 1949 | 7.6 | Severe damage to property |
| Upper Assam | August 15, 1950 | 8.7 | ~1520 people died(One of the largest known quakes in history) |
| Patkai Range, AP | 1950 | 7.0 | Property damaged |
| Manipur- Myanmar border | 1954 | 7.4 | Property damaged |
| Darjeeling | 1959 | 7.5 | Property damaged |
| Indo-Myanmar border | August 6, 1988 | 7.5 | No casualty reported |

### *2.2.2 Seismicity of Nagaland*

Nagaland lies within one of the six most seismically active regions of the world (Fig. 2.4). It is placed in Zone-V, the highest zone of the Seismic Zonation Map of India (2002). The boundary margins of earthquakes activity cover wide areas. They are the most destructive and unpredictable of all the natural phenomena. The whole region is a segment of a seismic domain. Hence, seismic data covers the regions affected. The region experienced 18 large earthquakes (M≥7) during the last hundred years including that of Shillong and the Assam-Tibet border (M8.7) of 1950 (Tiwari, 2002).

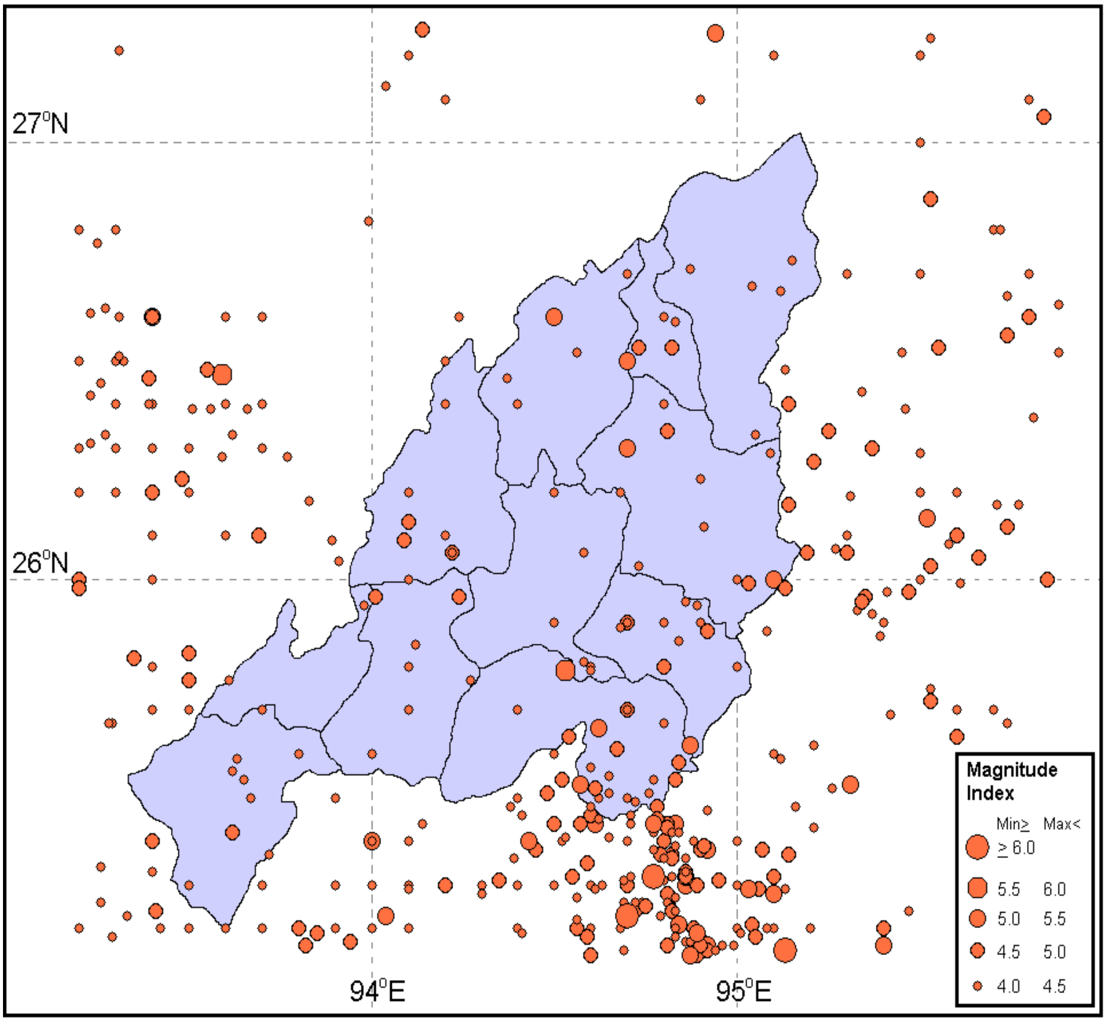



**Fig.2.4:** Seismicity and epicenter map (1982-2018) of Nagaland and the adjoining region (after CSIR-NEIST, 1987; USGS, 2004)

According to the USGS (2004), the epicenters of three earthquakes were near Kohima. The first (M4.5) was about 20 km east of Kohima, in the Phek district. The second (M5.7) was about 41 km to the south. The third (M5.4) was about 58 km east of Kohima. However, there were no reports of casualties or damage to property. According to Tiwari (2002), an earthquake (M7.0) occurred in 1932 in Nagaland, which caused extensive destruction to property.

The hypocentral distribution pattern of the majority of the earthquakes originating in the ranges of the Naga Hills indicates a shallow Benioff zone. The collision of the Indian Plate against the Burma microplate resulted in the formation of major structural feature of NE India and Myanmar. Desikachar (1794) and Nandy (1976) explained the evolution of these features in terms of plate tectonic models. The Andaman-Arakan-Assam basin lying between the Myanmar landmass and the Indian Plate extends from 5°to 27°, which is supported by oceanic magnetic anomalies (McKenzie and Sclater, 1971) and paleomagnetic studies (McElhinny,1973). Subduction of the Indian plate under the Burma microplate began during Cretaceous-Eocene; the process is still continuing (Verma, 1985). This can be seen from correlation of high seismicity, depth of foci and large negative isostatic anomalies to the west of the Arakan-Yoma subduction. Northeast India and its adjoining areas are located in the northern collision and eastern subduction domains of the north drifting Indian Plate characterized by active tectonic movements causing intense seismic activity in the region (Nandy, 2007).

Like all other north-eastern states, the population density and developmental activities in the major urban localities of Nagaland are increasing at an alarming rate. The rapidly growing human habitat in Kohima, Dimapur, and most other district headquarters, continually increases the risk posed by recurring earthquakes and induced landslides and ground failure.

## 2.3 Seismotectonics of Nagaland

Nagaland, located along the Arakan-Yoma fold belt, has uneven topography with high and steep hills and deep valleys. The study area is criss-crossed by numerous lineaments trending NNE-SSW. Kohima is situated in the Kohima Synclinorium, near the margin of the BoS with its imbricate thrust sheets (Fig. 2.5). The lineaments, including faults and thrusts, represent the tectonic features of Nagaland. The sites of the past two great earthquakes of 1897 and 1950 with epicenters at the Shillong Plateau and Assam-Arunachal border, and frequent earthquakes along the Indo-Myanmar border are significant, in that these may be the sites for future great earthquakes. Some earthquakes of M4.7 and M5.5 (Table 2.2), which occurred recently near Kohima, may be precursors of future larger shocks in the region.

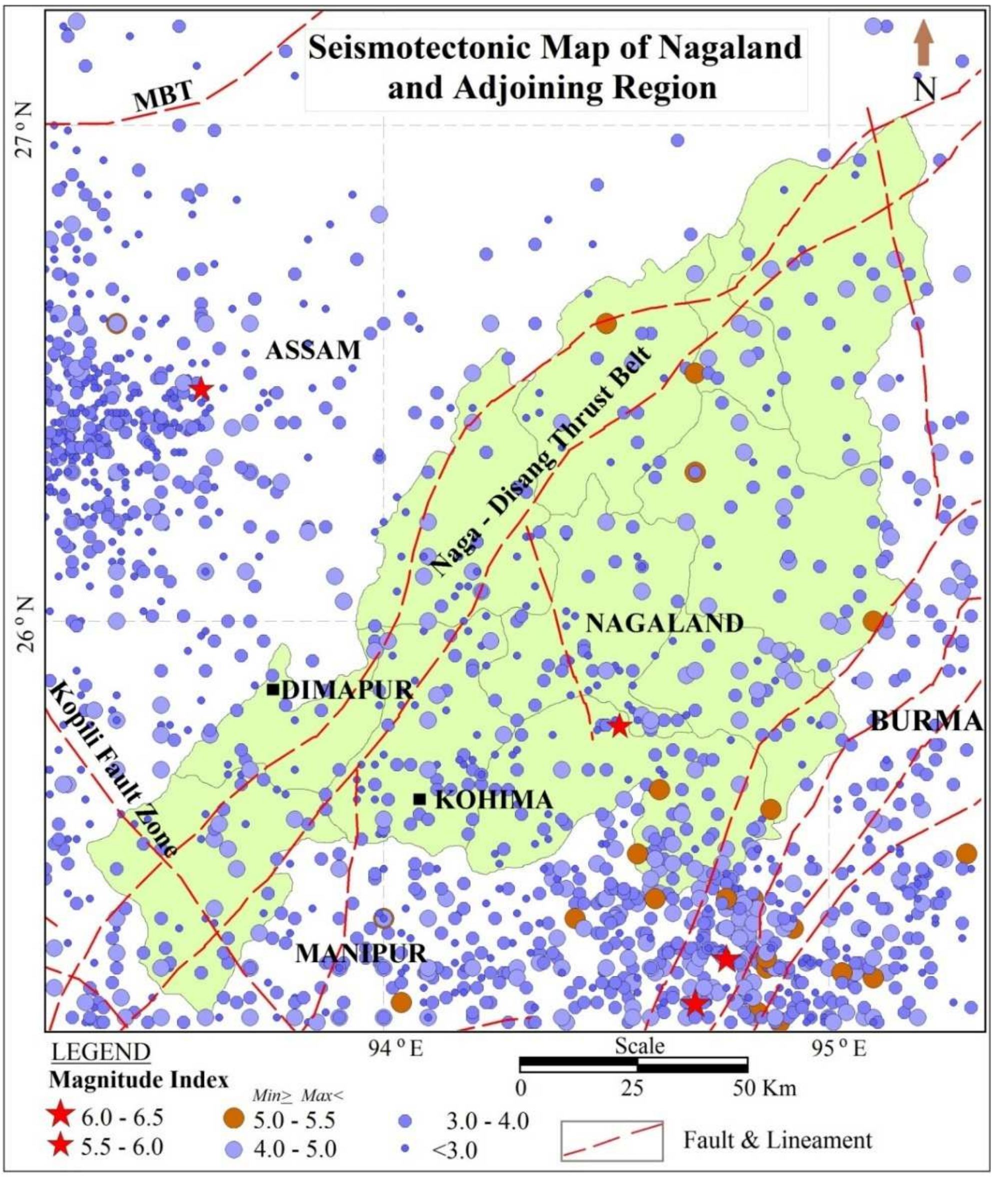



**Fig. 2.5:** Seismotectonic map of Nagaland (after CSIR-NEIST, 2016)

**Table 2.2:** Earthquake inventory of the region around the study area

| Date | Place | Magnitude/Depth | Effects/Damage |
|---|---|---|---|
| Aug. 12, 2009 | SE of Imphal<br>Lat. 24.32N<br>Long. 94.79E | 5.4 / 85 km | Felt in parts of Nagaland |
| Aug. 31, 2009 | SE of Kohima<br>Lat. 925.231N<br>Long. 995.127E | 5.4 / 15 km | Moderately felt |
| Sep. 3, 2009 | SE of Yaoyimsen<br>Lat. 2432N<br>Long. 94.79E | 5.7 / 97 km | Slightly felt in parts of Nagaland |
| Sep. 21, 2009 | 37 km NE of Pfutsero<br>Lat. 27.23N<br>Long. 991.00E | 4.7 / 50 km | Faintly felt in parts of Nagaland |
| Dec. 29 2009 | 240 km SE of Yaoyimsen<br>Lat. 24.37N<br>Long. 94.85E | 5.2 / 110 km | Moderately felt throughout NE |
| Dec. 31, 2009 | 75 km north of Guwahati<br>Lat. 27.30N<br>Long. 91.66E | 5.5 / 15 km | Moderately felt in Assam and its surroundings, but no casualty or destruction |
| Oct. 3, 2012 | West AP | 5.2 / - | Moderately felt in Assam and its surroundings |
| Jan. 3, 2013 | Churachandpur | - | Moderately felt throughout NE |
| Jan. 7, 2013 | Arunachal Pradesh<br>Lat. 28.1N<br>Long. 94.3E | 4.2-4.5 / - | Felt in parts of Assam and Nagaland |
| Jan. 9, 2013 | Phek District<br>Lat. 25.36N<br>Long. 94.84E | 6.0 / 105 km | Moderately felt throughout NE |
| June 28, 2015 | Dibrugarh | 5.6 / - | Hit Nagaland and Assam: 3 people dead |
| Jan. 3, 2016 | Tamenglong, Manipur | 6.7 / 30 km | Buildings cracked at Dimapur, buildings damaged in Tening |

## 2.4 Major structural and tectonic features of Nagaland

The Naga Hills ranges forms a major tectonic element in the structural framework of the IMR and delineates the ancient plate margin. The complex structural behavior of the BoS formed by the successive, easterly dipping thrust sheets indicates an E-W crustal shortening of more than 320km due to the Indo-Burma plate collision in the geologic past. The intense crustal shortening in Nagaland has also resulted in large allochthonous blocks of pelagic sediments with bedding plane dipping at 90° angles and mega thrust sheets of mafic-ultramafic rocks with mineralized zones, which are all highly susceptible to seismic slip movement. Tectonically, the Naga-Arakan fold belt is considered a result of the collision and subduction of the Indian Plate under the

Burma microplate. The resultant tectonic features of Nagaland can be divided into the following structural regions.

- Foreland Spur (Dimapur &Upper Assam plains
- BoS (Naga overthrust belt)
- IFB (Kohima-Patkai Synclinorium)
- Eastern zone including ophiolites

### *2.4.1 Foreland Spur*

The Foreland Spur, including the Dimapur-Upper Assam plains above the basement of ancient crystalline rocks, extends several kilometers beneath the alluvial plains of the Brahmaputra, Dhansiri and their tributaries. Above the basement lie Tertiary and post-Tertiary rocks, which exhibit low inclinations and are cut across by faults. These features are revealed in eroded valleys along shattered fault belts. This foreland, covering very little of Nagaland, lies beneath new alluvium around Dimapur.

### *2.4.2 Belt of Schuppen*

The BoS consists of a number of imbricate thrusts, including the Naga, Sanis-Chongliyimsen, Lakhuni, Kongan, Piphema and Disang thrusts. These imbricate thrust planes may be potential sites for amplification of ground motion during strong earthquakes.

### *2.4.3 Inner Fold Belt*

Anticlinal and synclinal reversals of Paleogene rocks lying to the east of the Disang Thrust is the Kohima-Patkai fold zone. This has been variously referred to as the Naga Fold Zone and Central Flysch Zone (Kanju and Khar, 1985). It extends from the Pangsu Pass in Arunachal Pradesh and continues into Manipur. The characteristic feature of this zone is the reversal of topography with anticlines valleys and synclines hills (Ganju et al., 1986). Most of the anticline valleys are exposed in the older Disang Group while the Barail rocks are restricted to mere capping of synclinal hills. Reversal of topography with anticline valleys and syncline hills may influence the amplification of ground motion.

### 2.4.4 Eastern Zone

The Changrang-Zungki Thrust along the Indo-Myanmar border separates the IFB from the Eastern Zone. On the basis of available data, this zone has been classed as Naga Metamorphic Belt, Nimi Formation, NHO and Lower Disang.

## 2.5 Stratigraphic succession of the Inner Fold Belt and Belt of Schuppen

The stratigraphic succession of Nagaland (Table 2.3) was established by Mathur and Evans (1964) and later modified by the DGM (1978).

**Table 2.3:** Stratigraphy of Inner Fold Belt and Belt of Schuppen

| Age | Group | Formation | Lithology |
|---|---|---|---|
| Recent | | Newer or low level alluvium | Clay, silt and fine sand |
| Pleistocene | Dihing | Older or high level alluvium | Boulder beds with gravel, medium to coarse sand and clay |
| ---------Unconformity--------- | | | |
| Mio-Pliocene | Dupi Tila | Namsang Beds | Sandstone, mottled clay, grit and conglomerate |
| ---------Unconformity--------- | | | |
| Miocene | Tipam | Girujan Clay<br>Tipam Sandstone | Clay, mottled clay, sandy shale, coarse and ferruginous sandstones and conglomerate |
| | Surma | Upper Bhuban<br>Lower Bhuban | Shale, sandy shale, sandstone, mudstone and lenticular coarse ferruginous sandstone |
| ---------Unconformity--------- | | | |
| Oligocene | Barail | Renji<br>Jenam<br>Laisong | Well bedded sandstone, shale, carboniferous shale, sandy shale interbedded with hard sandstone |
| Upper Cretaceous - Eocene | Disang | | Splintery dark grey shale, siltsone, mudstone with thin and compact sandstone |

### 2.5.1 Disang Group

(Mallet (1876) proposed the name Disang for the dark grey shales and minor intercalations of sandstone. Evans (1932) later named it the Disang Series and opined that, as the rocks extend over a great area, it would be convenient to have several typical sections rather than a few formally designated ones. The Disang Group is made up of dark grey and black, fissile, splintery shales with minor sandstones. The thickness of the Disang varies considerably from around 1600 m in the type section to over 3000 m in the mobile belt.

The Disang Group comprising flysch sediments (DGM, 1978) are the oldest Tertiary rocks of Nagaland. These rocks, exposed over half the surface area of Nagaland, range in age from Upper Cretaceous to Eocene. They consist of thick monotonous sequences of splintery shale (Mallet, 1876). The splintery nature of the Disang is attributed to the intersection of bedding and a prominent fracture cleavage (Soibam, 1998). This group is divided into two distinct formations, a basal argillaceous and an upper arenaceous horizon designated as Lower and Upper Disang formations respectively (Sinha et al., 1982). The Disang occupy the intermediate hilly region in the IFB of Nagaland and are confined to the east of the Disang Thrust. The Disang consists of well-bedded, splintery, dark grey shale intercalated with fine grained, well cemented siltstone. The shales are finely laminated and are occasionally curved or concentric. Ferruginous concretions and nodules are noted in areas of red soils. Brine and sulphur springs and iron pyrite are common in Disang areas. At places the Disang are carbonaceous. These rocks are commonly crumpled and squeezed to a very high degree. The Disang are occasionally penetrated by thin quartz veins and serpentinized intrusions. Metamorphism is noted towards the east in the form of hard, glossy, dark greyish to blue slates. They grade into talc- and chloritic-phyllite and schist further east (Oldham, 1883; Goswami, 1960). These rocks abut against an igneous body further southeast which may be a projection of the parent rock of the Arakan-Yoma. Due to the presence of discontinuities, secondary porosity is increased considerably in these rocks which further enhance weathering. Weathering of shale is brought about by two main processes namely, air breakage and the dispersion of colloidal material (Badger et al., 1956). As a result, talus and scree form at the base of slopes and thick columns of soil are developed on slopes, which render the Disang dominated areas highly vulnerable to various forms of landslides and subsidence. Site amplification of ground motion can have devastating effects on such slope material.

### *2.5.2 Barail Group*

The Barail Group, essentially an arenaceous suite of molasse sediments, has been named after the Barail Range in the North Cachar Hills of Assam. These rocks of Upper Eocene-Oligocene age conformably overlie the Disang. The Barail comprise thick sequences of sandstones intercalated with thin papery shale. They are found scattered all over Nagaland, being exposed in the southern and eastern parts and western margin of Nagaland. Along the east some of the highest peaks of the state like

Saramati and its ranges are located. These rocks occupy the intermediate hill regions in the IFB and BoS of Nagaland.

In the south and southwest of Nagaland the Barail are classed into three formations including Laisong, Jenam and Renji. In the northern intermediate hills of Nagaland, they are recognized as Tikak Parbat, Baragolai and Naogaon formations. The Laisong Formation comprises very hard, grey, thin-bedded sandstones alternating with hard shale. Occasionally, massive sandstones with intercalations of carbonaceous shale and thin streaks of coal are encountered. The Jenam is made up predominantly of massive sandstones with intercalations of shale, sandy shale and calcareous and iron stained shale. The Renji extends beyond the south and southwest borders of Nagaland into Manipur and Assam. The Renji sandstones, intercalated with minor shale, are massive, hard, ferruginous and very thick bedded. This formation forms a very thick forested range with high peaks such as Japfü (3015 m) in southern Nagaland. These rocks are of marine to estuarine origin, are confined to the BoS along the western margin of Nagaland, where they are exposed due to strike faulting. They exhibit a number of sedimentary structures such as ripple marks, load casts, flute marks and current bedding, but however, lack in fossils.

Rocks of the Tikak Parbat, Baragolai and Naogaon formations are extensively exposed as high ranges in the northeastern parts of Nagaland. The Naogaon sandstones are hard, grey, thin bedded, fine to medium grained and intercalated with some shale and carbonaceous shale. Concretionary structures are occasionally noted. The Tikak Parbat and Baragolai formations are made up of sandstone, shale, carbonaceous shale, and coal. The Tikak Parbat contains workable coal reserves.

### *2.5.3 Surma Group*

The Surma Group of Lower Miocene molasse unconformably overlies the Barail. They comprise alternations of well-bedded sandstone, shaly sandstone, mudstone, sandy shale and thin beds of conglomerate. The rocks are exposed on the western margin of Nagaland in the BoS as long narrow strips. They gradually thin out toward the north. The Surma are subdivided into the Bhuban and Boka Bil formations, the former characterized by the presence of some conglomerate.

### *2.5.4 Tipam Group*

The Tipam Group of molassic sediments overlies the Surma. This Mio-Pliocene group includes the older Tipam Sandstone and the younger Girujan Clay. These formations are exposed along the western fringe of Nagaland in the BoS as long, narrow strips due to strike faulting. The Tipam Sandstone Formation comprises massive sandstones that are highly friable and contain subordinate clay and shale. The sandstones are generally coarse-grained, occasionally gritty and ferruginous. They are commonly green in colour due to the presence of chlorite, but are found to be weathering to different shades of brown. The Girujan Clay Formation is essentially argillaceous, consisting of bluish-gray mottled clay, sandy clay and subordinate sandstone.

### *2.5.5 Namsang Beds*

The Namsang Beds belonging to the Dupi Tila Group are considered Mio-Pliocene. They lie unconformably over the Girujan Clay. They consist of sandstone, pebbles of lignite, conglomerate, grit, mottled clay and lenticular seams of lignite. They are also confined to the BoS.

### *2.5.6 Dihing Group*

The Namsang Beds are unconformably overlain by the Plio-Pleistocene Dihing. This group consists of an unconsolidated mass of Barail boulders and pebbles interspersed with clay and soft sand. Patches of these deposits are observed in the BoS.

### *2.5.7 Alluvium and high-level terraces*

Alluvium and high-level terraces are found exposed in many parts of Nagaland. The high-level terraces are dominantly boulder beds with gravel, coarse sand and clay at various levels above the present rivers. The older alluvium occupies the north-eastern tract of the Naga-Patkai ranges while the newer alluvium covers the western border of Nagaland. The older alluvium is composed mainly of cobbles and boulders with considerable sand, silt and clay. The younger alluvium includes the recent alluvial deposits of rivers and streams. They are principally composed of dark gray to black clay, silt, and sand deposits.

## 2.6 Study area

### *2.6.1 Background*

Kohima, the capital of Nagaland is the administrative center of the State. Kohima town is a hill station situated at an altitude of 1444.12m above msl. It was a Sub-Divisional headquarters of the erstwhile Naga Hills District in 1871 under Assam and subsequently upgraded as Chief Administrative Centre of the Naga Hills-Tuensang Area (NHTA) in 1878. Nagaland attained statehood on 1$^{st}$ December, 1963. Kohima Town has a population of 297,988 (Census 2011) and is the second largest urban center of the state. There are 19 wards under the Municipal Council and it comprises more than 75 urban blocks within 4 Assembly Constituencies.

Kohima is a historical town that is witness to the ravages of the Second World War. The famous Commonwealth War Cemetery with 1421 graves is located here. Kohima is also known to have the second largest village, the Kohima Village, in Asia, the largest Cathedral in NE India and the only breeding center in the world for the rare Blyth's Tragopan. Vital highways, such as the NH29, NH61 and SH-2 pass through this township. The NH 29 links this town with Assam in the west and Myanmar, through Moreh in the east. The present township, about50 sq km in area, lies sprawling atop rugged, hilly terrains, with elevations varying from 1000 to 1800 m.

### *2.6.2 Climate and rainfall*

Nagaland enjoys a typical monsoonal climate varying from sub-tropical to temperate. The torrential monsoon rains are an integral feature of the weather condition of the state, which receives abundant rainfall from June to September. The average annual rainfall is about 2500 mm. In general, the maximum temperature in summer is 35°C and minimum in winter 4°C. The average rainfall of Kohima town is about 1700 mm and maximum and minimum temperatures range from about 28°C to 4°C.

### *2.6.3 Physiography and drainage*

Nagaland lies between the Brahmaputra-Dhansiri valley in the west and the Chindwin valley of Myanmar in the east. It consists of narrow hill ranges trending NNE-SSW, which vary in altitude from 600 m to 3700 m above mean sea level (msl). The highest peak, Saramati is 3840 m above msl. The hills occupy about 95% of Nagaland, with negligible plain areas in the Dimapur valley. The hills of Nagaland are characterized by rugged topography and serrated ridges that are separated from each other by deep valleys, with streams and rivers flowing almost north to south or vice versa. The hill ranges rise from west to east. The five major rivers draining Nagaland are the Doyang, Jhanji, Dhansiri, Dikhu and Tizu-Zungki, which are all tributaries of the Brahmaputra River and the Chindwin River. These rivers flow almost parallel to each other, pointing to structural control.

The southern portion of the study area is very hilly, with high hills and steep slopes, being composed dominantly of the Barail rocks. The major part of the study area to the north of the Barail range is made up of the Disang sediments. The hills here are much lower and, more or less, rounded. In the Disang areas the valleys near stream channels are very steep due to intense base-level and toe erosion of the swift-flowing streams. The drainage patterns range from trellis to parallel, being controlled by lineaments (Fig. 2.6). Some dendritic pattern is also seen. The drainage density towards the Barail range is medium while it is high in the Disang dominated areas. The Dzüna Ru, Sanuo Ru and Dzütsü Ru form the main drainage network and are the main sources of surface water in the area. Sand, silt, clay and unsorted rock fragments are abundant along the course of the Dzüdza River, which makes it highly vulnerable to site amplification.

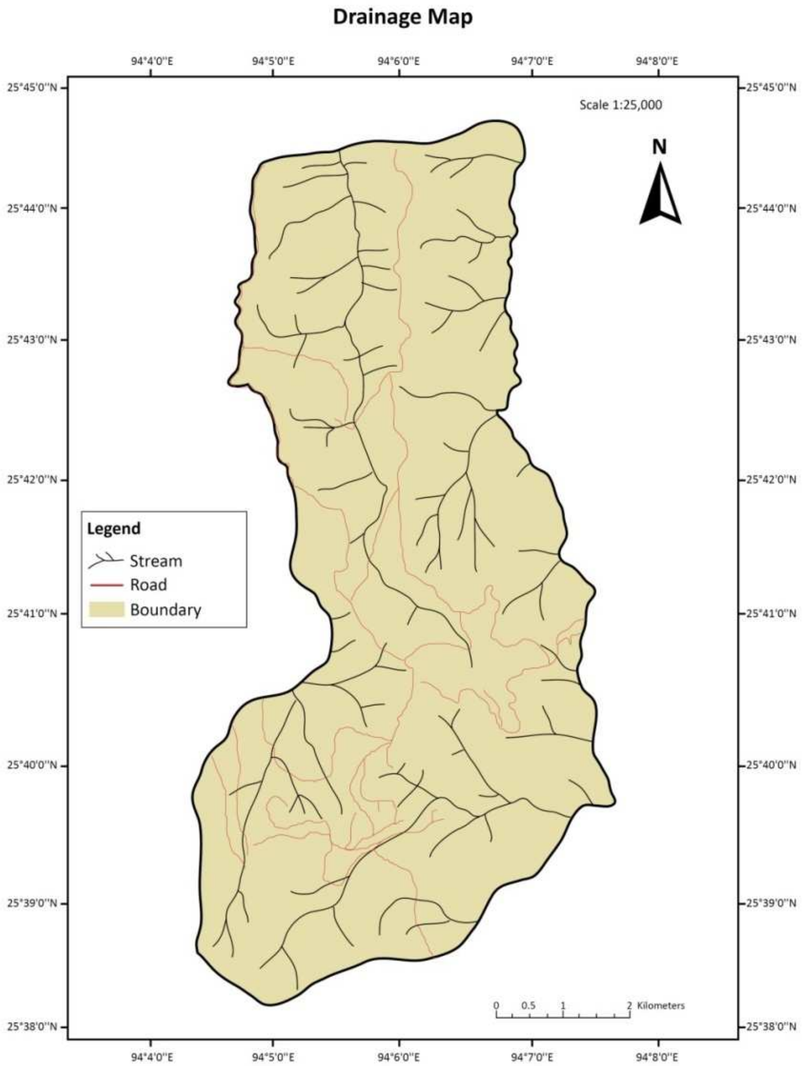



**Fig. 2.6:** Drainage map of the study area

### *2.6.4 Geology*

Geologically, Kohima town is located within the Kohima Synclinorium, in the vicinity of the tectonically active BoS. The dominant rock types are shale with thin alternations of siltstone of the Disang Group (Fig. 2.7). The Barail Group is made up of hard, well-bedded sandstone with thin compact shale.

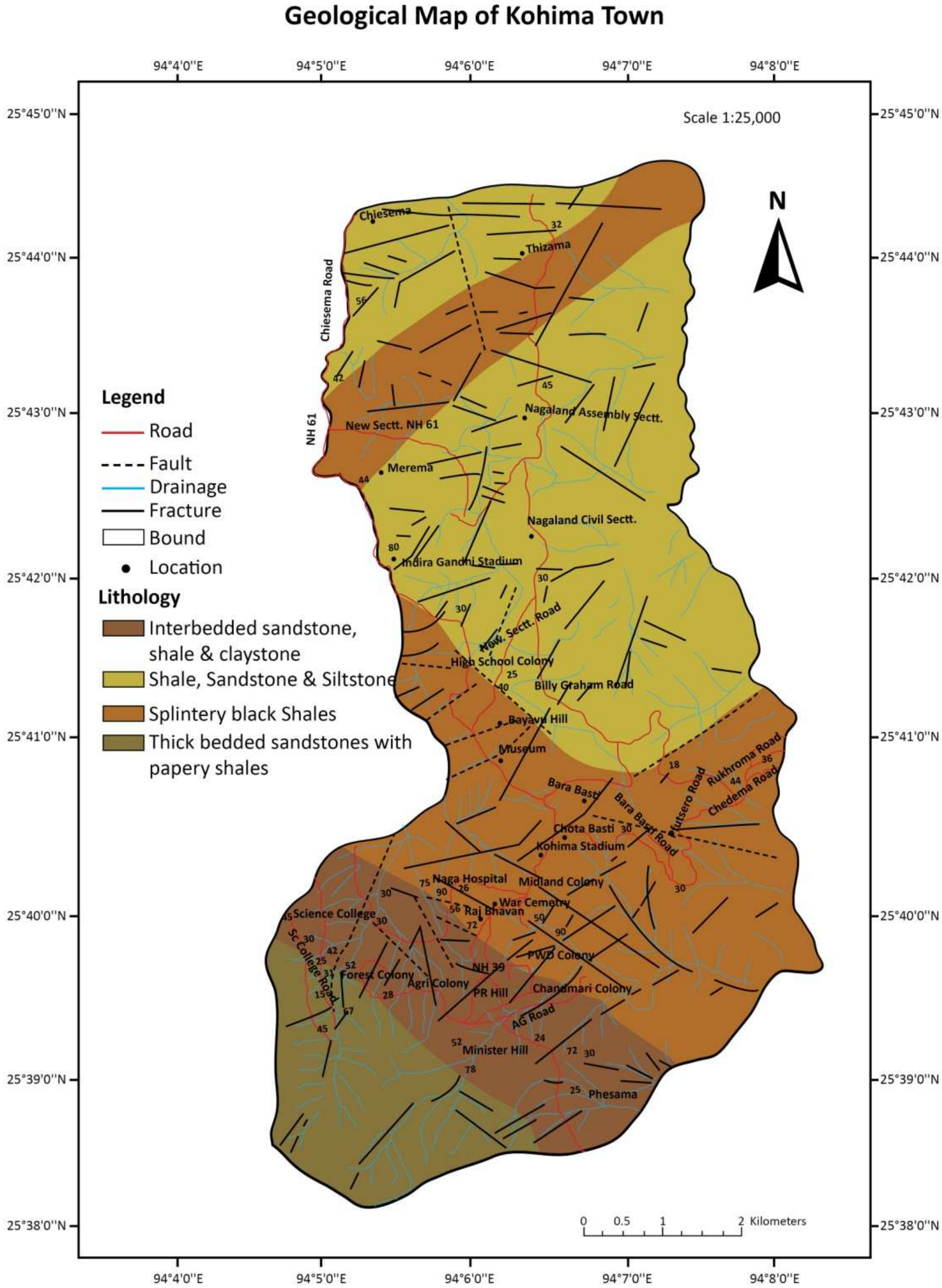



**Fig. 2.7:** Geological map of the study area

The colossal deposits of Cretaceous-Tertiary sediments of the Naga Hills were subjected to intense folding, faulting and thrusting during the under-thrusting of the Indian Plate beneath the Burma microplate. Evans (1964) estimated a crustal shortening of 320 km across the Naga Hills.

The Disang Group of Upper Cretaceous-Eocene age is made up of shale with minor siltstone. The shales are ferruginous and grey to black in colour. They are commonly splintery, with concretions and thin alternations of siltstone and mudstone. The arenaceous sandstone suite of the Barail Group contains minor siltstone and shale. The shales are highly susceptible to weathering and disintegrate on exposure to air. The residual soils making up the slope debris are derived from the underlying bedrock. These clayey to silty material are mixed with rock fragments. These fine sediments, being highly plastic and expansive in nature, are susceptible to slides and amplification of seismic waves.

The sequences of sandstone with minor shale of the Barail Group form steep, sharp-created ridges whereas the dominantly shale sequences of Disang Group form moderately round-crested ridges in the area. Spectacular scarp faces developed in the sandstone areas are common in the west and SW of Kohima. The upper ridges of the high Barail hills have thinner soil cover, which ranges from 0-2 m. The low lying hills and valleys, on the other hand, have thicker overburden of shale fragments ranging from 2 to over 4m.All the hill slopes of Kohima town are susceptible to slope failure. In general, the rocks at the south trend NW-SE, while those towards the north trend NNE-SSW, with dip amounts ranging from 30° to 45°.

As the thickness of the weathered column increases, the slopes are rendered more unstable due to the influence of gravity and water. As a result, in numerous places buildings, ring wells, retaining walls, etc. develop cracks and displacements over time. Various perennial and ephemeral springs are found along the slopes. The area is dissected by numerous joints and fractures, which accelerate weathering in the presence of abundant water, resulting in the formation of weak zones. Bedded rocks and those with cleavage planes along slopes, in areas of abundant groundwater, are highly susceptible to amplified ground motion and landslides.

#### *2.6.5 Geomorphology*

The structural features of this area are attributed to Tertiary orogenic upheavals, which have created three morphotectonic units, viz., moderate to steep slopes and highly and moderately dissected and denuded structural ridges. It has been recognized that the destructiveness of ground shaking during earthquakes is affected significantly by topographic amplification. Strong topographic relief affects ground shaking magnitude and frequency. Post destructive investigations have indicated that buildings located on top of hills, ridges and canyons suffered more intense damage than those located at the base.

The northern part of the study area is made up of steep ridges and narrow valleys that run parallel to each other from north to south. They are linear, narrow and often steep-sided. The landscape of this hilly area is continuously deforming due to landslides and erosion caused by incessant rainfall.

### *2.6.6 Structure*

The area within the Kohima Synclinorium has undergone intense tectonism. As a result, the formations are highly folded, forming tight anticlines and synclines with dips varying from 45° to 65°; at places they are almost vertical. These formations are continuously affected by neotectonism. The rocks generally strike NE-SW to NNW-SSE and dip in southeasterly directions.

The study area is tectonically disturbed which is reflected in the folded, jointed, fractured, faulted and sheared rocks. Numerous lineaments of local and regionally extent are observed here. The rocks are affected by three to four sets of joints that trend NE-SW, WNW-ESE and NW-SE. Along the NW-SE planes, normal faults and tensile fractures are noted. Regionally, they trend NNE-SSW along which the major thrusts occur. Surficial geological structures have a significant impact on ground motion mainly because they affect the wave field trapped in the valley sediments. The valleys have soft and unconsolidated sediments that trap seismic waves, thereby increasing their amplitudes, as waves cannot pass quickly through soft sediments.

The major lineaments in the area cutting across the rock units trend NNW-SSE and NNE-SSW. There are also minor faults of local extent that trend parallel to the major faults. The active faults and other lineaments within the township are a major concern for site amplification. The rock formations at the sites of the lineaments are weak and therefore, make those areas vulnerable to site amplification during earthquakes.

## 2.7 Groundwater and rainfall

The movement of subsurface water through fissures in the rocks and its impact on ground failure is of great concern for site amplification. Most parts of the study area are highly saturated during the monsoon, with the water table rising appreciably. Under normal conditions the area between Chakhabama and Kohima remains dry as the water table is low, but in areas that are perennially wet, the water table rises high because of absorption, which is the cause of water logging. Veder and Hilbert (1980) state that a consolidated soil may swell only if hydrostatic pressure increases and earth pressure remains constant. The groundwater condition in the area is not consistent and indicates fluctuating water tables. Piteau and Peckover (1989) showed fluctuating water tables can contribute markedly to the alteration and periodic changes in the mechanical properties of rocks. In several places water oozes out as springs, indicating fracture zones and shallow water table conditions, which make the area vulnerable to site amplification.

Rainfall data provides useful information on hydrological conditions of an area. Rainfall effects lithology and groundwater condition. This is an important factor contributing to terrain stability, which in turn has an impact on earthquake risk and ground failure. During years of heavy rainfall, more landslide incidences are noted, which influence site amplification due to infiltration of surface runoff. During such periods the groundwater levels rise, affecting the weaker lithologies. The heavy rainfall and weak lithology has made the area more vulnerable to seismic hazards, thereby raising the risk of the township during earthquakes.

## 2.8 Landslides

Landslides play an important role in site amplification of ground motion. Landslide zones being unstable are potential sites for amplification during earthquake. Several paleoslide zones were identified in study area.

# CHAPTER 3

## LITERATURE REVIEW

### 3.1 Introduction

Site amplification hazards are associated with ground shaking. Earthquake ground shaking is enhanced by amplification of site conditions. Local site conditions are considered the most significant factors for ground motion. Seismic vulnerability of highly populated cities can be assessed through quantification of site amplification behaviour, shaking intensity and resonance pattern of ground vibration and their impact on the built environment. The significant damage and loss of lives due to earthquake impact on site amplified ground motion is directly related to site conditions, such as local geology, topography, structural features, rock types, soil types and groundwater conditions. It is widely accepted that local geological conditions have a pronounced impact on seismic ground motion of sites (Aki, 1988; Finn, 1991).

Local ground amplification is controlled by the upper sedimentary sequence, which leads to trapping of seismic energy due to the impedance contrast between the soft upper surface soils and the underlying bedrock. Surface layers are greatly influenced by intensity of shaking, which can either attenuate or amplify earthquake motion transmitted through rock strata. Site amplification hazards have become a threat to urban population and the built environment. Hazards increase due to human activities. The hazards become a risk because humans and their activities are constantly exposed to natural forces (Tobin et al., 1997).

### 3.2 Geology of the region

Mallet (1876) gave the earliest account of the geology of the Naga Hills. Geological studies of Kohima and parts of Manipur were carried out by Oldham (1883). Hayden (1910) described some coal fields of Nagaland. Pascoe (1912) conducted a geological traverse from Dimapur to Saramati. The Tertiary succession of Assam including the tectonics of Nagaland was reported in the works of Evans (1932). Mathur and Evans (1964) proposed a lithostratigraphic classification and described the structures and tectonic framework of parts of NE India. The geological evolution of the rocks of the

Upper Cretaceous-Tertiary basin has been dealt with in detail by Raju (1968) and Bhandari et al. (1973). Krishnan (1968) gave a general description of the geology and tectonic framework of Nagaland.

Based on paleontological records, the NHO has been assigned an early Cretaceous-Eocene age (Brunnschweiler, 1966; Chattopadhyayet al., 1983). Bhattacharjee (1997) dealt with the tectonism of the Indo-Burman region. The petrography and geochemistry of the ophiolites, particularly the mafics and ultramafics, were initiated by Ghose (1979), Singh (1979), Ghose and Singh (1980) and Chattopadhyay et al. (1983). Agrawal (1985) and Agrawal and Ghose (1986) described the litho-assemblages of dismembered bodies of the ophiolite.

Studies of the NHO by the DGM (Agarwal and Shukla, 1996) concluded that drainage is mainly structurally controlled with most rivers flowing along a multitude of lineaments trending NE-SW. Rao et al. (2003), Subba Rao et al. (2004, 2005) and Srikanth et al. (2004) contributed to the geology of the NHO. Ezung (2007) described the geochemistry and petrography of the basalt and spilite of the NHO. Studies carried out in the IFB give an account of the Disang and Barail sediments of the region. Sarmah (1983) gave a detailed account of the Upper Cretaceous-Paleocene sediments of Kohima town and its surroundings. Thong and Rao (2006) gave an account of the provenance and depositional environment of the Disang sediments of Botsa. Vineetha (2004) discussed the geochemistry of the shales of Kohima town to arrive at their origin. Srivastava and Pandey (2011) discussed the provenance of the Barail sandstones of Kohima.

The seismicity and seismo-tectonics of NE India was discussed by Nandy (2001) and Kayal et al.(2006). They predict devastating earthquakes in the near future. Pascoe (1912), Evans and Crompton (1946) and Brunnschweiler (1966) contributed extensively to the geology of the Naga Hills. The geology of the Naga Hills is important in that it lies within a zone of plate collision characterized by frequent shallow and intermediate earthquakes. Several workers (Graham et al., 1975; Hutchinson, 1975; Mitchell and McKerrow, 1975; Saikia et al., 1981; Le Dain et al., 1984) correlate the development of the orogen with the interaction of the Eurasian and Indian plates. Dutta and Saikia (1976) and Saikia et al. (1981) discussed seismicity and tectonic development of the region in terms of plate tectonics. Fitch (1970), Rastogi et al. (1973), Chandra (1975), Verma et al. (1976) and others used fault plane solutions to decipher plate movements.

The gravity anomaly maps of Evans and Crompton (1946) for NE India identify distinct belts of negative and positive anomalies along the mountain ranges. Verma et al. (1976) studied the relationship between gravity and seismicity in the region and observed that the seismic zone underlying Myanmar is characterized by negative isostatic anomalies, indicating the probable existence of a subduction zone beneath the Arakan-Yoma and Myanmar plains. The high seismicity in the Naga Hills region indicates that movements are still continuing and that the BoS has not attained isostatic equilibrium (Verma et. al., 1976).

### 3.3 Landslide hazards

Landslides are down-slope movements of rock debris or earth masses along curved or planar surfaces, due to gravitational failure when materials lose their shearing strengths with or without the aid of excess water. Landslides are unpredictable natural calamities that damage property and vital infrastructure every year and adversely affect human lives. They are amongst the most rapid of all mass movements and pose very great hazards in mountainous terrain (Sharma et al., 1996). Slope failure may be triggered by a number of external factors such as intense rainfall, subsurface water level changes, ground vibrations due to earthquakes, storms and rapid stream channel erosion (Dai et al., 2002). Aier et al. (2009a) opine that the load and vibrations due to heavy vehicles along weak slopes may play a minor role in slope failure.

Sondhi (1941) first studied landslides in Nagaland along the Dimapur-Manipur National Highway. Sharda and Bhambay (1980) conducted environmental and geotechnical studies of Kohima town and prepared geotechnical and slope maps. Anand (1988) discussed the landslides between Chumukedima and Mao. Lotha (1994) studied the Chiepfütsiepfe slide of Kohima. Bhattacharjee et al. (1998) studied some landslides along NH 29. The Central Road Research Institute (2000a) investigated the weak zones between Chumukedima and Maram. A preliminary geological report of the Mao slide of Manipur with mitigation measures was submitted by Thong et al. (2004) to the Border Road Organistion (BRO). Aier et al.

(2005) provided the BRO mitigation measures for the Lalmati slide at Peducha. Thong et al.(2007) reported on the 179-km-slide along the NH 29. Aier et al. (2009b) gave a detailed account on SMR and kinematic analyses along part of NH 61 of Nagaland. Aier et al. (2011b) studied instability at Merhülietsa of Kohima town. The DGM (2011) carried out Remote Sensing and GIS-based Landslide Hazard zonation studies along the NH 29, between Dimapur and Kohima for mitigation and management.

### 3.4 Ground amplification

It is noted that intensity of ground shaking in the 1857 Neapolitan earthquake was related to geologic surface condition. It has also been recognized for a very long time that local site conditions can profoundly affect strong ground motion amplitude, frequency, contents and duration (Mallet, 1862). Gutenberg (1927) first developed the site amplification factors from recordings of microseism at sites with different soil conditions. But despite considerable evidences of the existence of the effects of sites, provisions, especially accounting for local site responses, did not appear building codes until the 1970s (Ministry of Urban Development, 1977).

Evidences of surface topographic effects also abound in literature (Brambati et al., 1980; Celebi, 1987). Instrumental evidences of the Chile earthquake of 1995, point to topographic controls. The best known is that of peak horizontal acceleration of 1.2g recorded during the 1971 San Fernando earthquake (M6.6). Accelerograph record of high peak acceleration was associated with dynamic response of the ridge (Trifunac and Hudson, 1971). Aki (1988) and Sanches Sesma (1990) estimated topographic impact considering a wedge shaped medium. Significant differences between the amplification function and the centers and edges of valleys have been observed during different earthquakes. Many theoretical studies and analytical approaches (Berd and Gabriel, 1986) have indicated that for irregularly shaped alluvial valleys, the resulting ground motion can be very complex and chaotic.

A number of destructive earthquakes in the recent past vividly accentuate the fact that site amplification response factors govern large-scale damage to specific areas. Such phenomena were pronounced in case of the great Japan earthquake of 1891(Milne and Burton, 1891) and the San Francisco earthquake of 1933(Wood, 1933). The extensive damage caused by the 1989 Loma Prieta earthquake was due to enhanced ground shaking(Holzer,1994).The NorthRidge earthquake of 1994 left several pockets of severely damaged buildings within a 1-km-radius of largely undamaged area across the Los Angeles region. More recently, the Jabalpur earthquake of 1997 and Bhuj earthquake of 2001 showed irregular damaged patterns. The damage pattern observed during the Bhuj earthquake is attributed to local behaviour and period of ground motion. A similar situation was also reported from MexicoCity after the Michoacán earthquake of 1985 (Holzer, 1994).

Ground motion characteristics during earthquakes are also controlled by local geotechnical conditions. Local site conditions vary due to variation in soil properties, depth of bedrock and water table and have significant effects on the characteristics of earthquake ground motion (Idriss, 1990; Letchet et al., 1996; Makra et al., 2001). Joyner and Fumal(1985) and Ansal and Slejko(2001) suggested that the upper 30m of the soil profile plays an important role in wave amplification, and can be used as one of the important parameters for estimating site amplification.

Several recent studies have demonstrated that local geology and ground conditions can highly amplify seismic ground motion. It is also well documented that an increase in site amplification associated with such weak site conditions leads to local intensity increment up to as much as 2 to 3 degrees (MM scale). Site amplification of ground motion is the most desired component in seismic hazards assessment. It is widely accepted that local geological conditions have pronounced impact on seismic ground conditions of the site (Aki, 1988; Finn, 1991). Local ground amplification is controlled by the upper sedimentary sequence, which leads to trapping of seismic energy due to the impedance contrast between the soft upper surface soils and the underlying bedrock. The surface layer is greatly influenced by intensity of shaking, which can either attenuate or amplify earthquake motion transmitted through rock strata.

Observations from the Bhuj earthquakes of2001, Michoacán and Loma earthquakes of 1985, Prieta earthquake of 1989, San Francisco earthquake of 1933, etc. have demonstrated the extensive damage to concrete high-rise buildings due to ground motion amplification and reveal that amplification is more pronounced in weak ground motion than for strong ground motion. During the 1985 Michoacán earthquake, though the epicenter was located more than 350 km away from Mexico City, the earthquake caused extensive damage to the city, which is underlain by loose deposits (Zeeveaert, 1991).

It is evident from several recent studies that the geological condition exerts a strong influence on ground motion and the damage pattern (Seed et al., 1972, 1991; Chang et al., 1996). Extensive damage to buildings and other structures during the Loma Prieta earthquake (1989), Bhuj earthquake (2001), San Francisco (1933) and Michoacán earthquake (1985) were caused by enhanced ground shaking, local site conditions and the period of ground motion (Holzer, 1994).

Cities built on soft, loose, unconsolidated sediments collapse easily during earthquakes due to site amplified ground motion. Site amplification studies therefore, are important for mitigation of hazards. This needs identification of hazards, local site conditions and location of safe sites for settlements and regulatory measures for the built environments.

From a review of past earthquake events related to site amplification impact on the built environment, the following inferences can be drawn with respect to the present study area of Kohima town and its surroundings.

Kohima town is located near the tectonically active BoS, which is seismically active. Therefore, the study area is highly disturbed, tectonically, which is manifested in the numerous folds, fracture sand faults, besides the extensive shearing of the rocks. As surface ground motion is strongly amplified by geological conditions during earthquakes, geological conditions are high-potential sites for amplification of ground motion.

The study area is dominantly made up of the Disang shales and abundant loose debris and weathered horizons, which have a great influence on site amplification of ground motion. Local geology has a strong influence on seismicity and resulting damage (Narayan and Sharma, 2001). The irregular hills and undulating valleys filled with abundant loose material can have a great impact on site amplification and extensively damage buildings.

The region has experienced two great earthquakes in the past - the Great Shillong Earthquake of 1897 (M 8.7) and the Great Assam Earthquake of 1950 (M8.7). The epicenters of both earthquakes were about 300 km away from the study area and yet there were strong ground motion, which triggered widespread landslides in parts of Nagaland, such as Kohima, Mokokchung, Tuensang, etc. During that period of time the area was not developed and therefore, there was not much damage to buildings and loss of lives. During the Bhuj earthquake of 2001, the city of Ahmedabad located at a distance of 300km from the epicenter was extensively damaged due to local site conditions. The Michoacán earthquake of 1985 also heavily damaged buildings some 350 km away from the epicenter. In the study area also, local site conditions are similar, with soft rocks, loose debris and weathered material, geological therefore, high-magnitude earthquakes can case extensive damage. Seismologists have predicted devastating earthquakes in the north-eastern region of the country in the near future (Nandy, 2001; Kayal et al., 2006). Possible epicenters may be the fault lines of the two great earthquakes; these could enhance site amplification and damage buildings and other structures in Kohima town.

The vulnerability to earthquakes has increased in Kohima town due to rapid population growth, rampant settlement and extensive developmental activities in landslide-prone areas. This hilly terrain and the unstable ground conditions have compounded the risk to landslides due to site amplification.

The study of landslides thus, helps in an understanding of surface instability, especially paleoslide zones. Several paleoslide zones have therefore, been identified in the study area, which are potential sites for site amplification, liquefaction and ground failure.

# CHAPTER 4

# METHODOLOGY

The method adopted for the present study involves a first order assessment of site amplification hazards for the urban area of Kohima town. It is a flexible approach that includes geological field studies and laboratory analyses. The aim is to establish ground conditions that enhance ground motion, which in turn affects the built environment during earthquakes.

## 4.1 Materials used in geological field studies

- SoI toposheet No. 83 K/2 NW on 1:25,000 scale
- GPS to map faults and lineaments
- Brunton compass to measure dip and strikes of beds and joints
- ASTER and LISS-3 satellite imagery
- ArcGIS 9.3 software
- ILWISS software for processing satellite imagery
- GPR survey to obtain subsurface data

Field surveys include mapping of geomorphic features, groundwater conditions and the litho-units. Field studies also aim at determining the trends of geological discontinuities such as bedding planes, joints and faults. Besides, the depth of soil layers and surface stability conditions are evaluated. Samples were collected from drill holes to develop litho-logs and assess groundwater condition. The impact of the above parameters and the influence of rainfall on the soils in the built environment are taken into consideration for this study.

Atterberg limits and triaxial tests were carried out to determine surface stability conditions for safe location of future buildings for urban settlement and sustainable development.

Assessment methods and determination of the nature and potential amplification of sediments are yet unclear among seismologists and earthquake engineers. The methodology adopted aims to improve landuse and settlement. It is also useful for regulation of urban planning, policy formulation and demarcation of safe sites for urban settlement. An attempt is thus made to assess seismic site amplification hazards of Kohima town considering the current seismic scenario, population growth, socio-economic condition and their impact on built environment. Owing to lack of recorded ground motion data and seismic equipment, emphasis is put on field studies, GPR surveys and laboratory tests. A broad overview of site amplification assessment is given below (Fig. 4.1).

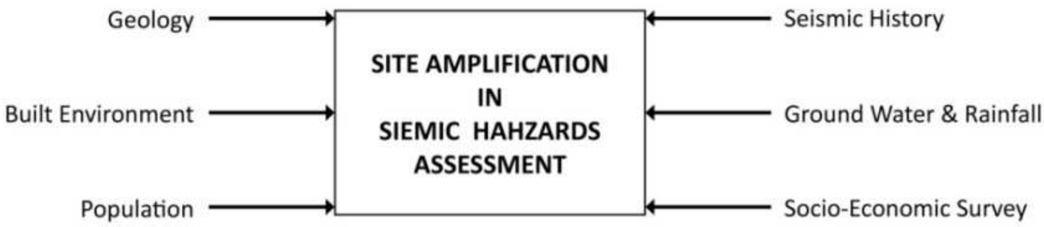



**Fig.4.1:** Seismic site amplification of hazard assessment

The work can be divided into two categories, A and B on the basis of their nature. Category A involves geological fieldwork, seismic and landslide studies, data collection and study of satellite imagery related to influence of site amplification (Fig. 4.2). Category B constitutes data generation of the built environment, which includes

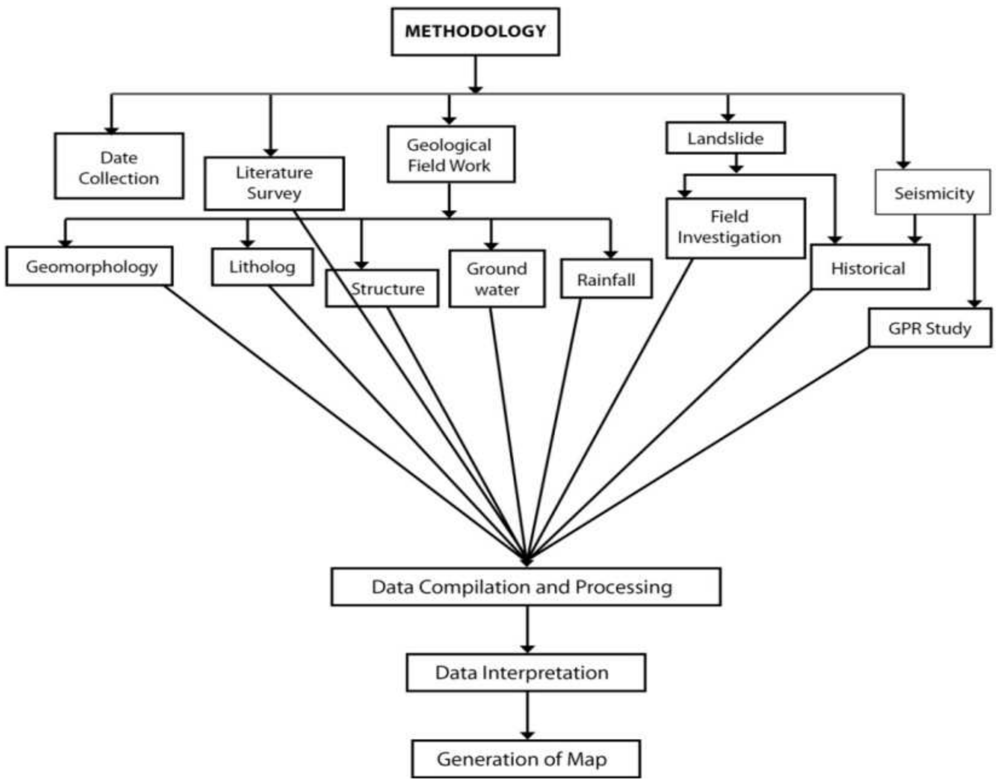



**Fig. 4.2:** Flow chart showing methodology based on geological parameters

buildings, other structures and developmental assets that exist in areas vulnerable to damage by site amplified ground motion. It also includes socio-economic surveys, collection of data on population growth, existing regulatory measures for landuse and settlement and enforcement policies (Fig.4.3).

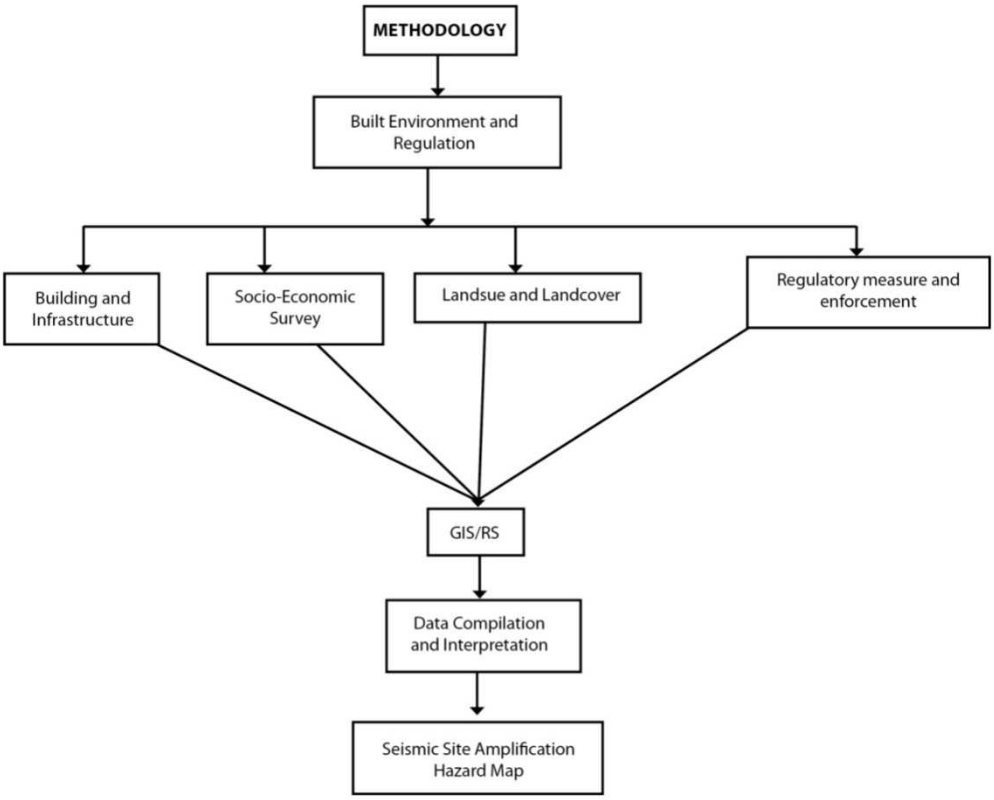



**Fig. 4.3:** Flow chart showing methodology based on the built environment

SoI toposheet was used for preparation of geological, geomorphological, lithological, seismotectonic, hydrogeological and land use/land cover maps to identify areas of site amplification. Litho-logs from boreholes were collected to generate lithological data. Rainfall data was collected from the Directorate of Soil & Water Conservation, Nagaland. A GPR was employed to generate subsurface data. All the above information was synthesized to determine potential site amplification behavior.

## 4.2 Data collection

Data collection consisted of primary and secondary. Primary data was generated in the field and laboratory. Secondary data was obtained by literature survey, journals, books, internet and reports. Remotely sensed data helped in mapping lineaments on the regional as well as local scale. A lineament map was prepared using satellite imagery and topographic map; the data generated was verified in the field.

### *4.2.1 Remote sensing*

- Indian Remote Sensing Satellite (IRS-P6) multispectral (LISS-1V) mosaic digital data of $4^{th}$ Dec.2006 (path/raw-616/279) and $27^{th}$ Jan.2007 (path/raw-617/279) (Table 4.1).
- IRS-P5 CARTOSAT-1panchromatic mosaic digital data acquired on $7^{th}$ Dec.2007 (path/raw-616279) and $8^{th}$ March, 2007 (path/raw-617/279).
- CARTOSAT stereopair for generating DEM.

**Table 4.1:** Satellite specifications

| | | |
|---|---|---|
| IRS-P6 (Resourcesat) | Multispectral bands (μ) | Bands-3 |
| | Resolution(meters) | 0.52-0.59 (green) |
| | Swath width(km) | 0.62-0.68 (red) |
| IRS-P5 (Cartosat-1) | Spectral bands(μ) | 0.77-0.86 (NIR) |
| | Instantaneous Geometric Field of View (IGFOV) | 5.8 |
| | | 29.3 MX mode |
| | Swath width(km) | Panchromatic 0.50-0.85 |
| | | <2.5 m |
| | | 30 km |

### *4.2.2 Auxiliary data*

- Existing maps and literature.

## 4.3 Field studies and laboratory analyses

Field and laboratory tests were carried out to determine ground stability conditions for identification of site amplification.

### *4.3.1 Laboratory analyses*

Atterberg limit: An Atterberg test (ASTM Test D-4318) defines the ranges in moisture content within which a soil will behave as solid, plastic and liquid. The liquid limit of a soil is the moisture content above which the soil behaves as a liquid. The plastic limit is the moisture content above which the soil behaves plastically. The numerical difference between the liquid limit and plastic limit is the plasticity index (PI). The Atterberg limit standards are given below:

| | |
|---|---|
| 0 | - Non plastic |
| 1- 5 | - Slightly plastic |
| 5-10 | - Low plasticity |
| 10-20 | - Medium plasticity |
| 20-40 | - High plasticity |
| >40 | - Very high plasticity |

Triaxial test: A triaxial test is performed on cylindrical cores of soil samples to evaluate their shear strength. The triaxial test attempts to replicate in-situ stresses (stresses in the original place from where the soil sample was taken) on soil or rock cores. Typically, triaxial tests are used to solve to stability problems by determining the shear strength and stiffness of soil. It is also used to measure pore-water pressure and determine contractive behavior, which is common in sandy soils. Therefore, data obtained by this method is important for improvement of building designs.

### *4.3.2 Field studies*

Field mapping was carried out to obtain information on geology, geomorphology, lithology, soil characteristics, faults and lineaments, land use and land cover, groundwater conditions, built environment, lithology, etc. A GPR was employed to study shallow subsurface soil layers/rocks and deformation features in and around the Kohima town. Lineaments, including faults, were mapped using satellite imagery, which was supported by geological data, lithological maps, drainage patterns and field observations.

### *4.3.3 Ground Penetration Radar surveys*

A GPR was used to retrieve shallow, subsurface geological data of the study area. The GPR consists of a transmitter, which sends electromagnetic energy into the soil and other materials. A GPR emits pulses into the subsurface and records the echoes that result from the objects. GPR imaging devices also detect variation in the composition of ground material. It is important for locating objects underground and is useful in inferring depths and thicknesses of soil horizons. This geophysical method uses radio waves to capture images of the subsurface in a minimally evasive way.

The instrument is fitted with four wheels, an antenna facing the ground and a monitor. As the instrument is pushed over flat ground the antenna captures images below ground surface and sends the signals to the receiver in the monitor, which is then stored. The data is then taken for image processing in a computer.

## 4.4 Built environment

The built environment for seismic vulnerability assessment by site amplification was carried out in the light of earthquake-resistance of buildings, past earthquake damage history and construction practices adopted.

### *4.4.1 Building typology*

The existing buildings of the towns of Nagaland are a rich mix of several different building types and construction technologies, which are as follows.

- Buildings made of GI sheets, thatch and other light weight and cheap material (Type-A).
- Masonry structures with reinforced concrete roofs, using cement mortar in most cases and mud/lime mortar in some (Type-B).
- Reinforced concrete frame building with in-filled brick walls (Type-C).

The latter two are engineered constructions in which assistance from qualified structural engineers are sought at each stage in most of the cases. The first category, the non-engineered structures, is governed by socio-economic considerations rather than engineering.

### *4.4.2 Landuse and landcover*

Areas under vegetation are less affected by landslides. The areas utilized for human settlement are estimated to provide an assessment of the safety of the environment, property and lives. Environmental conditions and socio-economic pressure on land provide the data for landuse and land cover in the study area. The area is classified into dense forest, open mixed forest, degraded forest, terrace cultivation, mixed cultivation, dry agricultural land, scrub land, settlement and plantation. Landuse is concerned with human settlement in stable areas safe from natural hazards like landslides and earthquakes.

### *4.4.3 Socio-economic surveys*

Earthquakes not only devastate buildings and cause loss to lives but also disrupt the social fabric of society. Hence, socio-economic surveys are important in site amplification studies. The socio-economic survey focuses on population growth and migration from other places, infrastructure, development activities, utility assets, institutions, industries and factories and other resources. The population survey helps in an understanding of the impact of population and infrastructural development on site amplification of ground motion during an earthquake.

### *4.4.4 Population of Kohima*

Kohima, being the capital and administrative head of the state of Nagaland, attracts people from the other districts of the state. It also serves as the business center for many of the small towns and villages in the district. The concentration of educational institutions in the town attracts students from all over the state. The Urban Development Department of Nagaland contemplates on including the neighboring villages of Meriema, Thizama and Jotsoma into the Master Plan of Kohima town. The rapid growth of the township in the recent past has exerted pressure on suitable land for construction of houses and development activities.

# CHAPTER 5

# RESULTS AND DISCUSSION

Seismic hazard assessment of Kohima urban town was taken up from the seismic site-amplification hazard perspective, based on historical seismic data, geological site studies, lithology, GPR surveys, groundwater condition, rainfall data and surveys on the built environment. GPR surveys were conducted in randomly selected stations for mapping of subsurface soil layers and rock deformation. The data generated is used for site response studies. Geological field studies were directed to identification and mapping of rock types and their lithological characters, structures, paleoslides and active landslides. Groundwater levels were estimated and litho-logs constructed from boreholes in the study area. Various ground features, such as topography, slope, lithology, etc. have a profound impact on local site amplification.

## 5.1 Topography

Topography plays an important role on site conditions; its effects causes a variation in seismic motion due to different physical phenomena, such as focusing of seismic waves near the crest because of reflection on a free surface and/or the interaction between incident and diffracted waves (Bard, 1982). As is known, structural heterogeneities affects wave propagation. Consequently, in many real cases the topography is one of the contributors to local site amplification.

Numerical simulation of ground shaking in complex topography predicts that seismic waves are amplified around ridge and crests (Boore, 1973; Massa et al., 2014; Poursatrip et al., 2017). Both seismic noise analysis and strong motion records confirm that strong shaking often occurs at topographic highs (Chaves Garcia et al., 1996; Durante et al., 2017; Harzel et al., 2014; Massa et al., 2010). Meuner et al. (2008) pointed out that earthquake-induced landslides tend to cluster around ridge crests as a consequence of these topographic site effects, yet the amplification of ground shaking around the crests predicted by numeral studies is found to be modest, mostly 1.2 to 2.5 times the flat model. This being the case, buildings on slopes and high relief areas are at greater risk of landslides due to amplification of ground motion. Thus, topography has much influence due to site amplification. Significant damage due to earthquakes at the top of topographic irregularities suggests that relief plays a significant role in the propagation of seismic waves. Consequently, topographic effects have had a substantial impact on seismic hazards of many historical centers built at the top of ridges or along very steep hillsides. The influence of topography on seismic response has been observed and proven numerically and experimentally (Athanasopoulos et al., 1999; Sepulveda et at., 2005; Lee et al., 2005a).

The study area represents an irregular hilly terrain with undulating valleys, which have high potential of site amplification of ground motion due to relief and valley-filled alluvium (Fig. 5.1).

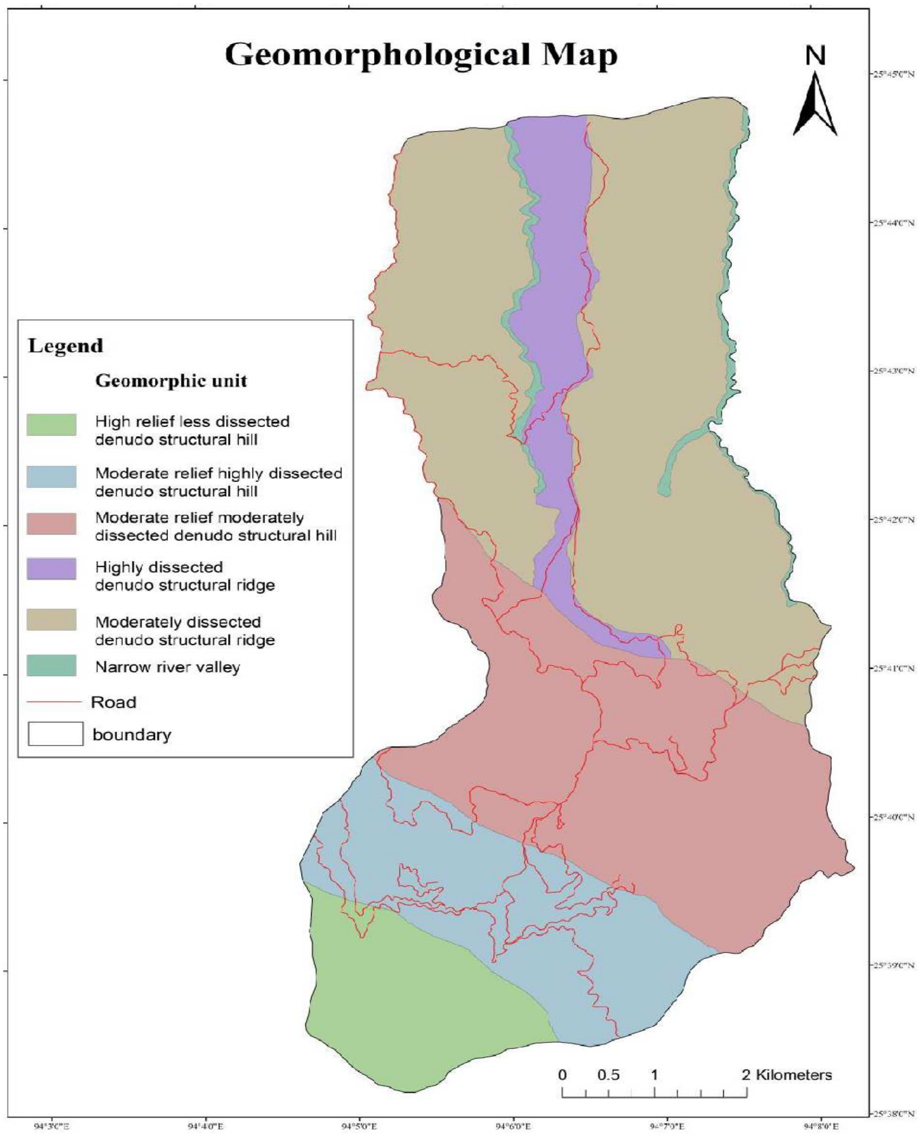



**Fig. 5.1:** Geomorphological map of the study area

### 5.2 Slope

Slopes play a significant role in determining infiltration of runoff water. Infiltration is inversely related to slope, that is, the gentler the slope, the greater the infiltration and lesser the runoff, and vice versa. The following slope classes have been generated from the slope map (Table 5.1) prepared from Cartosat DEM.

**Table 5.1:** Slope angles and classes of the study area

| Slope angle (in degrees) | Class |
|---|---|
| 1-3 | 1 |
| 5-10 | 2 |
| 10-15 | 3 |
| 15-20 | 4 |
| >20 | 5 |

Gentle slopes permit greater infiltration, which influence groundwater levels. Consequently, the weakened lithology becomes vulnerable to site amplification due to ground motion. The shale formations of Kohima, being friable and easily soaked with water, are highly susceptible to landslides and site amplification.

### 5.3 Lithology

The rock types exposed in the area generally consist of sequences of dark grey splintery shale with erosional dark clay and claystone with thin sandstones and siltstone bands (Fig. 5.2). These shale sequences are, at places, overlain by the Barail sandstone. The shales slake and swell in contact with water, and on exposure to air, disintegrate. The weathered soil and debris derived from the underlying bedrocks are clay, silt, sand and rock fragments. The clays are highly plastic; they swell and are expansive in nature, which make them susceptible to landslides. Water weakens rocks that have been jointed, fractured, folded and faulted. Froehlich et al. (1992) maintain that high density of joints in rocks of a region is related to high tectonic activity. Ground motion is amplified more in soft soils and loose material. Therefore, the weaker the rocks or soils at a site, the larger will be the waves generated during ground motion. Therefore, softer soils amplify ground motion. The rocks in the study area are weak and highly susceptible to weathering and landslides, which in turn will influence site amplification during ground motion. Water saturated mud has the strongest amplification during shaking and are hence, highly prone to liquefaction.

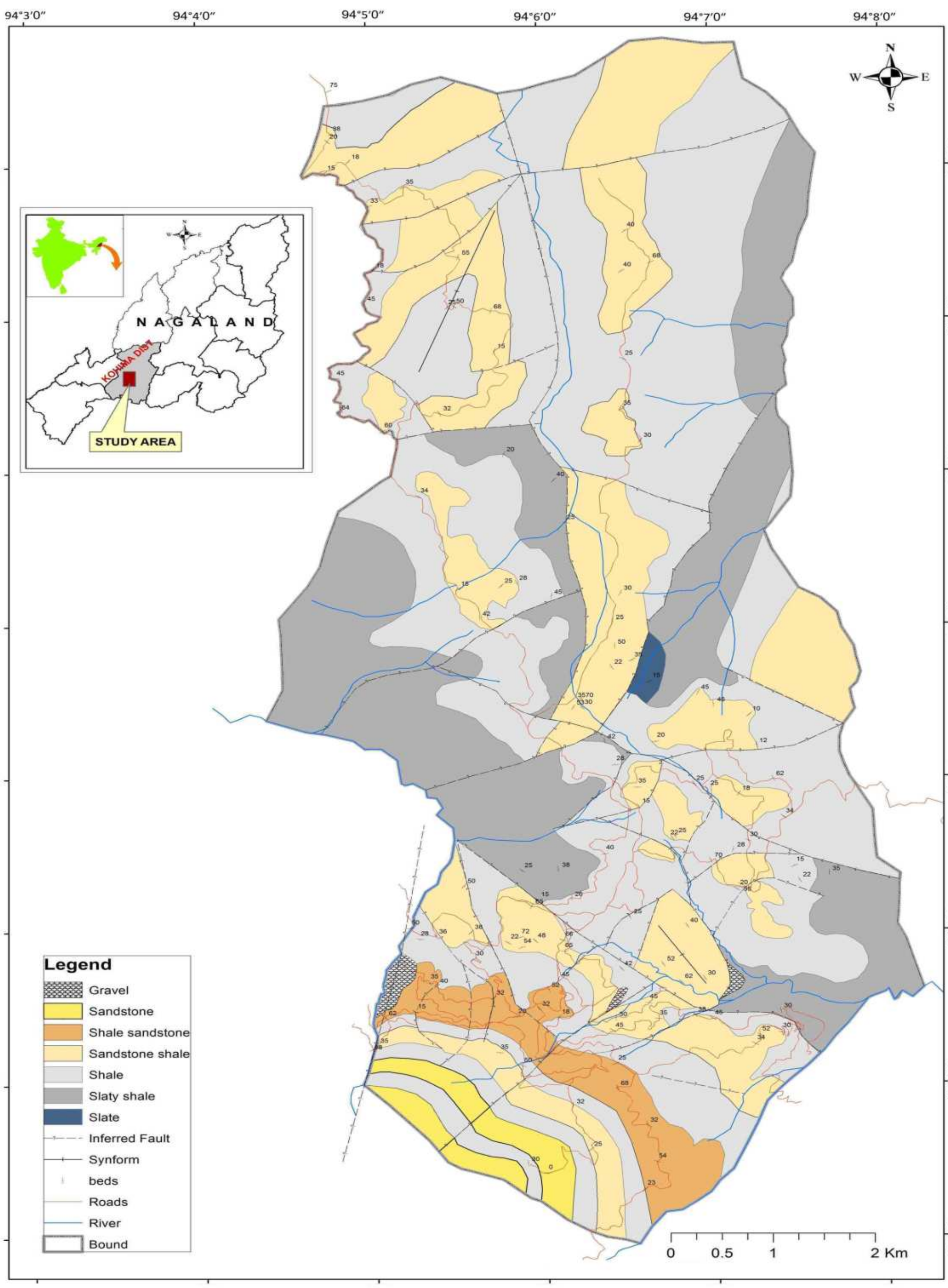



**Fig. 5.2:** Lithological map of the study area

Litho-logs from boreholes of the study area show that the rock constituents from 0.6 m to 54.50 m depth are soft and splintery shale with thin intercalations of siltstones (Table 5.2). Such sites are susceptible to site amplification and therefore, sliding.

**Table 5.2:** Litho-logs of Kohima town and its surroundings

| Sl. No. | Location | Coordinates | Elevation (m) | Lithology and depth (m) |
|---|---|---|---|---|
| 1 | Jotsoma (Phezhu) | 25°39′59.0″N<br>94°04′39.3″E | 1617 | 0-30 = Silty sand<br>30-45 = Soft splintery shale<br>45-66.5 = Hard splintery shale<br>66.5-77 = Fine grained flaky sandstone |
| 2 | Chief Secretary's Residence | 25°40′2.77″N<br>94°05′57.9″E | 1035 | 0-10 = Weathered shale<br>10-62 = Splintery to hard shale |
| 3 | Chief Minister's Residence | 25°39′17.10 ″N<br>94°05′7.9″E | 1525 | 0-15 = Light grey shale<br>15-32.8 = Dark grey sandstone<br>32.8-54.04 = Dark grey shale<br>54.08 -73.2 = Fine grained, dark grey sandstone<br>73.2-88.45 = Alternation of sandstone and shale |
| 4 | Working Womens' Hostel | 25°41′27.80″N<br>94°`06′07″E | 1370 | 0-5 = Light grey shale<br>5-15 = Black phyllitic shale<br>15-35 = Light grey shale<br>35-55 = Black phyllitic shale |
| 5 | New Capital Complex | 25°40′35.5″N<br>94°0627.9″E | 1030 | 0-4 = Weathered shale<br>4-14.5 = Splintery shale<br>14-65.5 = Alternation of sandstone and shale |
| 6 | Thizama RP Gate | 25°43′27.7″N<br>94°06′31.3″E | 1325 | 0-4 = Weathered shale<br>4-27 = Soft dark shale<br>27-30 = Hard dark shale<br>30-37 = Silicious mudstone<br>37-46 = Alternations of hard, dark grey and splintery shales |
| 7 | Rusoma Village | 25°43′20.26″N<br>94°08′13.12″E | 1463 | 0-4 = Shale<br>4-13 = Soft splintery shale<br>13-34.5 = Hard splintery shale |
| 8 | Merhülietsa | 25°66′18.7″N<br>94°09′67.6″E | 1429 | 0-6.9 = Soil cover<br>6.9-12.19 = Fine grained, splintery shale<br>12.19-24.38 = Fine grained sandstone<br>24.38-61 = Splintery shale |
| 9 | St. Paul School, Phesama | 25°37′14.2″N<br>94°06′43.0″E | 1590 | 1-1.5 = Fine grained sandstone<br>1.5-7 = Carbonaceous shale<br>7-13 = Fine grained papery shale<br>13-21 = Soft shale<br>21-54.5 = Hard splintery shale with mineralization along fractures |

Areas with potential of site-amplified hazards were demarcated in and around Kohima town based on lithology. The areas lying in the central part of Kohima including southern part of Mission Compound, eastern part of the NST Complex, Merhutlitsa Colony, New Market Colony, Midland, Kezieke, Lower Chandmari, Assam Rifles Colony, Forest Colony, etc. where population concentration is higher, are prone to higher amplification due to thick overburden of unconsolidated sediments. These areas are potential zones for site amplification and need serious attention for mitigation of earthquakes and landslides. Other high amplification zones are noted at the Indira Gandhi (IG) Stadium, southern Meriema, northern Jotsoma and eastern part of Tseisema.

### 5.4 Lineaments

Lineaments are linear or curvilinear features that play a vital role in geomorphic and structural studies. Lineaments like joints, fractures, etc. develop due to tectonic stresses. They provide clues of surface features, are responsible for infiltration of surface-water into the subsurface, and help movement and storage of groundwater that make sites vulnerable to amplified ground motion. A number of fractures, joints, shear zones, faults, etc. is encountered within the township. Some of these faults are active. Thus, these weak rock areas are vulnerable to site amplification during earthquakes. Rock exposures seen along riverbanks and road cuttings are commonly deformed. Kohima town, located within the Kohima Synclinorium, has undergone a high degree of tectonic activity. The formations form tight anticlines and synclines with dips varying from 45° to 65°; at places they are almost vertical. Deformation is continuing due to ongoing tectonism. The general trends of the strikes vary from NE-SW to NNW-SSE (Fig. 5.3), with dips of 30° to 55° in a southwesterly direction. Two to three sets of joints are common in the rocks of the study area.

A major lineament was mapped near the Don Bosco School and along the Sanuo Rü, a northerly flowing stream. This trace is recorded at an altitude of 1495 m above msl. (25°41'N and 94°07'10"E). Another lineament noted south of the IG Stadium, trends NE-SW. The trace of a third lineament is seen near the New Secretariat Complex, at the confluence of the northerly flowing Sanuo Rüand another stream flowing east at an altitude of 1435m above msl. A lineament cuts through the Vurie area, west of the police check gate at the Kohima bypass. Numerous joints and fractures are associated with this lineament. The trace of this is at an altitude of 1200 m above msl (25°40'26''N latitude and 94°5'00''Elongitude. A SW-trending fault in the Mehrülietsa Colony continues NE through the Lower Chandmari, passing through the Police Reserve Hill. A spring is associated with this fault. Another fault traverses the Naga Bazar-Oking-Midland area. Another lineament is noted at the Kezieke-Kohima Village area.

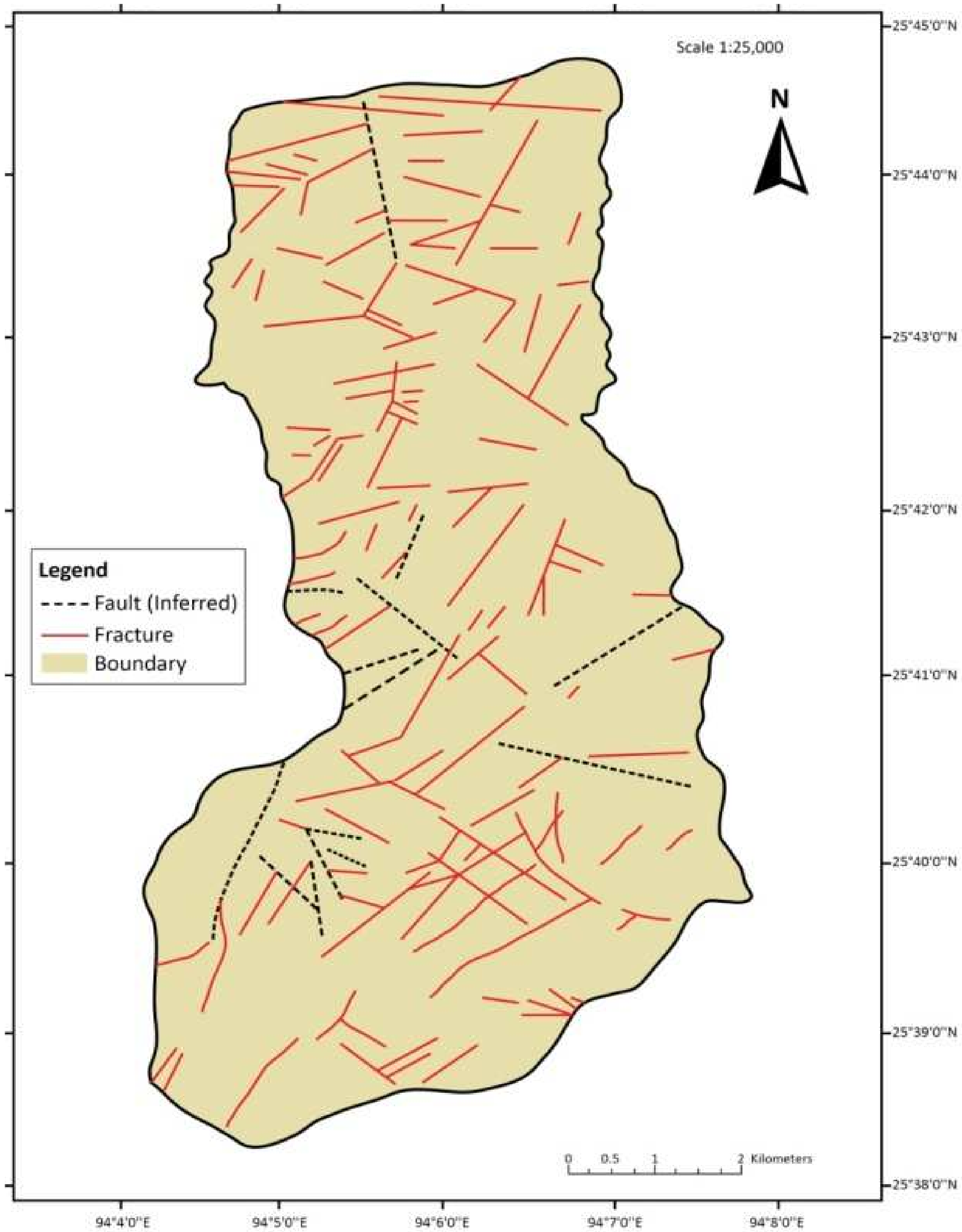



**Fig. 5.3:** Lineament map of the study area

## 5.5 Landslides

Landslides and subsidence of different dimensions and magnitudes frequently disrupt normal life in this hilly town. The main causes are surface water infiltration and groundwater conditions in the area. Site amplification is related to condition of geological formation and water. The study area is made up of fractured and sheared shales, which enable percolation of surface water. Ground and surface waters have a great influence on site conditions. Saturated conditions favor amplification, which can cause surface instability and sliding of slope masses. Kohima town and its surroundings are highly prone to landslides. Therefore, the impact of site amplification on landslides can have tremendous effects and is therefore, an important factor in assessment of seismic hazards. The study reveals that the geological formations of Kohima town are highly susceptible to landslides, which are common in most of the wards (Table 5.3).

**Table 5.3:** Major landslide-prone areas of Kohima town that can influence site amplification

| Sl. No. | Locality / Colony | Ward No. | Year of occurrence |
|---|---|---|---|
| 1 | Kezieke | 2 | 1956 / 64 / 76 / 96 |
| 2 | Assam Rifles / D Block | 5 | 1965 / 2010 |
| 3 | Mehrülietsa | 9 | 1968 / 89 / 99 |
| 4 | Naga Bazaar | 3 | 1966 / 74 / 2010 |
| 5 | Serüzou, NH 29 | 7 | 1976 / 84 / 88 |
| 6 | Merhülietsa | 15 | 1989 / 2011 |
| 7 | Lower AG & PR Hill | 14 | 1989 / 98 / 99 |
| 8 | PWD office, Midland | 8/10 | 1989 / 99 |
| 9 | Lower AG colony | 13 | 1992 / 98 / 99 |
| 10 | Choto Bosti & Sepfüzuo | 4 | 1964 / 65 |
| 11 | Govt. High School area | 1 | 1964 / 88 |
| 12 | Daklane | 6 | 1965 |
| 13 | Lower PR Hill | 1 | 1989 / 98 / 99 |
| 14 | AG / Chandmari | 11 | 1911 / 13 / 90 / 2010 / 11 |
| 15 | Lower AG, Chiepfütsiephe | 13 | 1992 / 98 / 99 |
| 16 | New Market | 13 | 2007 |

Landslide prone zones have a significant influence on site amplification of ground motion. Hence, identification of paleoslide zones is important. The following six paleoslide zones in the area were identified in the field (Fig. 5.4) to locate potential areas of site amplification.

- Supply Point
- Naga Hospital
- SKV Enterprise(IOC)
- New Market
- Ao Baptist Church
- Kezieke

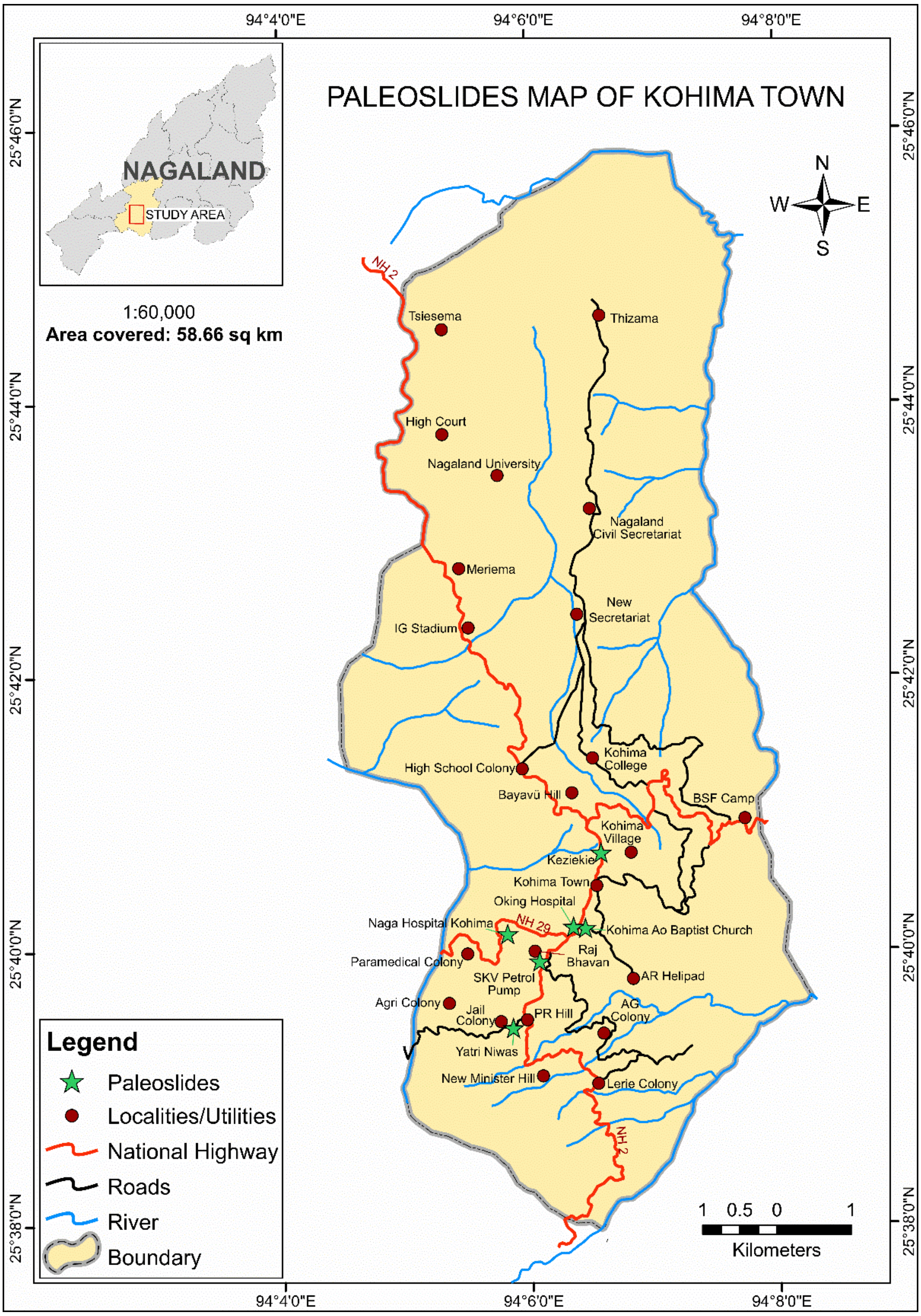



**Fig. 5.4:** Paleoslide map of the study area

Studies were carried out in some landslide zones of Kohima to assess the various parameters of the soils.

### *5.5.1 Dzüchie slide*

This slide is located at Dzüchie, about 7 km NW west of Kohima town. The slide lies on the north-eastern slope of Jotsoma village (175-km stone, former KMC garbage dump), which is. It is one of the oldest active slides along NH 29, between Dimapur and Kohima. It lies at 25°40'54"N latitude and 94°04'09"E longitude. Portions of this site have been continuously creeping very slowly for many decades, accompanied by minor slumps. A major landslide occurred on 7$^{th}$ August 2010, which completely cut off the vehicular movement for nearly ten days. This complex slide is affected by both lateral and vertical movements. The length of the slide from crown to toe is about 830 m. It had damaged about 300 m of the highway.

The laboratory tests of soils of the area, including Atterberg limits, triaxial, etc. show abundant clays in the soils. Abundant clays are responsible for unstable ground condition, which tend to amplify ground motion. Some samples collected from this slide zone indicate that the materials are highly plastic. The plasticity index ranges from 4.64 to 30.77 (Table 5.4), which is inconsistent but generally highly plastic (Fig. 5.5). The data points to most plastic materials near the surface. The highly plastic clay materials are distributed horizontally and vertically as thin layers, which are responsible for the overall instability of the slopes. Pore-water pressure is also an important factor contributing to slope failure. Results show high water content of the soils; such soils are susceptible to site amplification during strong earthquakes.

**Table 5.4:** Atterberg limit test results of the soil samples of Dzüchie

| **Location / Sample depth** | **Liquid limit** (%) | **Plastic limit** (%) | **Plasticity index** (%) |
|---|---|---|---|
| S-1 / 0-0.3 m | 50.00 | 19.23 | 30.77 |
| S-2 / 0.3-1.5 m | 23.14 | 18.50 | 04.64 |
| S-3 / 1.5-2.1 m | 50.50 | 23.50 | 27.00 |
| S-4 / 0-2.1 m | 37.50 | 28.00 | 09.50 |
| S-5 / 2.1-3.0 m | 26.20 | 12.50 | 13.70 |
| S-6 / 3.0-3.4 m | 21.30 | 15.70 | 05.60 |

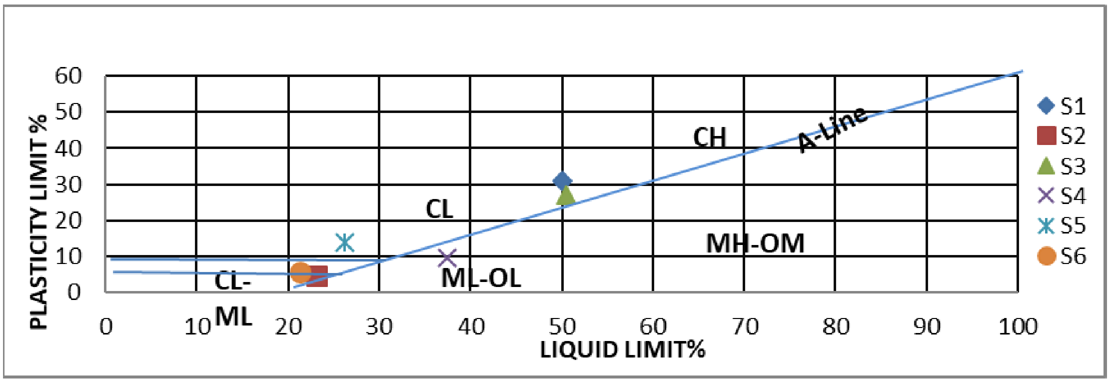



**Fig. 5.5:** Plasticity chart of the soil samples of Dzüchie

Triaxial shear tests were conducted for soil samples from two pits at Dzüchie without measuring the pore pressure and volumetric change (Table 5.5). The soils have low shearing angles; the general slope failure in the Disang shale is at low angles.

**Table 5.5:** Triaxial shear test data of soil samples of the study area

| Parameters | Pit 1 | Pit 2 |
|---|---|---|
| Angle of shear | 7° | 1° |
| Cohesion | 0.175 | 0.1 |
| Soil bearing capacity (T/m$^2$) | 2.5 | 3.0 |

### *5.5.2 Phesama slide*

This major slide is located about 10 km south of Kohima town. This landslide, first triggered in the 1960's, got aggravated in 2013 and then again in 2015 during incessant rains. The landslide occurred along the Disang-Barail contact. The landslide completely destroyed about 1 km of the highway along with several buildings and terraced paddy fields, which slid about 500 m downhill. Soil samples from the landslide zone were collected and analyzed for their natural moisture content and consistency limits (Table 5.6) to determine their shearing properties.

**Table 5.6:** Consistency limit determination sheet

| **Sample no.** | **Natural water content** (%) | **Liquid limit** ($W_L$) | **Plastic limit** ($W_P$) | **Liquidity index** ($I_L$) | **Plasticity Index** ($I_P$) | **Consistency index** ($I_C$) |
|---|---|---|---|---|---|---|
| P-1 | 22.25 | 25.2 | 9.45 | 0.8126 | 15.75 | 0.1873 |
| P-2 | 14.15 | 27.8 | 14.63 | -0.0364 | 13.17 | 1.0288 |
| P-3 | 10.68 | 27.5 | 16.40 | -0.5153 | 11.1 | 1.5153 |

The $I_P$ of all three samples is moderate. The negative $I_L$ depicts higher moisture content and the consistency index values of zero and one indicate soft and stiff soil types respectively. The natural water content ranges from 10.68% to 22.25%. The $I_C$ values of P-1 indicate soft soils whereas P-2 and P-3 represent stiff soils. The water content of P-1 exceeds P-2, which means that the soil is more plastic. Such soils are vulnerable to plastic deformation and prone to mudflows (Budhu, 2015), and therefore, are highly susceptible to site amplification.

Direct shear test of the soil of the landslide zone along NH 2 in Phesama was determined for one soil sample (Table 5.7).

**Table 5.7:** Normal and shear stress values of a soil sample of Phesama

| Sample no. | Normal stress (σ) ($kN/m^2$) | Shear stress (τ) ($kN/m^2$) | Cohesion(c) | Internal friction angle (ϕ) |
|---|---|---|---|---|
| P-1 | 10.41 | 28.63 | 26 $kN/m^2$ | 15° |
| | 20.93 | 29.67 | | |
| | 34.51 | 36.19 | | |
| | 57.89 | 42.01 | | |

The estimated value of c from the graph (Fig. 5.6) is 26 $kN/m^2$ and ϕ is 15°. Hence, slopes of the area are prone to slope failure. The soils of this area favour site amplification of ground motion. During an earthquake, waves travelling through soft and loose soils are amplified. Soils with higher clay content are more plastic and hence, amplify ground motion.

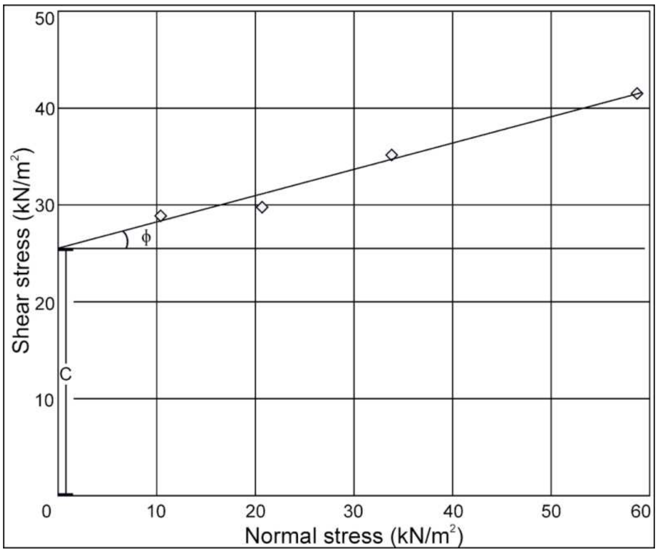



**Fig. 5.6:** Shear stress vs. normal stress of a soil sample of Phesama

Results of the soil samples collected from the Dzüchie and Phesama slide zones point to high plasticity, which indicates that earthquake waves can be amplified due to the weak character of the soils. Therefore, buildings in the area can be damaged to great extents.

## 5.6 Groundwater

The movement of subsurface water through fissures in the rocks and soils and its impact on ground failure is of great concern for site amplification. Most portions of the study area are highly saturated during the monsoon, with appreciable rise of the water table. Under normal conditions the area between Chakhabama and Kohima is dry as the water table is low, but in perennially wet areas the water tables are high because of absorption and extremely slow drainage. This is a reflection of moisture retentivity of the formations. Veder and Hilbert (1980) state that a consolidated soil may swell only if hydrostatic pressure increases, earth pressure remaining constant.

Groundwater is manifested in the form of springs, which is associated with fractures, joints and shear zones. The presence of springs and paleoslides has made the area vulnerable to site amplification. The groundwater condition in the area is not consistent and indicates fluctuating water tables (Table 5.8). However, springs are observed in several places, indicating shallow water tables, which point to vulnerability to site amplification due to ground motion.

**Table 5.8:** Depth of water table in different localities of the study area

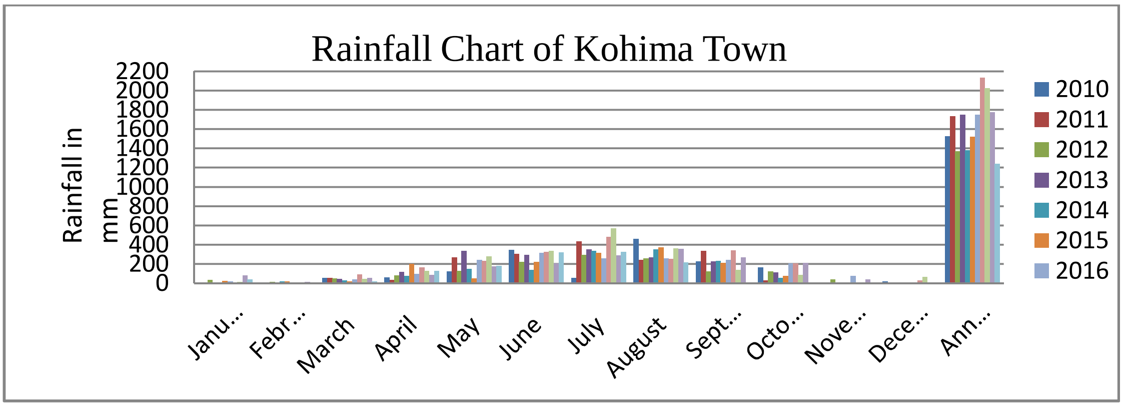
| **Sl. No.** | **Location above msl** (m) | **Elevation** (m) | **Depth of water table** (m) |
|---|---|---|---|
| 1 | Jotsoma Village | 1617 | 20.00 |
| 2 | Old Minister's Hill | 1558 | 2.59 |
| 3 | Forest Colony | 1526 | 2.59 |
| 4 | Jail Colony | 1512 | 2.27 |
| 5 | Lower Police Reserve Hill | 1490 | 3.81 |
| 6 | Raj Bhavan | 1493 | 7.00 |
| 7 | Midland | 1390 | 8.52 |
| 8 | Kezekie | 1411 | 6.10 |
| 9 | Mission Compound | 1552 | 11.58 |
| 10 | Bayavü | 1330 | 3.20 |
| 11 | Tin Pati | 1410 | 8.84 |
| 12 | High School junction | 1247 | 9.14 |
| 13 | Indira Gandhi Stadium | 1495 | 37.00 |
| 14 | Nagaland Civil Secretariat | 1333 | 26.00 |
| 15 | Cathedral Complex | 1560 | 5.88 |

## 5.7 Rainfall

Rainfall affects groundwater condition and lithology. This is an important factor contributing to terrain instability, which in turn has an impact on earthquake risk and ground failure. During years of heavy rainfall, more landslide incidences are noted. These can influence site amplification due to intense infiltration of surface runoff. During rainy periods the groundwater levels rise to affect the upper weaker rocks and soils. Heavy rainfall and weak lithology has made the area more vulnerable to seismicity, thereby increasing the risk of the township during earthquakes.

The rainfall data of Kohima shows more rainfall from May to September every year, with the highest in July (Table 5.9). Heavy rainfall accelerates surface runoff and water infiltration into the subsurface. The pattern of rainfall triggers landslides to a different degree. Areas with high annual rainfall are generally associated with more landslides. Landslides triggered by extreme rainfall point to a decrease in the shearing strength of the soil due to swelling (Veder and Hilbert, 1980). A sequence of dry and wet spells during the rainy season is another important factor affecting landslides activity (Aier and Thong, 2003).

**Table 5.9:** Rainfall status of Kohima




## 5.8 Landuse and land cover

Unregulated developmental activities lead to rampant settlement in potentially fragile zones that may damage and destroy buildings, leading to loss of lives during an earthquake by site amplification of ground motion. The intervention of building bylaws, land use and settlement regulations and enforcement of regulatory policies therefore, are necessary to reduce risk.

Landuse / landcover maps help identify settlement areas that maybe potential sites for amplification of ground motion and damage to the built environment**.** Buildings constructed in landslide-prone areas, such as steep slopes, fracture and shear zones and reclaimed and filled-up areas are prone to damage as such areas will amplify ground motion. Therefore, to make an assessment for mitigation, it is important to identify those areas in unstable and stable zones.

More than 75 percent of the buildings are used for residential purposes; the rest are institutions, commercial sites, public buildings, etc. Most of the buildings surveyed were constructed without taking into consideration any seismic measures. Therefore, they are vulnerable to damage during strong earthquakes. Open mixed forest cover about 53.25 percent of the study area (Table 5.10). The built-up area constitutes about one-fourth of the total area. Settlements are concentrated more in the heart of town, along the valley slopes and hill tops. Agricultural land, water bodies and mixed forests are insignificant (Fig. 5.7).

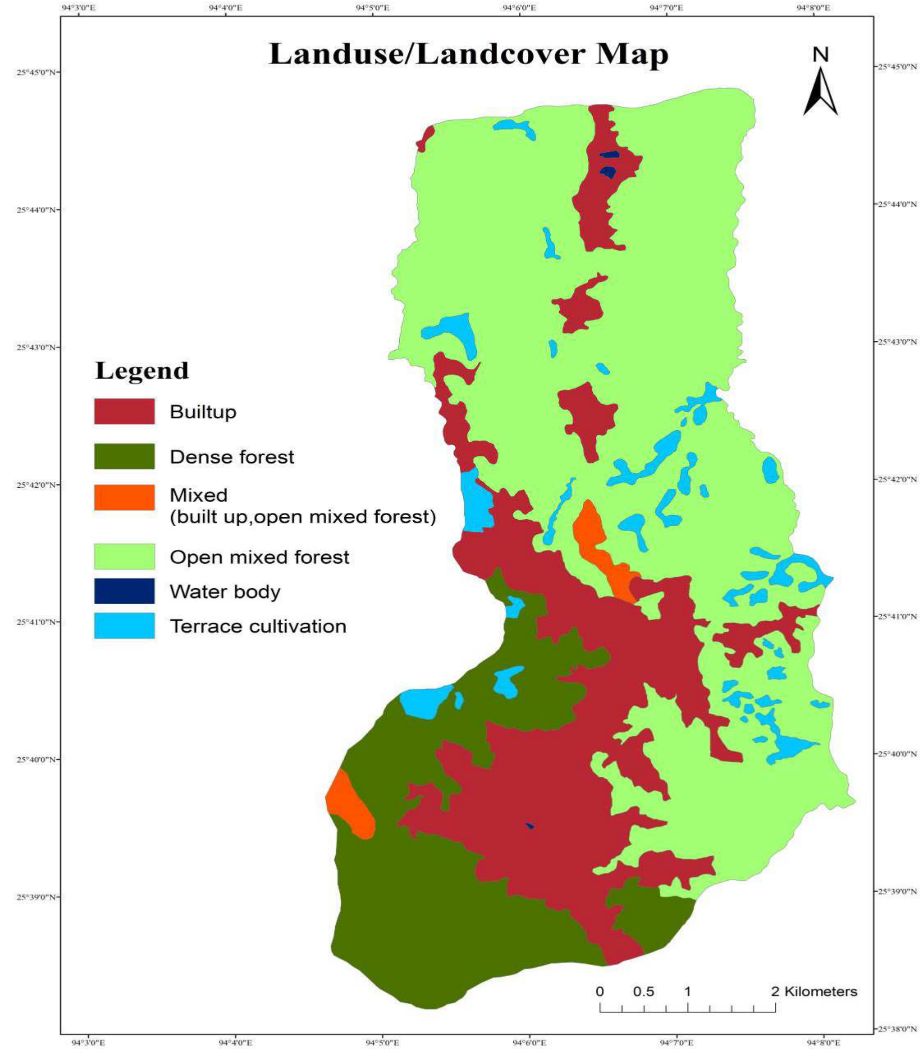



**Fig. 5.7:** Land use / land cover map of the study area

**Table 5.10:** Land use / land cover of the study area

| Sl. No. | Land use | Area ($m^2$) | Area percentage |
|---|---|---|---|
| 1 | Open mixed forest | 25,411.85 | 53.25 |
| 2 | Dense forest | 8,486.55 | 18.80 |
| 3 | Settlement | 11,102.19 | 23.26 |
| 4 | Terrace field / water body | 2,029.83 | 4.25 |
| 5 | Scrub / others | 684.96 | 1.44 |
| 6 | Total | 47,725.40 | - |

*5.8.1 Built environment*

As most of the existing buildings in the study area were constructed without any earthquake resistant designs, they are highly vulnerable to damage during strong earthquake.

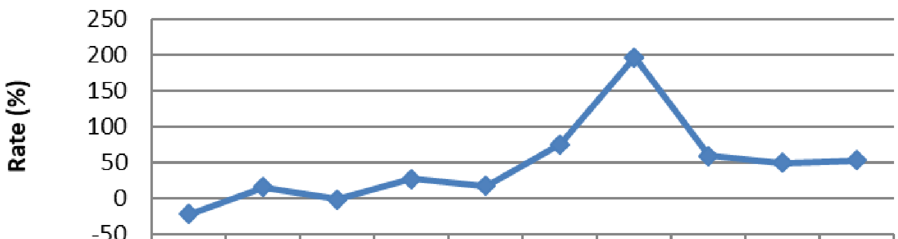
*5.8.2 Socio-economic survey*

The socio-economic survey focuses on population growth and migration from other places, infrastructure, development activities, utility assets, institutions, industries and factories and other resources. A random survey on demography and socio-economy of Kohima town portrayed high risk due to seismic damage in view of its location in this geologically fragile zone. Due to unstable ground conditions frequent landslides disrupt road communications, which causes communities to suffer.

*5.8.3 Population data of Kohima*

Kohima being the administrative headquarters of the state of Nagaland attracts people from the different districts of the state. It also serves as the business center for many of the small towns and villages of the district. The concentration of educational institutions in the town attracts students from all over the state. The population of Kohima in 1991 was 51,418 persons and in 2001 it rose to 78,584. The decadal population growth rate of Kohima between 1991 and 2001 was 52.83 percent. The population growth rate of the town was uneven over the years. The highest growth rate of 197.34 percent was recorded during 1961-1971 (Table 5.11). This is the decade when Nagaland attained statehood(Source: Urban Development Department, Government of Nagaland, 2002).

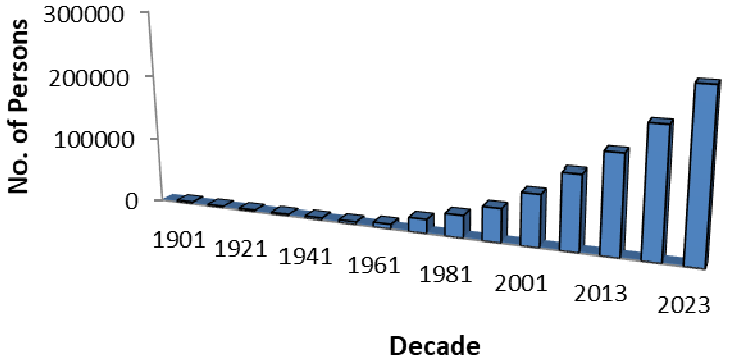
**Table 5.11:** Population growth rate of Kohima




| | 1901 - 1911 | 1911 - 1921 | 1921 - 1931 | 1931 - 1941 | 1941 - 1951 | 1951 - 1961 | 1961 - 1971 | 1971 - 1981 | 1981 - 1991 | 1991 - 2001 |
|---|---|---|---|---|---|---|---|---|---|---|
| Rate% | -21.7 | 15.15 | -1.11 | 27.11 | 17.62 | 75.66 | 197.3 | 59.39 | 49.73 | 52.83 |

The projected population of Kohima (Table 5.12) includes Kohima town and Kohima and Meriema villages, which are included in the Perspective Structure Plan of Greater Kohima (Master Plan).

**Table 5.12:** Population projection of Kohima Town




A random survey of the demography and socio-economy of Kohima town and its surroundings reflects high risk in view of its location in seismic Zone-V, the geologically fragile setup due to ongoing tectonic disturbances and the heavy constructions. Due to unstable ground conditions, frequent landslides occur in the area. The rapid population growth and infrastructural development has added to the risk. As the town is built on unstable ground and the buildings constructed with no earthquake-resistant design, there is likelihood of much damage to buildings and loss of lives by site amplification of ground motion during strong earthquakes. The density of population and buildings (Table 5.13) give an idea of the damage to buildings and loss of lives.

**Table5.13:** Density of population and buildings

| Sl. No. | Density class | No. of persons per building | No. of buildings per ward |
|---|---|---|---|
| 1 | Low density | < 8 | 605x19 = 11495 |
| 2 | Moderate density | 9-13 | 122x19 = 2318 |
| 3 | High density | >14 | 17x19 = 323 |

The population density of buildings is grouped into three classes, viz., low density(<8 persons per building), moderate density (9-13 persons per building and high density(>14 persons per building).As most buildings (~75%) are residential, the human population is highly vulnerable to earthquake shocks. The rapid population growth and urbanization has created resource constraints, leading to lack of facilities and shortage of suitable land for settlement and development. Hence, traffic congestion, water crises, unemployment, pollution, sanitation, economic problems and social imbalance is leading to social issues.

### 5.9 Regulations and enforcement

Non-implementation of building bylaws and land use / settlement regulations and lack of enforcement of regulatory policies has indirectly posed a great impact on site amplification of ground motion. Unregulated developmental activities have led to rampant settlement in geologically fragile zones of the town. This can lead to damage and destruction of the buildings and cause loss of lives during an earthquake by site amplification.

### 5.10 Earthquakes

The two notable great earthquakes of the region had a great impact on Nagaland. Earthquakes and landslides are two natural phenomena that pose threat to this populated township. During the great earthquakes of Shillong (1897) and Assam (1950) Kohima suffered substantial damage of building and roads. Landslides and subsidence were noted at several places. However, the destruction was low since there were no high-rise buildings and infrastructural development minimum in this thinly populated town.

The cause of seismicity in the region is because of its geologically complex tectonic setting involving the subduction of the Indian Plate beneath the Burma microplate. The Arunachal Himalaya represents a collisional boundary of the Indian and Eurasian plates. This mechanical interaction between these plates causes friction that accumulates strain energy, which ultimately ruptures. This was the cause of an earthquake of 7.1-magnitude at a depth of 61 km that damaged the Tuli Paper Mill in 1988.Its epicenter was located along the Nagaland-Myanmar border (94°5' E and 24°75' N). Most of the damage in this area was associated with amplified ground shaking. In Kohima district, ground shaking was severe in the sheared and fractured zones along the strike of the Disang Thrust due to rupture.

Sarmah (1999) statistically analysed earthquakes recorded in the region from 1897 to 1992 and estimated an average return period of 55 years for earthquakes of magnitude 8 or greater. Based on paleo-seismic studies, a return period of 500 years for great earthquakes of magnitude 8 in the Shillong Plateau is predicted (Sukhija et al., 1997).Based on these predictions, if any such high-magnitude earthquake occurs in the region, which is very likely in the near future, major portions of the region will be devastated. Considering the seismic situation and the fragile geological conditions, Kohima is at high risk of site amplification of ground motion that can destroy buildings and cause loss of lives, which therefore, requires immediate attention for safety measures.

## 5.11 GPR soil profiles

GPR data was acquired from depths ranging from 10-14 m, from nine randomly selected sites in and around Kohima town and graphs plotted (Fig. 5.8a-i).

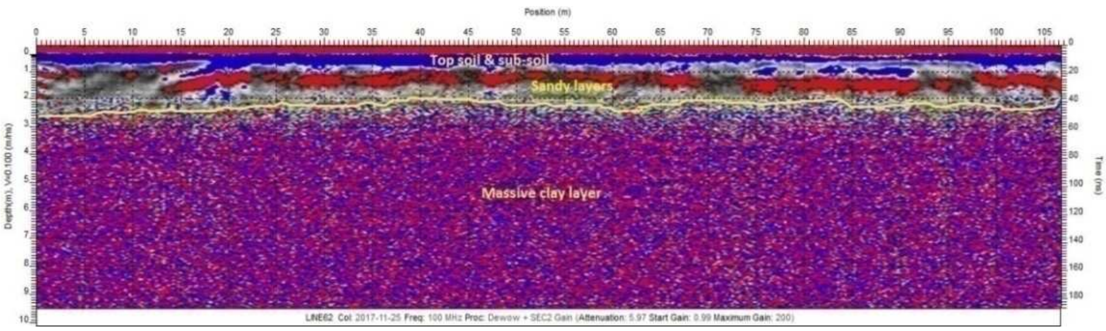



**Fig.5.8a:** GPR profile at the Government High School, Kohima

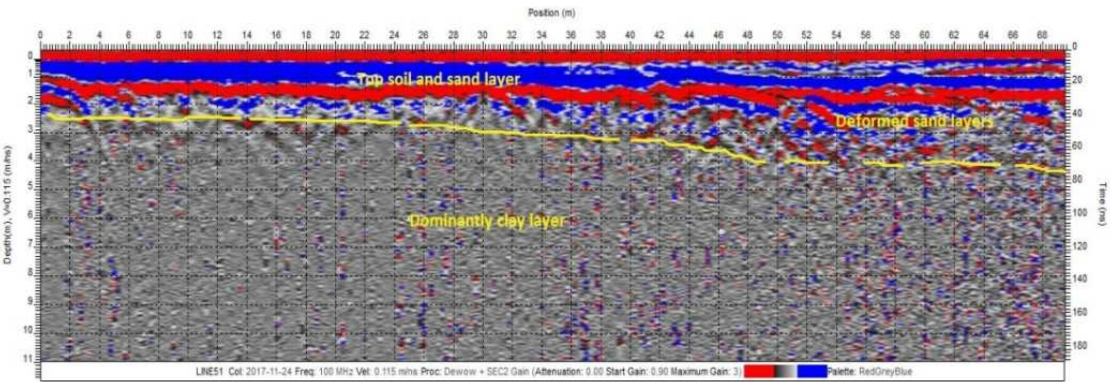



**Fig.5.8b:** GPR profile at the Church compound, Kohima Science College, Jotsoma

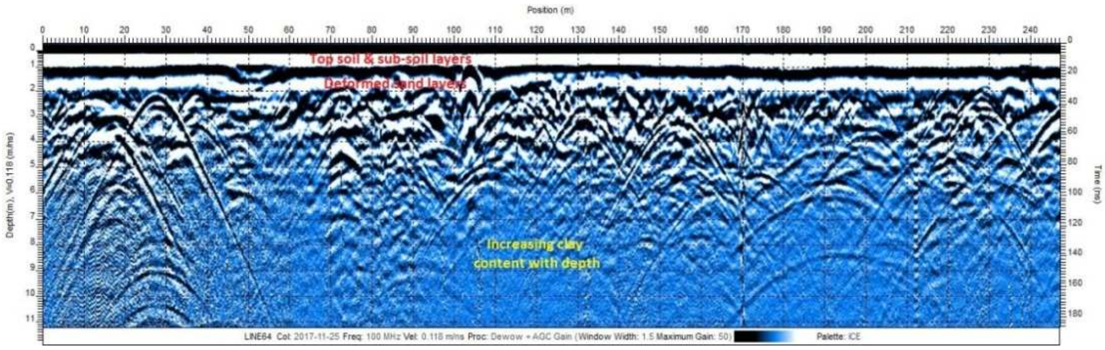



**Fig.5.8c:** GPR profile at the Public Health Engineering Office, Kohima

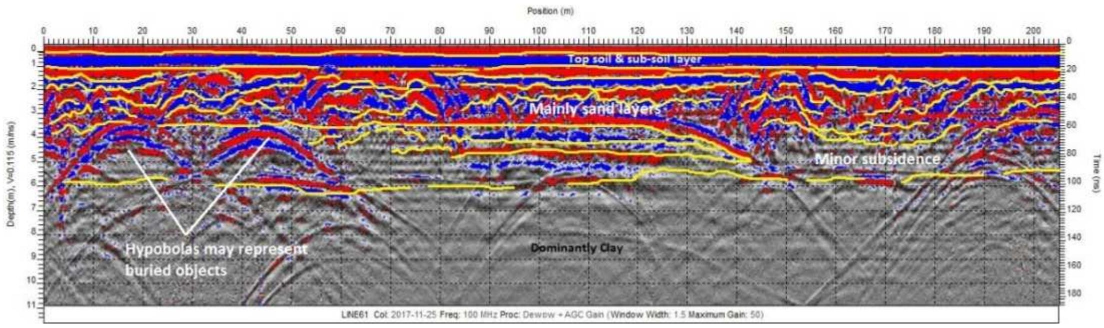



**Fig.5.8d:** GPR profile along the New Secretariat road - 1

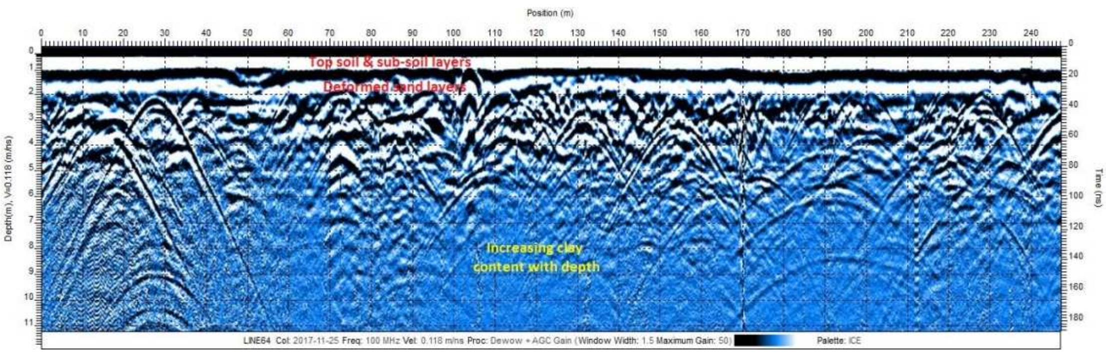



**Fig.5.8e:** GPR profile along the New Secretariat Road - 2

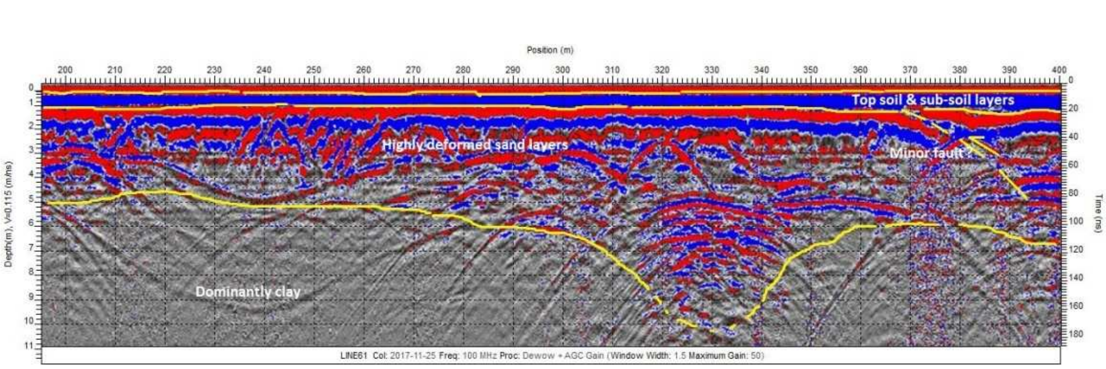



**Fig.5.8f:** GPR profile along the New Secretariat Road - 3

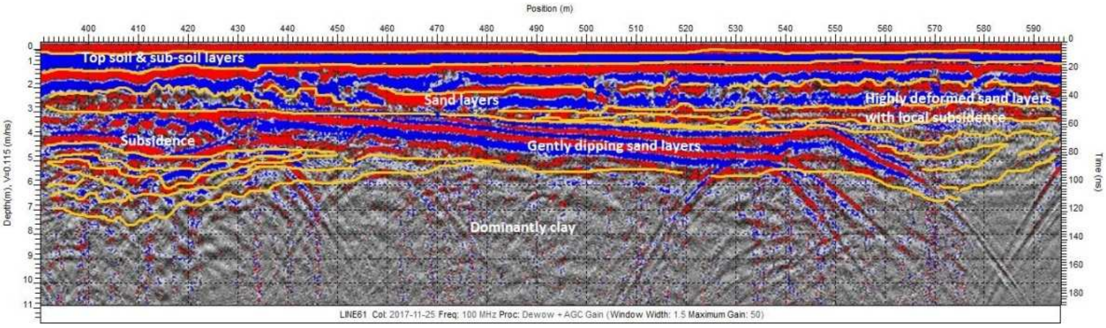



**Fig.5.8g:** GPR profile along the New Secretariat Road - 4

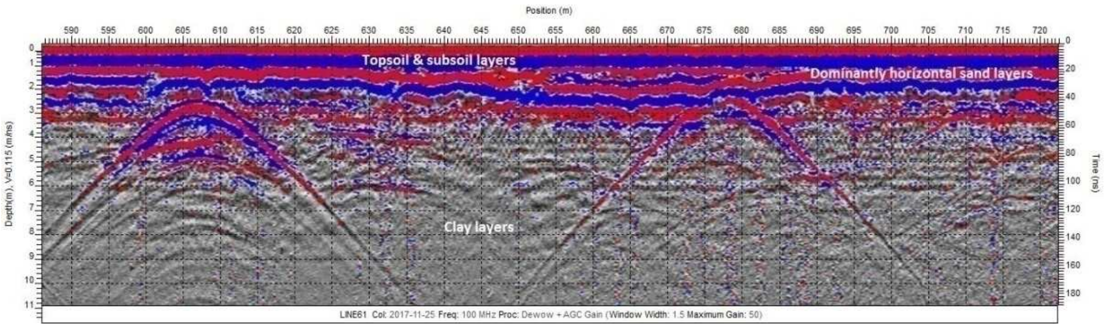



**Fig.5.8h:** GPR profile along the New Secretariat Road - 5

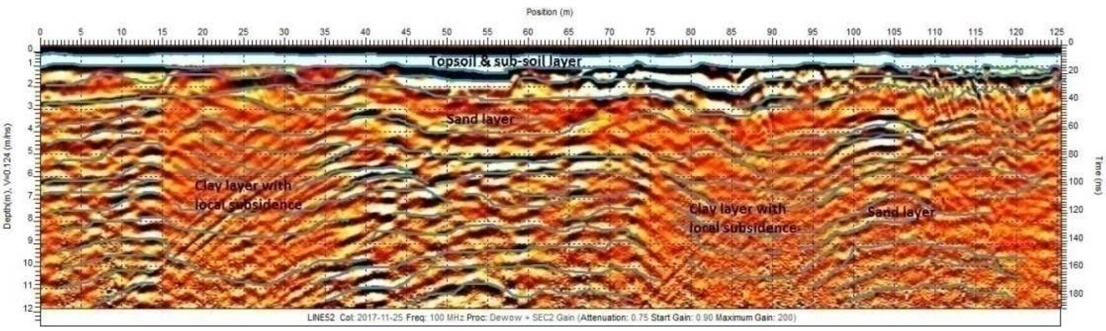



**Fig.5.8i:** GPR profile at Zubza

The soil profiles show alternations of sand and clay layers (Table 5.14).The GPR profiles and lithological information reveal that the top soil varies from about a meter to more than 2 m in thickness.

**Table5.14:** GPR soil profile logs of the study area

| Sl. No. | Name of the station | Soil Layer-1 | Soil layer-2 | Soil Layer-3 |
|---|---|---|---|---|
| 1 | Govt. High School | Topsoil & subsoil (humus) layers | Sandy layers | Massive clay layers |
| 2 | Kohima Science College | Topsoil & sand layers | Deformed sand layers | Dominantly clay |
| 3 | Zubza (NH-29) | Topsoil & subsoil | Deformed sand layers | Clay increases with depth |
| 4 | New Secretariat Road-1 | Topsoil & subsoil | Sand layers & buried object; minor subsidence | Dominantly clay |
| 5 | New Secretariat Road-2 | Topsoil & subsoil | Deformed sand layers; minor fault | Dominantly clay |
| 6 | New Secretariat Road-3 | Topsoil & subsoil | Highly deformed sand layers; local subsidence | Dominantly clay |
| 7 | New Secretariat Road-4 | Topsoil & subsoil | Horizontal sand layers | Clay layers |
| 8 | PHED Office | Topsoil & subsoil | Sand layers | Clay layers; local subsidence |

Apart from the topsoil, three other layers are also clearly visible in the GPR profiles. In most GPR sections the soil layer is directly underlain by a silty-sand layer varying in thickness from 3 m to about 5 m, which is moderate to highly deformed and laminated. The third layer, composed mainly of silty-sand, appears denser with depth and increasing clay content. This layer varies from 4-7 m in thickness. The last layer of the GPR profiles is mainly composed of moderate to stiff sandy-silt. Field evidences and GPR data show a massive non-laminated unit. Borehole data show medium to fine grained, stiff sand in this unit. This bottom of this >6-m-thick unit cannot be identified from GPR profile due to limitation of depth resolution. However, borehole data reveals that this layer extends beyond 18 m depth. The thickness of the litho-sequences gradually increases from north to south. A better GPR resolution is observed from north to south, which is likely caused by the presence of cleaner sand and lesser clay towards the south. It is noted that shallow water saturation also tends to influence the depth resolution of GPR data. Apart from lithological criteria, it is also observed that the sediment sections in the upper part are highly deformed due either to tectonic disturbances or load deformation.

The GPR soil profiles of the study area indicate unstable subsurface conditions. In all the stations the layer below the top soil are sandy, and slightly to highly deformed. At places, subsidence is noted; the minor faults observed indicate tectonic impact. Below these sandy layers are clay layers, which are also affected by subsidence at places. The clay layers dominantly increase with depth, down to over 18 m as confirmed from borehole logging (Fig. 5.9). Therefore, it is inferred that the soil condition in the area is highly susceptible to site amplification of ground motion during strong earthquakes.

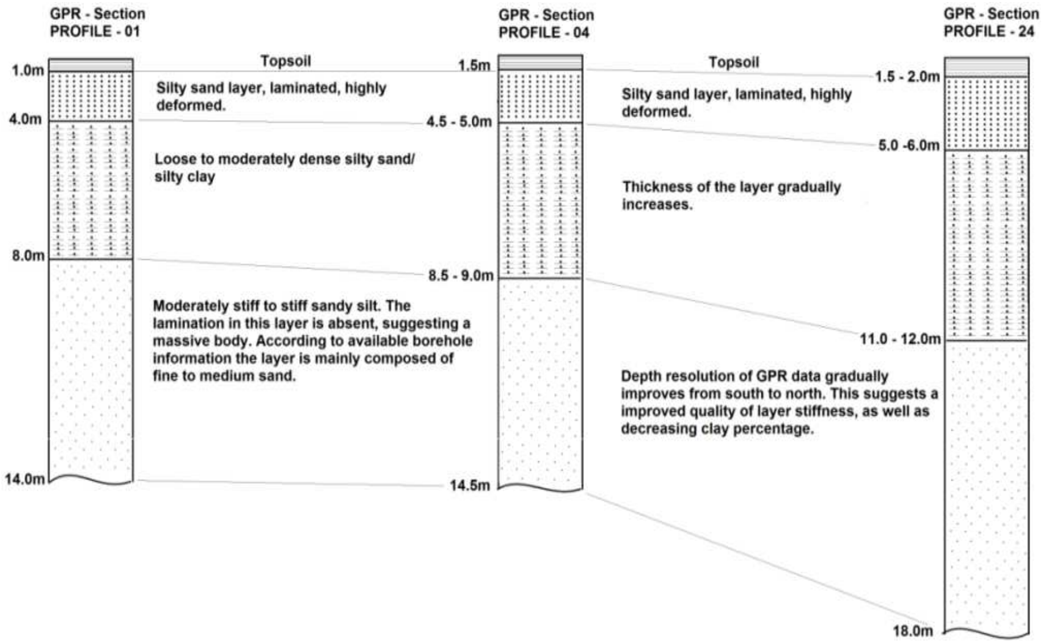



**Fig.5.9:** Litho profiles derived from GPR, boreholes and field data

## 5.12 Soil profiles and their impact on site amplification

### *5.12.1 Surface material behavior*

Near-surface clay layers tend to amplify seismic ground motion regardless of epicentral distances. The dominant period of ground motion will invariably lengthen, irrespective of the intensity and duration of ground motion in the presence of shallow soft clay layers, which are highly vulnerable to far-field strong ground motion. The lengthening of the dominant period and amplification of ground acceleration due to the presence of near-surface clay layers may induce differential settlement of massive clay layers, causing significant damage to buildings. Therefore, the nature of the clay formation plays a significant role; the softer the clay layer, the greater the probability of site amplification and lengthening of the dominant period of vibration.

Nevertheless, the stiffness of the soil layer generally degrades when exposed to large seismic loading, which will influence the natural period of vibration.

### *5.12.2 Alternations of sand and clay layers*

The thick alternations of sand and clay in the study area will significantly amplify seismic ground motion. If the soft sand layers are saturated due to shallow groundwater levels, they will significantly lose strength and stiffness during large earthquake motion. Such conditions may cause liquefaction in the sand strata, which will damage buildings and other infrastructure. The third is a silty-sand layer, which becomes denser with depth and increasing clay content. Data for the last layer indicate medium to fine, stiff sand without lamination.

Local site conditions and the built environment have a great influence on site amplification of ground motion. The shale with thin beds of siltstone and the abundant hill-slope debris are major concerns for enhancement of damage potential. Moreover, the rocks that are fractured, jointed, faulted and sheared to varying extents will amplify earthquake waves passing through them. The nature of the clays will play a significant role in site amplification of ground motion. The softer the clay layers, the greater the probability of site amplification and lengthening of the period of vibration. Alternations of sand and clay will significantly amplify seismic ground motion. The soft sand layers are saturated due to shallow groundwater levels. Such strata will lose strength and stiffness during large earthquake motion.

Kohima town, located within the Kohima Synclinorium, has undergone a high degree of tectonic deformation. The formations are highly folded and faulted and the topography irregular, with valley-filled alluvial soil and colluvium. The area is riddled with landslides and paleoslide zones. The annual rainfall is high, which causes much surface runoff and infiltration into the subsurface. Infiltration leads to high groundwater tables, which saturates the soils and fractured rocks. Such weakened ground conditions will greatly amplify ground motion during earthquakes. This implies that buildings and other structures in populated areas on fragile geological conditions are at high risk of intense damage and loss of lives.

The irregular topography of Kohima consists of thick soils on the slopes and in the valleys, which are underlain by soft argillaceous shales intercalated with thin siltstones. These are ideal conditions for amplification of seismic waves during earth movements. The topographical impact on ground-shaking amplification has been observed during past earthquakes. Field measurement by instruments show strong effects of topography, where amplification on hills and slopes are noted (Davis and West, 1973; Celebi, 1987). In recent years Kohima town, like all other state capitals of NE India, has experienced a rapid increase in human population and urbanization. Kohima town and its suburbs face a high level of seismic risk due to the complex geological structure, soft argillaceous rocks and multistoried concrete buildings constructed on steep, landslide-prone slopes. Rampant settlement, unregulated landuse pattern and lack of awareness among the common masses have increased the risk in the face of earthquake and landslides. The associated seismic hazards besides ground shaking may involve movement along fault planes and landslides.

Environmental degradation, climate change and fast paced developmental activities have compounded the problem, and hence, the risk. The lack of preparedness in mitigating seismic hazards and landslides in the region is astounding. Thus, the region is not prepared to face earthquakes and other natural hazards. Therefore, the present research on site amplification is very relevant and will be very helpful to the planners.

# CHAPTER 6

# SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Summary

Local site conditions and the built environment have a great influence on site amplification of ground motion. The shale with thin beds of siltstone and the abundant hill slope debris are major factors that will enhance the damage potential. Moreover, the topography of the area and the rocks that are fractured, jointed, faulted and sheared to varying extents will amplify earthquake waves and cause destruction to the built-up environment. The results obtained from site response studies are briefly discussed below.

### *6.1.1 GPR surveys*

GPR surveys show sandy, silt and clay layers with alternations of sands and clay layers. In general, the soil layers are upward-fining, with medium to fine sand at the bottom. Silty-clay sections with thin laminations have gradually developed upwards in the sequence. Fine laminated clay and silty-sand are observed at shallow depths.

GPR studies of soil layers generally show alternating layers of sand and clay. Alternations of sand and clay significantly amplify seismic ground motion. The nature of the clay formations plays a significant role in site amplification of ground motion. The softer the clay layer, the more the probability of site amplification and lengthening of the period of vibration. Moreover, near-surface clay layers tend to amplify seismic ground motion regardless of epicentral distance. Soft sand layers are saturated under shallow water table conditions. Such strata lose strength and stiffness during large earthquake motion.

### *6.1.2 Field studies*

The formations of Kohima town have undergone high degree of tectonic deformation. Therefore, folding, jointing, faulting and shearing of the rocks are very common. The rocks are soft argillaceous shales with intercalations of minor siltstone. The upper crusts of the shales are commonly weathered to clays. Along fault planes and in shear zones the shales are crushed and weathered to a great extent. These clays are expansive and plastic in nature.

The topography in this township is highly irregular. The valleys are filled with hill slope debris and some alluvial soils. Numerous paleoslides have been identified in this landslide-prone area. Boreholes were used to determine groundwater levels and the subsurface litho-units. The lithological characters, topographic features, valley-filled deposits, faults, etc. have rendered the study area prone to site amplification of ground motion.

### *6.1.3 Laboratory analyses*

The triaxial, Atterberg limit and consistency limit tests conducted point to highly plastic soils. Strong ground motion can severely damage buildings constructed on such soils.

### *6.1.4 Groundwater and rainfall*

The annual rainfall in the study area is high. Besides overland flows, a good portion infiltrates into the subsurface raising the water table. This plays a great role on weakening the lithology by way of softening the subsurface material; such conditions can amplify ground motion. Buildings and other structures constructed on such fragile geological material are at high risk of intensive damage. In the more highly populated areas the potential to loss of lives by site amplification of ground motion is very great.

## 6.2 Conclusions

Site amplification is attributed to earthquake ground motion due to weak earth material. Most damage to building are due to site amplification of ground motion during earthquakes. Adverse effects of site amplification and its strong impact are of great concern. The Naga Hills represents a complex geological setup. Tectonically, Kohima is situated within the Kohima Synclinorium and near the BoS. This area lies near the seismically active subduction zone where the Indian Plate and Burma microplate have collided. Subduction is continuing at a rate of 45cm per year. The persistent rise of the Himalayas and continuous tectonic activities along the IMR poses a serious threat to the region and the study area. Site amplification accounts for diversity of earthquake effects on the local scale. It is therefore, important to obtain detailed information on geology, soil profiles, topography, depth of water table and nature of earthquake source as the local geology and soils play an important role in earthquake damage. Strong shaking will damage and destroy buildings and injure or kill their occupants. Amplified ground motion can cause excessive damage even at locations very far from the epicenter due to local geological site conditions. Classic examples include the Mexico earthquake of 1985 and Loma Prieta earthquake of 1989, which extensively damaged buildings located about 100 km away the epicenter due to site amplification. The 1988 earthquake of Nagaland along the Indo-Myanmar border (94°5'E - 25°75' N) caused a landslide that damaged the Tuli Paper Mill in Mokokchung, which may have likely been due to site amplification.

Site response parameters are used to identify areas of higher amplification based on surface geology, which can be correlated to soil frequency. Mapping of soil behavior provides and overview of possible damage. GPR surveys and litho-logs from boreholes were used for site response studies. Field studies were carried out in detail for structure, topography, groundwater condition and the built environment survey.

Different tests were carried out to determine the Atterberg limits and shear strengths by triaxial tests. For the built environment, surveys were carried out for building topology, land use and land cover, socio-economic situation and regulatory system for land use and settlement.

From the above studies it is observed that Kohima town and its surroundings is geologically at high risk of site amplification of ground motion during strong earthquakes. The rapid population growth and settlement in hazardous areas, unregulated landuse pattern and rampant construction of buildings without seismic designs will have a great influence on the devastation of buildings and loss of lives during earthquakes. Seismologists have predicted a 55-year return period of great earthquakes for the NE region; the last two great earthquakes occurred in 1897 and 1950.It appears the region is already overdue for one, but we are not prepared as yet. The region in general and the study area in particular need to pay serious attention to reduction of geohazards.

## 6.3 Recommendations

In the context of the present study, the earthquake-hazard related study should be considered important for this region of high seismicity. The past great earthquakes of the region and continuous recent seismic activity should get us prepared for the worst. The loss due to earthquakes is more due to negligence and not paying attention to preparedness. It is also due to lack of awareness of the geological factors concerning adverse local site conditions and construction measures. Therefore, creation of mass public awareness for application of seismic resistant design in construction of buildings and stability of the foundation should be taken up as priority.

It is recommended that strict regulations are in place for landuse, settlement and construction of buildings in hazardous zones. Construction of buildings in geological hazardous zones should not be permitted. Lawmakers need be made aware of the risks involved in the study area and to enforce building bylaws.

Intensive research should be carried out in the study area for safe location of buildings and other structures to reduce loss of lives and damage to property during severe earthquakes. Therefore, intensive research on earthquakes and landslides should be a priority.

# PLATES

**Plate 1:** Panoramic view of Kohima town

**Plate 2:** View of part of the study area

**Plate 3:** Shale siltstone sandstone exposure along Kohima Science College road

**Plate 4:** Barail sandstone exposure along Kohima Science College road

**Plate 5:** Disang shales exposed along nallah section at Midland colony (plastic and expansive)

**Plate 6:** Shale sandstone unit exposure below Naga Hospital Kohima


**Plate 7:** Swelling and expansion of highly plastic shale/clay at (A) Naga Hospital slide and (B) Dzuchie (KMC garbage Dumping site) slide

**Plate 8:** Pit-and-trenching at New Secretariat (Claystone exposure)

**Plate 9:** Siltstone sandstone exposure below Zubza, Kohima


**Plate 10:** Landslide at Lower Chandmari colony

**Plate 11:** Phesama slide along NH-29 leading to Manipur

# REFERENCES

Agarwal, P.N., 1986. A recent earthquake in Northeast India: Proc. 2nd Int. Sem. on earthquake prognostic.

Agarwal, P.N., 2000. Seismological aspects of earthquake damage reduction. 6th IGC Foundation Lecture, IGC, pp. 1-19.

Aki, K., 1988. Local site effects on strong ground motion. Proc. Earthquake Engineering Soil Dynamics, II, pp. 103-155.

Aki, K. and Irikura,K., 1991. Characterization and mapping of earthquake shaking for seismic zonation.In Proceedings of the Fourth International Conference on Seismic ZonationI, pp. 61-110, EERI, Oakland.

Alexander, J.E., 2009. The shock response spectrum - A primer. Proceedings of the IMAC-XXVII, February 9-12, 2009, Orlando, Florida USA. Society for Experimental Mechanics Inc.

Ansal, A.M. and Slejko, D., 2001. The long and winding road from earthquakes to damage. Soil Dynamics and Earthquake Engineering,v. 21, pp. 369-375.

Armijo, R., Tapponnier, P. and Han, T., 1989. Late Cenozoic right-lateral strike-slip faulting in southern Tibet.J. Geophys. Res., v. 94, pp. 2787-2838.

Bapat, A., 1996. Creation of awareness about earthquakes - Case Histories. Proc. Int. Conf. on Disaster and Mitigation, Madras, v. 1, A1-A13.

Bapat, A., Kulkarni, R.C. and Guha, S.K., 1993. Catalogue of earthquake in India and neighborhood from historical record up to 1979. Indian Soc. Earthq. Tech., Roorkee, India, 171p.

Ben-Menahem, A., Aboudi, E. and Schild, R., 1974. The source of the great Assam earthquake- An intraplate wedge motion. Phys. Earth Planet, Int., v. 9, pp. 265-289.

Bhattacharjee, S., 1998. Earthquakes in northeast India. Mitigation- A possible approach. Status of landslides in northeast India and Natural Disaster Management (Ed. G.D. Sharma), Assam University Press, pp. 77-84.

Bhattacharya, P.M., Mukhopadhyay, S., Majumdar, R.K. and Kayal, J.R., 2006. 3-D seismic structure of the Northeast India region and its implications for local and regional tectonics, J. Asian Earth Sci., v. 33, pp. 25-41.

Bilham, R. and England, P., 2001. Plateau ‘pop up’ in the great 1897 Assam earthquake. Nature, v. 410, pp. 806-809.

Bonnefoy-Claudet, S., Baize, S., Bonilla, L.F., Berge-Thierry, C., Pasten, C., Campos, J., Volant, P. and Verdugo, R., 2009. Site effect evaluation in the basin of Santiago de Chile using ambient noise measurements. Geophys. J. Int.,v. 176, pp. 925-937.

Bureau Indian Standards, 2004. Seismic Zonation Map of India.BIS publication.

Chandra, U., 1975. Seismicity, earthquake mechanisms and tectonics of Burma, 20°N 28°N.Geophys. J., v. 40, pp. 367-381.

Dewey, J.F. and Bird, J.M., 1970. Mountain belts and the new global tectonics. Jour. of Geophys. Res., v. 75, pp. 2625-2647.

Duarah, R., Saikia, M.M. and Bhattacharjee, C.C., 1983. Occurrence of the ophiolitic complexes along the Indo-Burman orogenic belt. Geol Mag., v. 120(2), pp. 178-182.

Dutta, T.K. and Saikia, M.M., 1976. Eastern limits of Himalayan orogenic belt, Indo-Burman orogen and its geodynamic development. Himalayan Geol., v. 6, pp. 303-313.

Evans, P. and Crompton, W., 1946.Geological factors in gravity interpretation illustrated by evidence from India and Burma. Q. J. Geol. Soc. London, v. 102, p. 211.

Evinson, F.E., 1982. Generalised precursory swarm hypothesis. Jour. Phy. Earth, v. 30, pp. 155-170.

Field, E.H. and Jacob, K.H., 1993. The theoretical response of sedimentary layers to ambient seismic noise. Geophysical Res. Letters, v. 20-24, pp. 2925-2928.

Field, E.H. and Jacob, K.H., 1995. A comparison and test of various site-response estimation techniques, including three that are not reference-site dependent. Bull. Seism. Soc. Am., v. 85, pp. 1127-1143.

Finn, W.D.,Liam, 1991. Geotechnical engineering aspects of seismic microzonation, Proceedings of the 4$^{th}$Int. Conf. on Seismic Zonation, August 25-29, Stanford, California, v. 1, pp. 199-250.

Fitch, T.J., 1970 Earthquake mechanism in the Himalayan, Burmese and Andaman region and continental tectonics in Central Asia. J. Geophys. Res., v. 75(14), pp. 2699-2709.

Guha, S.K. and Bhattacharya, U., 1984. Studies on prediction of seismicity in Northeast India. Proc. World Conf. on Earthquake Engineering, San Francisco, USA, July, 21-27.

Gupta, H.K., 1993. Patterns preceding major earthquakes in northeast India. Current Science, v. 64(11&12), pp. 889-893.

Gupta, H.K. and Singh, H.N., 1986. Seismicity of northeast India region: Part II: Earthquake swarm Precursory to moderate magnitude to great earthquakes, Jour. Geol. Soc. India, v. 28, pp. 367-406.

Holzer, T.L., 1994. Loma Prieta damage largely due to enhanced ground shaking. EOS: Transactions of the American Geophysical Union, v. 75(26), pp. 299-301.

Hutchinson, C.S., 1975. Ophiolites in Southeast Asia. Geol. Soc. Am. Bull., v. 86(6), pp. 797-806.

Idriss, I.M., 1990. Response of soft soil sites during earthquakes. Proc. H. Bolton Seed Memorial Symposium, J.M. Duncan (Ed.), v. 2, pp. 273-290.

Joyner, W.B. and Fumal, T.E., 1985. Predictive mapping of earthquake ground motion.In: Evaluating Earthquake Hazards in the Los Angeles Region - An Earth Science Perspective. pp.203-220, U.S. Geological Survey Professional Paper, no. 1360, (Washington: United States Government Printing Office).

Kayal, J.R., 1987. Microseismicity and source mechanism study: Shillong Plateau, Northeast India. Bull. Seismological Society of America, v. 77(1), pp. 184-194.

Kayal, J.R., 1998. Seismicity of Northeast India and surroundings - Development over the past 100 years. Jour. of Geophysics, v. 19(1), pp. 9-34.

Kharshing, A.D., Khattri, K.N., Moharir, P.S. and Chander, R., 1986. Neotectonics in Shillong massif and neighboring regions. Proc. Int. Symp. Neotectonics in South Asia, India. Feb. 18-21, pp. 407-416.

Khattri, K.N., 1987. Great earthquakes, seismicity gaps and potential for earthquake disaster along the Himalayan plate boundary. Tectonophysics, v. 138, pp. 79-92.

Khattri, K.N., 1993. Seismic gaps and likelihood of occurrence of larger earthquake in Northeast India. Current Science, v. 64(11&12), pp. 885-888.

Khattri, K.N., 1999. Probabilities of occurrence of great earthquakes in the Himalayas. Earth & Planetary Sciences, v. 108, pp. 87-92.

Khattri, K.N. and Tyagi, A.K., 1993. Seismicity patterns in the Himalayan plate boundary and identification of the areas of high seismic potential. Tectonophysics, v. 96, pp. 281-297.

Konno, K.and Ohmachi, T., 1998. Ground-motion characteristics estimated from spectral ratios between horizontal and vertical components of micro tremors. Bull. Seis. Am., v. 88, pp. 228-241.

Lachet, C., Hazfeld, D., Bard, P.Y., Theodulidis, N., Papaioannou, C. and Savvaidis, A., 1996. Site effect and microzonation in the city of Thessaloniki (Greece) comparison of different approaches. Bull. Seism. Soc. Am., v.86, pp. 1692-1703.

Larcave, C., Bard, P.Y. and Koller, M., 2000. Microzonation: Techniques and examples. Lecture notes.

Le Daine, A.Y., Tapponier, P. and Molnar, P., 1984. Active faulting and tectonics of Burma and surrounding regions. J. Geophys. Res., v. 89, pp. 453-472.

Lermo, J. and Chavez-Garcia, F.J., 1993.Site effect evaluation using spectral ratios with only one station. Bull. Seismo. Soc. Am., v. 83, pp. 1574-1594.

Lermo,J. and Chavez-Garcia, F.J., 1994. Are microtremors useful in site response evaluation? Bull. Seism. Soc. Am., v. 83, pp. 1574-1594.

Makra, K., Raptakis, D., Chavez-Garciaand,F.J. and Pitilakis, K., 2001. Site effects and design provisions: The case of Euroseistest. Pure and Appl Geoph, v. 158, pp. 23-49.

Maresca, R., Nardone, L., Pasquale, G., Pinto, F. and Bianco, F., 2011. Effect of surface geology on seismic ground motion deduced from ambient-noise measurements in the town of Avellino, Irpinia region (Italy). Pure Appl. Geophys.Published online: 03 Aug. 2011.

Milne, J. and Burton, W.K., 1891. The Great Earthquake in Japan.Crawford & Co., Yokohama, Japan.

Mitchell, A.H.G. and McKerrow, W.S., 1975. Analogus evolution of the Burma orogen and the Scottish Caledonides. Geol. Soc. Am. Bull., v. 86, pp. 305-315.

Molnar, P. and Tapponnier, P., 1975. Cenozoic tectonics of Asia: Effects of a continental collision. Science, v. 189, pp. 419-426.

Molnar, P. and Tapponnier, P., 1977. Relation of the tectonics of Eastern China to the India-Eurasia collision: Application of slip-line field theory to large-scale control tectonics. Geology, v. 5, pp. 212-216.

Molnar, S., Cassidy, J.F., Monahan, P.A., Onur, T., Ventura, C. and Rosenberger, A., 2007.Earthquake site response studies using micro tremor measurements in southwestern British Colombia. Proceeding volume: 9$^{th}$Canadian Conf. on Earthquake Engineering, Ottawa, Ontario, Canada, v. 26-29, pp. 410-419.

Nandy, D.R., 2001. Geodynamics of Northeastern India and the adjoining region. ABC Publications, Calcutta, 209p.

Ni, J. and York, J.E., 1978. Late Cenozoic tectonics of the Tibetan plateau. Jour. Geophys. Res., v. 83,pp. 5377-5384.

Sarmah, S.K., 1999. The probability of occurrence of a high magnitude earthquake in Northeast India. Jour. of Geophysics, v. 20(3), pp. 129-135.

Shuka, M.K., 1998. Earthquakes, management and application. Employment News, v. XXII(19), pp. 1-3.

Struck, D., 1999. Tokyo prepares for an overdue disaster. Times of India, October 11, p. 12.

Sukhija, D.S., Rao, M.N., Reddy, D.V., Nagabhusanam, P., Hussain, S., Chadha, R.K. and Gupta, H.K., 1997. Palaeoseismic investigations in the Shillong Plateau, Northeast India: Evidence of prehistoric major seismic events. Indo-US workshop on Palaeoseismicity, March 26-28, WIGH, Abs. Vol., pp. 70.

Tiwari, R.P., 1999. Disaster management- The utmost need of Mizoram. Proc. Sem. On Sci. & Tech. InMizoram for 21stCentury organised by Mizoram Science Society, Aizawl, p. 139.

Tiwari, R.P., 2000. Earthquake hazards and mitigation in India with special reference to Northeastern India. ENVIS Bulletin, v. 8(2), pp. 15-22.

Verma, R.K., Mukhopadhyay, M and Ahluwalia, M.S., 1976. Seismicity, gravity and tectonics of Northeast India and Northern Burma. Bull. Seism. Soc., v. 66, pp. 1683-1694.