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ADDIS ABABA UNIVERSITY

COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES

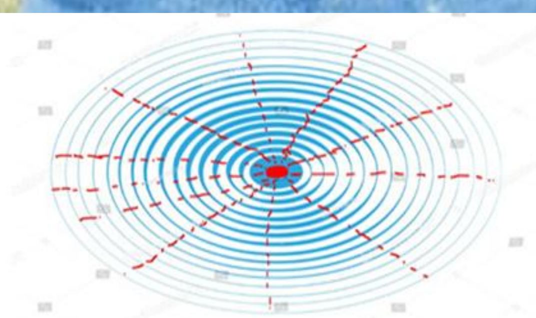
SCHOOL OF EARTH SCIENCES

REMOTE SENSING AND GEO-INFORMATICS STREAM

GIS-BASED EARTHQUAKE EFFECT VULNERABILITY ASSESSMENT OF BUILT-UP ENVIRONMENT, IN CASE OF ADDIS ABABA CITY, ETHIOPIA

By

Kaleb Tarfa



Advisor

K. V. Suryabhagavan (PhD)

A thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the requirement for the Degree of Masters of Science in Remote sensing and Geo-informatics

June, 2020

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Kaleb Tarfa

GIS-based Earthquake effect vulnerability assessment of built up environment: a case of Addis Ababa City, Ethiopia

Kaleb Tarfa, MSc. Thesis

Addis Ababa University, June, 2020

Abstract

The main issue in Earthquake effect vulnerability assessment is identifying all causative factors directly or indirectly related to risk of Earthquake to builtup environment. Earthquake risk vulnerability assessment plays a key role in risk mitigation efforts and seismic emergency planning, especially for urban areas with a high population density and a complex construction. Even though Studies on seismicity of the study area have been compiled by different researchers, A GIS-based seismic vulnerability assessment was not prepared for the city under investigation. To address this issue, an integrated approach of AHP method and GIS technology was presented and applied for Addis Ababa city for seismic effect vulnerability assessment. First earthquake input factors such as: geology, soil, slope, road networks, drainage density, shear velocity at 30m, lineaments and borehole depth are selected. All of these layers are brought to GIS environment to be given a weight by AHP. Then vulnerability index were prepared and applied to the study area. Finally, Earthquake effect suscestiplity map was prepared by overlaying all vulnerability indexes and accuracy was validated. The result indicated that AHP method and GIS technology could achieve the accurate and desired object while developing seismic vulnerability. The seismic vulnerability map of Addis Ababa was classified as: Very high, High, medium, low and Very low having an aerial extent of 30.34Km^2, 71.74Km^2, 97.36Km^2, and 219.34$Km^2$and, 108.46Km^2respectively. The present study is used to identify earthquake vulnerable zones and serve as a base in earthquake effect mitigation and reduction strategy for the city.

Keywords: AHP, Earthquake input factors, GIS, Multi-criteria analysis, Vulnerability assessment

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List of Acronyms

GIS	Geographic Information System
AHP	Analytical Hierarchy Process
MCDM	Multicriteria Decision Making Method
MMI	Mercalli Intensity Scale
UNDRO	United Nations Disaster Relief Organization
NEHRP	National Earthquake Hazards Reduction Program
UNISDR	United Nations Office for Disaster Risk Reduction
GSHAP	Global Seismic Hazard Assessment Program
RS	Remote sensing
USGS	United States Geological Survey
CR	Consistency ratio
DEM	Digital Elevation Model
KM	Kilometer
SRTM	Shuttle Radar Topographic mission

CHAPTER ONE

1.1 INTRODUCTION

Cities are growing and hazards are increasing worldwide. During urbanization process, cities in the developing countries are exposed to increased risk of disasters economically, socially and politically. The resulting losses from natural hazards is being increased by the rate of poor urban expansion, lack of awareness on effects of natural hazards on human life and built up environment and lack of urban management. Effects of Natural hazards represent an event that brings loss of life to human and total destruction to the physical infrastructure. Earthquakes being one of natural hazards constitute extremely serious and sever damages worldwide (Wei et al. 2017). Understanding potential impact of hazards that threaten the local population, infrastructure and economy have brought Risk identification and communication. Disaster risk assessment is the first step towards designing and implementing prevention and mitigation measures**.** Earthquakes are one of the most common and very serious geo hazards that have either total loss of life or destruction of structures in world wide. The frequency of occurrences increases with rising human populations.

The active Great Rift Valley makes Ethiopia susceptible to two types of seismic hazard: earthquakes and volcanic eruptions. The impact of natural hazards has increased due to increased population density in hazardous zones, often associated with poor human planning, and to the increase in the Frequency and intensity of extreme events as a consequence of climate change (Pachauri et al., 2007**).** In recent times, the effect of earthquake on urban environment has become a well-accepted fact. Ethiopia has experienced a number of earthquakes annually and these have caused some deaths, and damage to buildings in Addis Ababa as the city is highly affected by construction. To mitigate losses resulted by earthquakes, it is important to get all causative factors that are directly or indirectly responsible for geo hazard susceptibility in an area (Akkar, 2014). Seismic zonation for urban environment is the first and most key measure in Earthquake hazard analysis and mitigation strategy where population density is largely increasing with poor construction practice (Smith, 2013).

Studies on seismic zoning of Ethiopia as per Peak ground acceleration had been conducted earlier describing that the country lies within Medium seismic zone. According to the EM-DAT database, from 1900 to 2013 earthquakes in Ethiopia have caused a total of 93 deaths, 165 injured, 420 homeless, and affected 11,000 people, and a total estimated economic cost of more than US$7 million.(Herbert, S., 2013).Moreover, the effect is observed to be significant in moderately seismic areas like Addis Ababa city. According to studies, an earthquake of nearly same magnitude (Ms of 6.8) is anticipated in the near future at about 27 km away from the city. Addis Ababa city is characterized by varied ground formations and is dominated by soft soil deposits in the south and south-eastern parts. Geotechnical reports from different locations and studies on engineering geology of the area provide a brief description of general characteristics of soil conditions in the city. Extensive infrastructures and high-rise buildings are being built in the rapidly growing city of Addis Ababa. The population of the city is progressively increasing day by day as well. The combined effect of such growths with the moderate seismicity of the area and local soil conditions accelerate susceptibility of the city to damages from earthquake hazards. According to (Gouin, 1970), seismic hazard from a 6.5 magnitude earthquake could happen in areas of close proximity to Addis Ababa, causing as many as 4000-5000 deaths, 8000-10,000 injuries and a displacement of as many as 500,000 people and a total damage in excess of 12 Billion Birr (Source: report published in 1995).(Gouin, 1970), also stated that the closeness of Ethiopia's major cities like; Addis Ababa, Adama, Dire dawa and Hawasa to main fault belts such as Wonji fault, Adama fault, Addis-Ambo-Ghedo fault, and Fil Woha fault lines, make them susceptible to earthquake effects. Gouin also described that the quakes of 1906 with magnitude of 6.75 and estimated epicentral location of 100Km south of Addis Ababa have shocked the city and caused bells of church**.** Addis Ababa has witnessed a number of earthquakes in 100 years of its existence, some are: the 1906 an earthquake of magnitude 6.8 at epicentral distance of about 100 km south of Addis, the 1961 an earthquake of magnitude 6.6 occurred at a distance of 200km (Karakore Earthquake), the July1997 an earthquake with magnitude 4.0 at a distance of 22 km to the south west of the city. The capital Addis Ababa is located 75-100 km from the western edge of the Ethiopian Rift Valley within the seismic region of the country and has "moderate seismicity".

Earthquake mitigation and Preparedness require consideration of spatial distribution of earthquake input parameters. These input factors are either directly or indirectly related to earthquake risk of specified region a number of recorded earthquake ground motions provided numerous evidences associated with the effect of soil deposits on ground motion characteristics (Kramer 1996; Villa Verde 2009).

Vulnerability of cities and settlement areas to natural disasters such as earthquakes is to some extent a consequence of the role of human behaviors and is strongly related to the importance of planning systems in reducing the damaging effects of natural disasters. The geographic information systems (GIS) serve in ideal environments to compile different geospatial data required for any geohazard assessment due to Its ability to collect, influence, analyses and depict spatial and tabular data (Korte, 1997).

Recently, GIS tool has been used in geohazard assessment by (Malczewski 1999, Miles and Ho 1999, Sadek et al. 2000, Dai et al. 2001, Sunuwar et al. 2003, Lee et al. 2004, Mohanty and Walling 2008, Pal et al. 2008). Empirical techniques can develop hazard zonation maps by overlaying the location of past hazard events with environmental Earthquake input data relevant to the hazard process (Malczewski 1999, Sadek et al. 2000, Dai et al. 2001, Bathrellos et al. 2009, Hassanzadeh et al. 2013, Quadrio et al. 2015). The GIS technology with multi-criteria decision analysis techniques such as the (AHP), enables to account for added levels of details and complexity (Erden and Karaman 2012, Panahi et al. 2014).

The AHP method has been mostly used around the world to help in decision-making situations by using structured techniques such as: collection and examination of the complex quantifiable problems (Saaty, 2008). Environmental factors based identification of potential earthquake effect vulnerable areas is a basis for preparedness and reduce the expected risk. This study focuses on environmental factors based identification of seismic effect vulnerable zones in case of Addis Ababa city by using integrated method approaches and GIS. Application of GIS in supporting urban vulnerability assessment arises directly from the benefit of integrating a Geospatial technology designed to support spatial decision making to address numerous critical spatial decisions (Cova, 1999).

1.2 Scientific framework of the study

It is known that occurrence of an earthquake is concentrated along rift zones. Previous Studies have revealed that the geographical setting of Addis Ababa city allows experiencing future earthquake. As the specific time and place of earthquake occurrence is unknown and still not known by researchers, study focused on GIS-based identification earthquake effect susceptible areas is key important and basis for mitigating and decreasing risks by identifying vulnerable areas. This study was designed by following generally accepted global earthquake models and is composed of different aspects of vulnerability such as: susceptibility assessment in seismic hazard and seismic risk with its socio-economic impact**.** The hazard refers to probability of occurrence of an earthquake and resulting ground shaking at the study area. Vulnerability assessment is a complex tax which requires following certain procedures and responsible input factors. The risk assesses damage and losses such as fatalities, injuries and cost of repair resulted from the hazard. Further study can be occurred later to assess Damage resulted from future earthquake due to strong ground shaking.

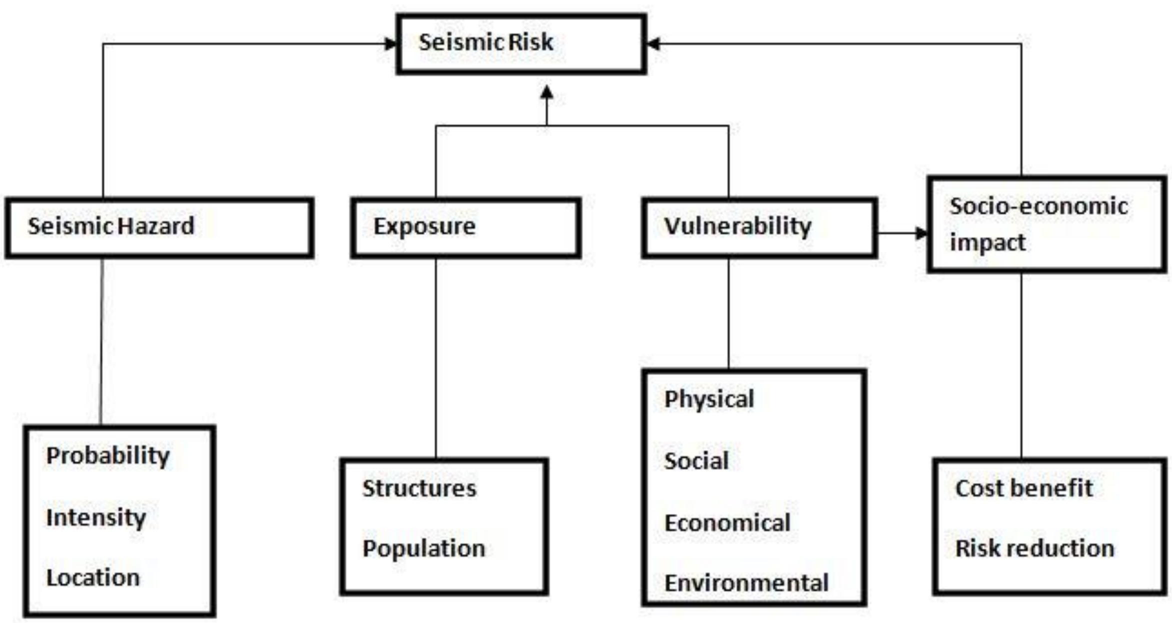


Fig: 1.1frame work of the study

1.3 **Statement of the problem and development of the challenge**

Ethiopia has experienced a number of earthquakes annually and these have caused some deaths, and damage to buildings. Addis Ababa city is a region highly affected by construction. Earthquake occurs persistently and endangers the lives and livelihoods of thousands of life. Earthquake occurs persistently in country and vicinity of the city continuously. According to the EM-DAT database, from 1900 to 2013 earthquakes in Ethiopia have caused a total of 93 deaths, 165 injured, 420 homeless, and affected 11,000 people, and a total estimated economic cost of more than US$7 million (Herbert, S., 2013). Most of existing works of other researchers conducted so far was focused on the general seismic characterization study area. But current study is unique in contributing a GIS technology and AHP method based earthquake input factors combination to develop earthquake effect susceptible areas in the city.

1.4 General Objectives

The main goal of the research was development of GIS-based earthquake effect susceptibility map of Addis Ababa city.

1.4.1 Specific objectives.

In addition to development earthquake effect vulnerability map of Addis Ababa city,

- Discussing methodology used for earthquake effect Vulnerability assessment for cities.
- Understanding the types of earthquake effect vulnerable themes.
- Identification of causative factors in earthquake effect assessment.
- Proposing a link between of the causative factors and severity of seismic effect**.**

1.5 Research questions

- What methodology is used for development of GIS-based earthquake effect Vulnerability assessment?
- What themes are vulnerable in general earthquake effect assessment?
- What are causative factors in earthquake effect vulnerability assessment?
- What are links between earthquake input factors and the severity of an earthquake effect?

1.6 Significance of the study

The main importance of current study is mitigation, reduction and preparedness for the next earthquake effects which is dominant for the human, animals, and environment. The current study primarily used as a base in hazard mitigation and reduction of the city. Also it to contribute the ease identification of earthquake effect vulnerable areas in analysis of spatial earthquake susceptibility in rift regions such as Addis Ababa. This study also seeks to response earthquake problems based scientific significance and appropriate methodology results and findings of this thesis are expected to be used by other researchers and urban planners to serve as base hazard map in useful decision making tool. Besides, any advanced study in this area will help in minimizing and mitigation of vulnerable elements that could be damaged due to the resulted risk. Moreover, the present study may also be used as a base line for city planners and other concerned body who are involved in Hazard mitigation

Identification of earthquake effect potential map of the study area is very useful for:

- ✓ Strengthening immediate measurements such as
- ✓ Making disaster mitigation plans to reduce the seismic risk.
- ✓ Understanding on environmental factors that triggers earthquake effect.
- ✓ Providing planners and decision makers with necessary information about the spatial distribution of the most vulnerable areas.
- ✓ Providing ease identification of vulnerable elements.

1.7 Description of Study area

1.7.1 Location

Addis Ababa, the capital city of Ethiopia is one of the most developing cities due to its: Surplus Resources, Industrialization, Commercialization, Transportation, Communication, Economic aspects, Educational and Recreational Facilities. The city was selected as political and social center of Africa and the seat for regional and international organizations. The geographical location of the city lies between latitude 8^{o} 49' 55.92"–9^{o} 5' 53.85" N and longitude 38^{o} 38' 16.55"–38^{o} 54' 19.54" E. It is speedily expanding and is represented by the large population with rapid growth rate. The city, sited in the central high plateau of the country, has an altitude ranging from 3100 m (Entoto) to 2050 m (Akaki) above sea level attaining an aerial extent of 527 km^2 as indicated below by Fig(1.2).

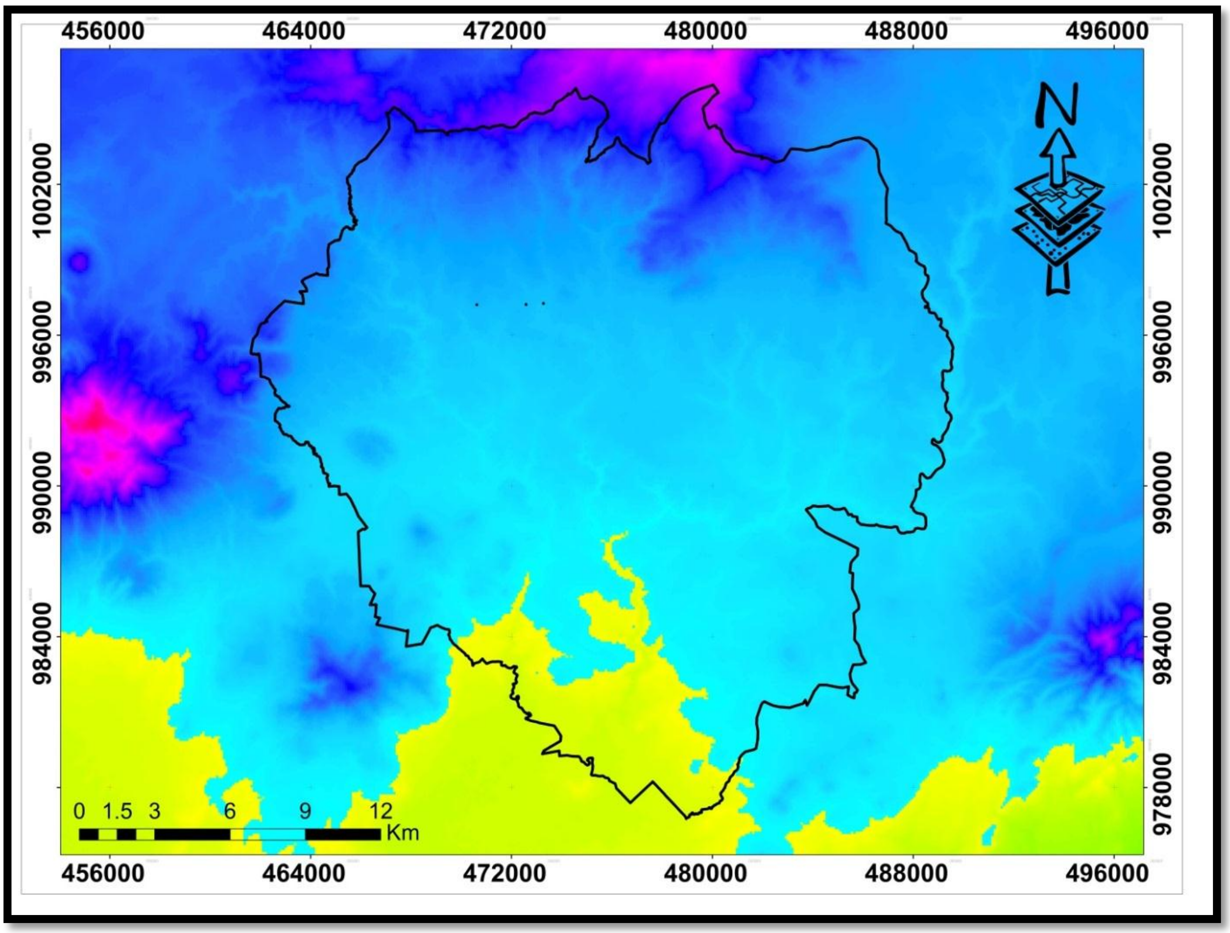


Fig: 1.2 Location of the study area

1.7.2 Physiographic map of the study area

The terrain in Addis Ababa is rather complicated. In general, the altitude decreases gradually from West to East. Generally, the mountainous part is strongly dissected and steep, and characterized by high mountain tops with altitudes ranging from 2020 to 3120 m. The highest mountain is Entoto. Terrain of this province is pretty complicated. High mountain, strongly dissected and slope, especially in the western part are the particular relief features of the province. Variation in the general geomorphology of the study area is resulted from past geological process and associated human activities such as deforestation, quarrying, construction activities and mining of construction materials. The highest elevation is Entoto Mountain and tends to decrease gradually towards East west and Akaki kality. The physiographic map of the study area is indicated below by (Fig: 1.3)

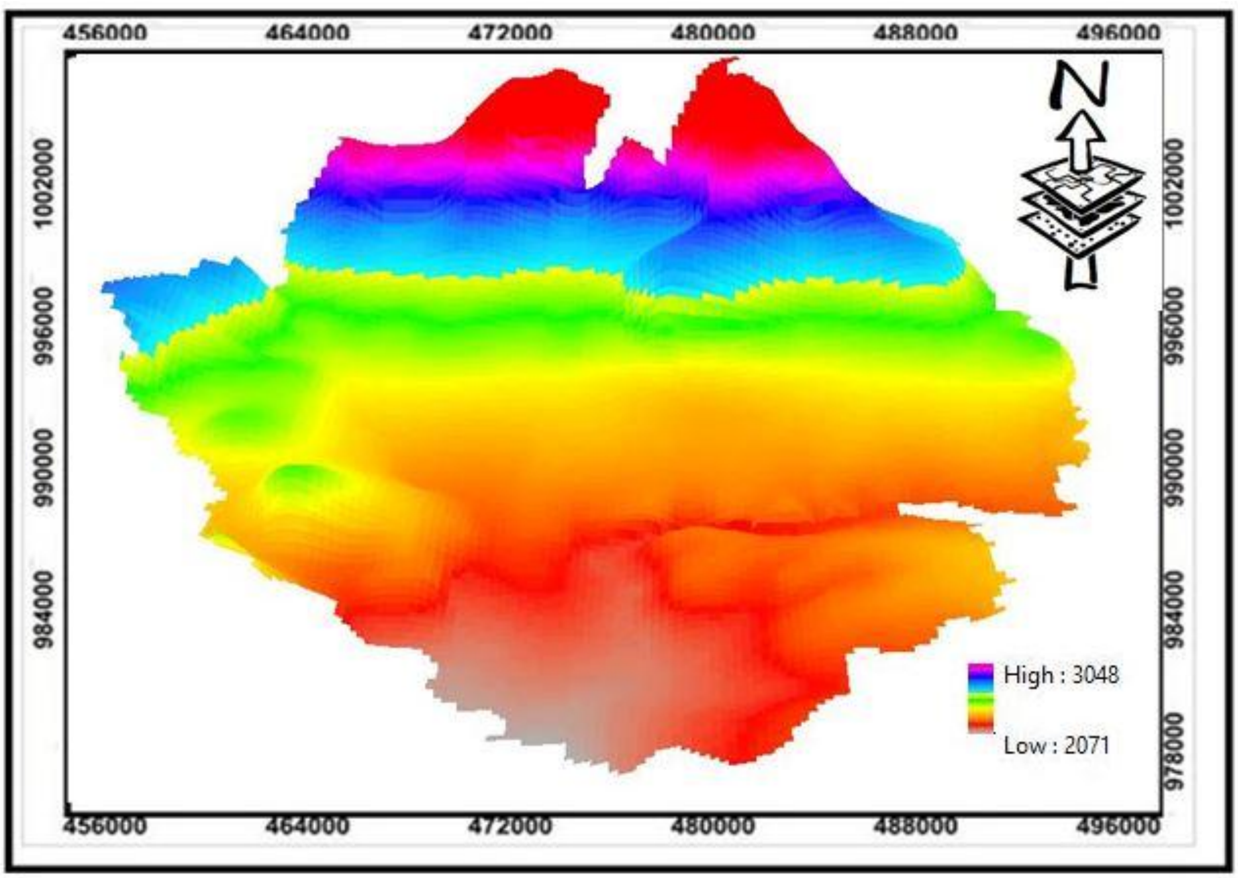


Fig: 1.3 Physiography of the study area

1.7.3 Climate

Addis Ababa lies in the tropical climate with strong monsoon influence that is a considerable amount of sunny days and high rate of rainfall and humidity. The climatic variation within the city is observed due to elevation variation. While the rainy season, normally begins March or April then continues to August or September. The temperature Addis Ababa fluctuates from January to December. The monthly mean maximum and minimum temperature recorded during the years between 1984 and 2019 indicates that the highest mean monthly maximum temperature occurs in the month of March, which is about 24.4oC and the lowest is in the months of August, which is about 20.2oC While the mean monthly minimum temperature ranges for the lowest from 7.2oC in December to the highest 10.9oC in the month of May. Long term mean annual maximum and minimum temperature of the city administration is 24.4oC and 7.2oC, respectively. The city has a mild climate. Nights are cool, even cold from November to February, when lows drop below 10 °C (50 °F), while days are pleasantly warm, around 23/25 °C (73/77 °F), except in July and August, at the height of the rainy season, when highs drop to about 20 °C (68 °F).

Table: 1.1 climatic variation representations

Addis Ababa - Average temperatures

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min (°C)	8	9	10	11	11	10	10	10	10	9	7	7
Max (°C)	24	24	25	24	25	23	21	21	22	23	23	23
Min (°F)	46	48	50	52	52	50	50	50	50	48	45	45
Max (°F)	75	75	77	75	77	73	70	70	72	73	73	73

1.7.4 Land use land cover

Human activities such as: deforestation, over construction of buildings, ground water withdrawn, quarrying and poor family planning has dramatically changed the general layout of the city. The most land use land cover in the study area includes Built up, Forest and farmlands. these land cover varies according to Geology, topography, types of soil, climate and human activities. Urbanization plays a very crucial role in earthquake risk vulnerability cases. In this study, three types of land use are considered: Built up, Forest and farmlands.. Land use land cover map of the study area is used to easily identify vulnerable classes to earthquake effect. Generally, Built up areas are of highly vulnerable seismic effect prone areas as it was indicated by Land use land cover of the study area was prepared from Land sat thematic mapper downloaded from USGS.

Source of data for land use land cover map is Institute of geospatial technology.

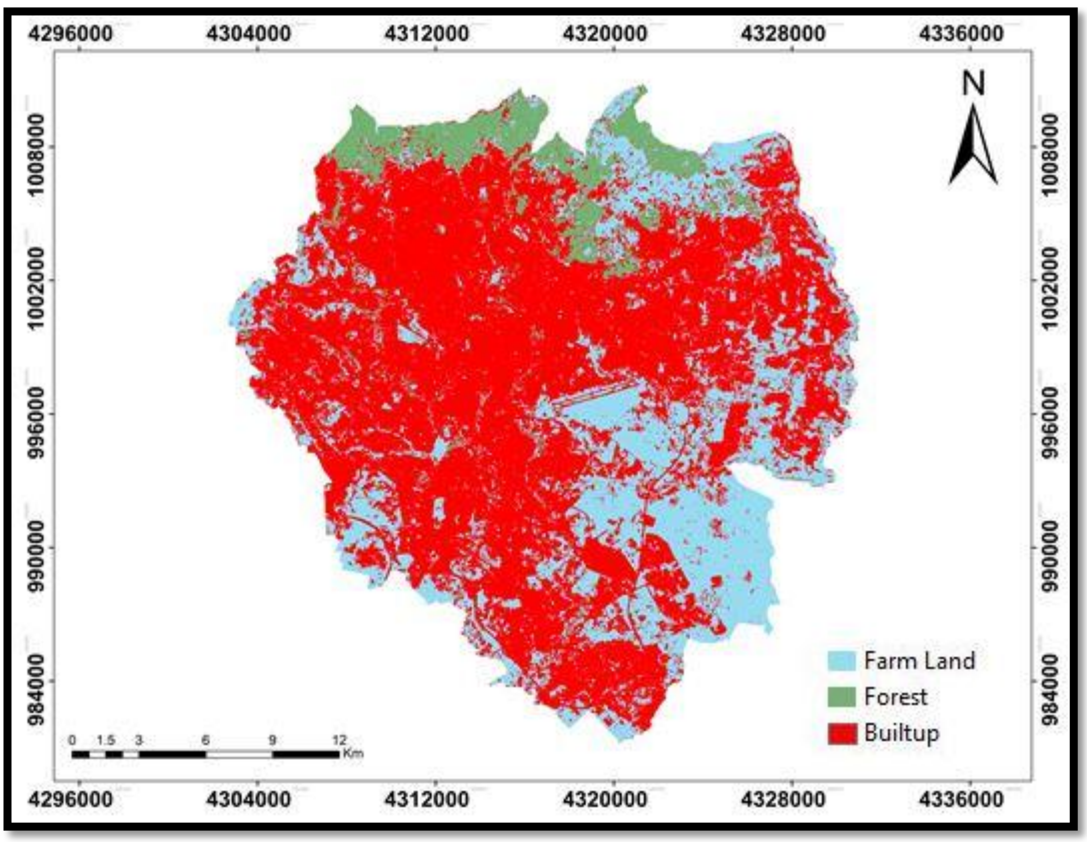


Fig: 1.4 Land use land cover map of the study area

1.7.5 River and stream systems

The Addis Ababa's topography is characterized by mountains, while smaller parts are hills and plains. Therefore, the rivers or streams have short lengths and steep longitudinal morphometries, which abruptly changes into gentle slopes in the plains. River and stream pattern of the study area is controlled by the nature of geology and types of geological structures that are formed during large scale tectonic movements and volcanism, earthquake, landslide and other geohazard. Drainage densities are densely structured along fault lines. Geologically, Fault lines are controlling the movement of streams.

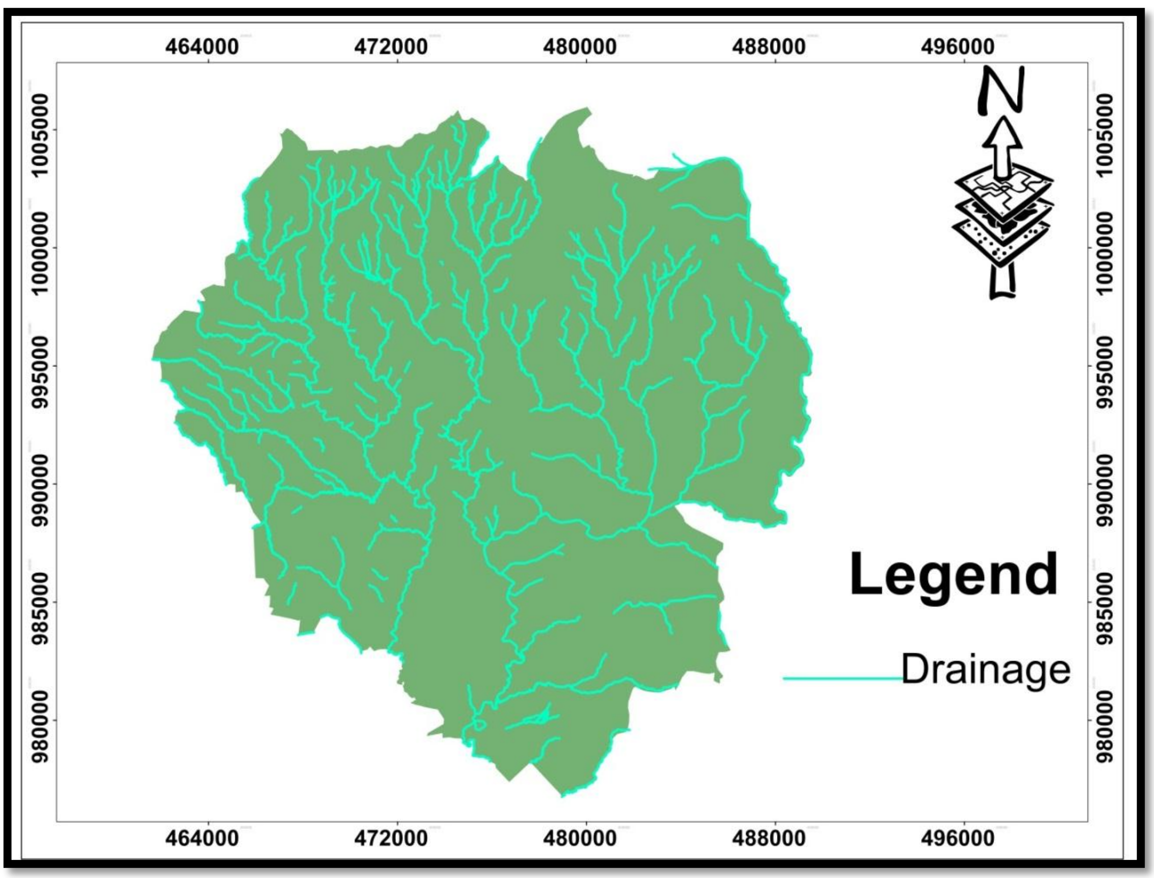


Fig: 1.5 River and stream systems

1.7.6Soil characterization

Physical Weathering of rocks and erosion could form soils of different character. As soils of different forms formed, seismicity of the study area is affected by these newly formed Soils. Accordingly, soil of the study area is characterized according to their texture, thickness, formation and color. The thick soil profile is favored due to climatic condition and topography of the city. Generally, soils in Addis Ababa are genetically grouped into alluvial, alluvial fan, residual, colluvial and lacustrine soil units.

Table: 1.2 characterize soil types in Addis Ababa city.

Soil type	Characteristics	How it formed	Where it found
Alluvial Soils	layered deposits	transported by streams	Akaki River, Kebena river
Alluvial fan deposit	sediment deposits	dissected by a deep gully	Entoto region
Residual Soils	intermediate to high plasticity	decomposition of rocks	central part, Gulele and Kolfe
Lacustrine Soils	black cotton soils	deposition of sediments	Bole, Lideta, and Mekanisa
Colluvial soils:	talus and debris	downward movement of soils and disintegrated bedrock	northeastern part of Entoto silicic

1.7.7 Existing Earthquake points around the study area

Continuous occurrences of earthquakes near the city the main existing problem. The trend of earthquake occurrence is directly linked with rapid urbanization of the city. Earthquake spots are tried to be compiled to analyze their frequency, intensity, magnitude and source site. As the study area is found near great main Ethiopian rift system, spots of small magnitude to large magnitudes are distributed thoroughly. Most of earthquake happened so far was closer to Addis Ababa city. Each point of earthquake have information such as: magnitude, intensity, depth of origination, elevation and geographical location of easting and nothings. The following earthquake points are downloaded from United States Geological Survey.

Table: 1.3 Earthquake point distribution around study area

Ground motion data recorded by USGS From 2010-2019				
Latitude	**Longitude**	**Depth(Km)**	**Mag(Mercalli)**	**places**
7.671	38.6682	10	5.3	4km NNE of Awasa, Ethiopia
7.0885	38.4794	10	4.4	20km NW of Metahara, Ethiopia
9.0216	39.7736	16.76	4.3	12km NE of Shashemene, Ethiopia
7.8935	38.1148	10	4.2	37km SW of Butajira, Ethiopia
7.411	38.8101	10.68	4.4	32km NE of Shashemene, Ethiopia
11.479	41.6783	14.55	4.6	27km ESE of Asaita, Ethiopia
10.6937	38.9343	10	4.2	55km W of Were Ilu, Ethiopia
7.643	37.868	10	4.4	10 km from Hosannas, Ethiopia
6.659	38.521	10	5	12 km from wendo,Ethiopia
7.521	37.839	10	5.1	1km from Hosaena,Ethiopia

1.7.8 Geological setting

Addis Ababa city comprises of different lithological layers of different composition and age. Each of geological layers differs in age and strength. predominantly in the Western side of Addis Ababa basalts overlie Intoto silicics and outcrops mainly occur in the Intoto Mountain, central Addis Ababa, along Akaki River course (South) in the vicinity of Lega Dadi dam to the north of Lake Gefersa and Southern part of the city. From North to South the lithological layers change from oldest volcanic sequences to the youngest. Alaji series includes the Entoto Mountain and extends to the North beyond the study area. It consists of basalts with rhyolites, trachytes, ignimbrites, tuffs and agglomerates. Intoto silicics composed of rhyolite and trachyte with minor amount of welded tuff and obsidian.

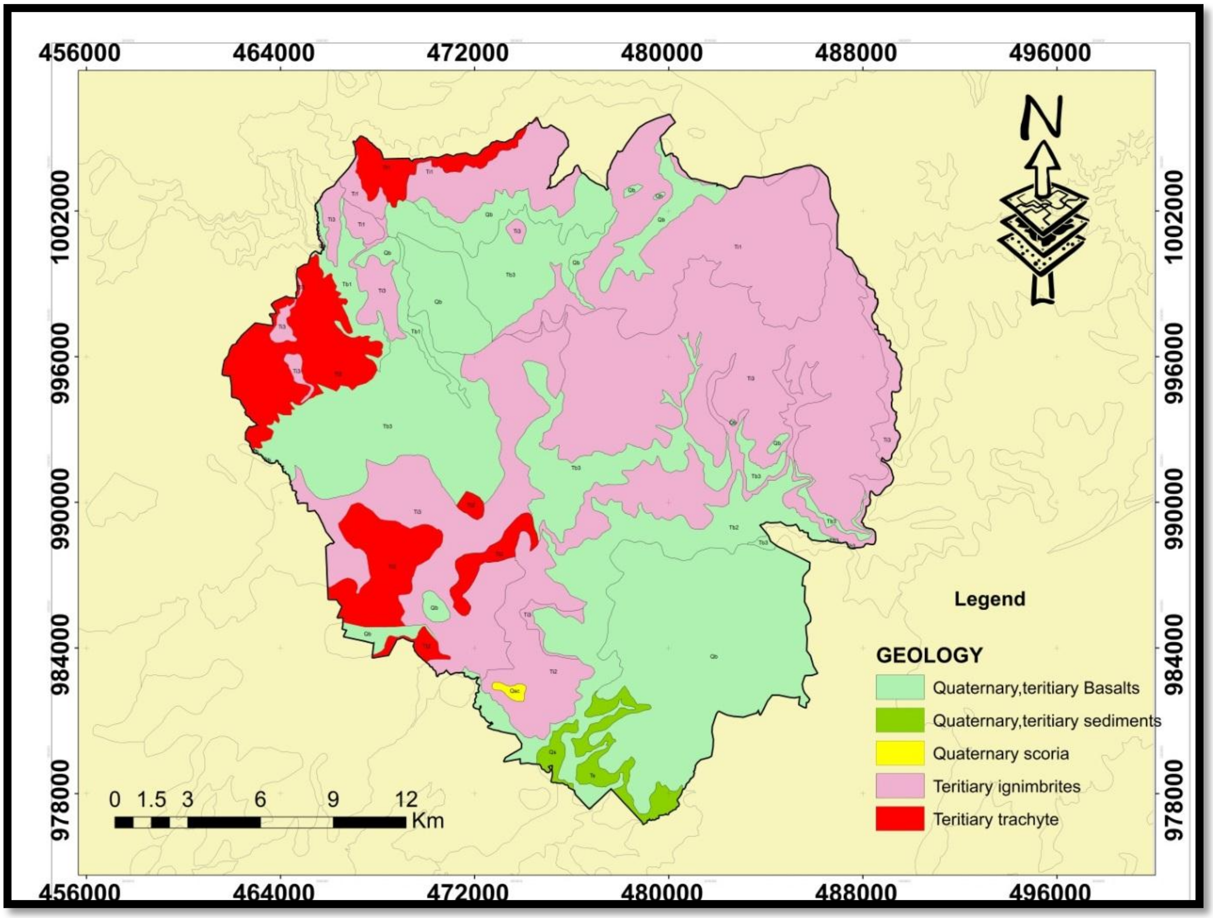


Fig: 1.6 Geological setting

1.7.9 Geological structures

The study area is experiencing different tectonic activity and is complex in structure because of its geographical location to the Main Ethiopian Rift or its margin. The main structures formed are lineaments, faults, bedding and volcanic layering. Different geomorphic features align mostly to the North East-South West direction which is parallel to the structure of the rift or rift margin. Most of the faults mainly observed in the South-East part of the study area and cut the entire unit. They have a structure trending in North East to South West direction. These faults are mainly normal faults. The lengths of the structures vary between few centimeters to several meters. In some places they are oriented normal to the flow banding and are parallel to each other.

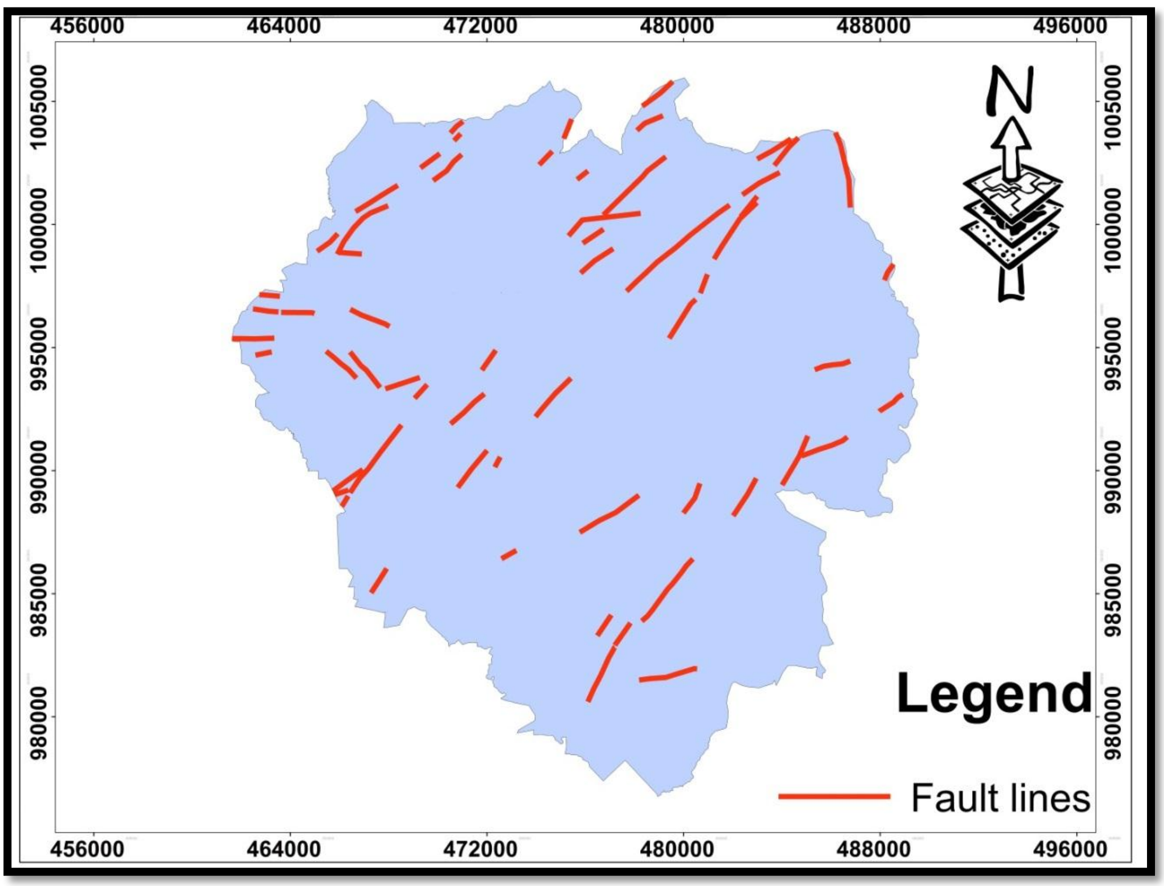


Fig: 1.7 Geological structures

1.8 Limitation and Scope of the Study

The study is limited to indirect Identification of earthquake effect susceptible areas by considering different earthquake input factors. Methodology used in this study is limited to Application of GIS technology and AHP method. The main limitation in this study and in general earthquake related study is lack of raw data to be used as an input. Another limitation during this study is emergency of COVID-19..

1.9 Organization of the Study

The present study was conducted by reviewing environmental earthquake input factors selected to map earthquake risk potential zones in Addis Ababa city. To present the results of the research in a more systematic manner, it is divided into six chapters and the scheme of presentation is as follows:

Chapter 1: comprises the introduction, which includes the background of the study, problem Statement, historical background of seismicity in Ethiopia, objectives of the Study, methodology, significance of the research, limitation and general description which includes geographical location, geology, physiographic and drainage conditions, soils, climate scope of the study and scheme of presentation.

Chapter 2: presents the literature review. The literature review comprises a brief description of the earthquake genesis and previous works relevant to the present research. It includes a thorough Review of Earthquake, studies made on input factors for earthquake risk potential mapping, Methodology used to assess vulnerability assessment methods. A brief methodology used in earthquake vulnerability assessment..

Chapter 3: presents all materials and Methodology with approaches used for vulnerability assessment

Chapter 4: presents relationship between Earthquake input factors and severity of earthquake effect

Chapter 5: presents overall discussion and result of the findings

Chapter 6: conclusion and recommendation

CHAPTER TWO

2.1 Literature Review

Environmental risks and damage of some Geohazard are a major focus of research, generally concern, and they provide an important arena for interdisciplinary collaboration between social scientists, natural scientists and engineers. Disasters are natural hazard events that can cause environmental destruction and damage to the property which includes earthquakes, mass movements, floods, volcanic eruptions and tsunamis. (Feizizadeh et al, 2011). According to (Alam et al, 2018), assessment of earthquake effect vulnerability of a city located on earthquake potential zone is important for preparedness and better understanding about risk mitigation plans. Identification of earthquake effect prone areas is of rising concern and its implication is essential in defining strategic planning and urban management. (Rahman et al, 2015.). According to different researchers, it is agreed that land use planning is a key tool for reducing and mitigating natural disasters.

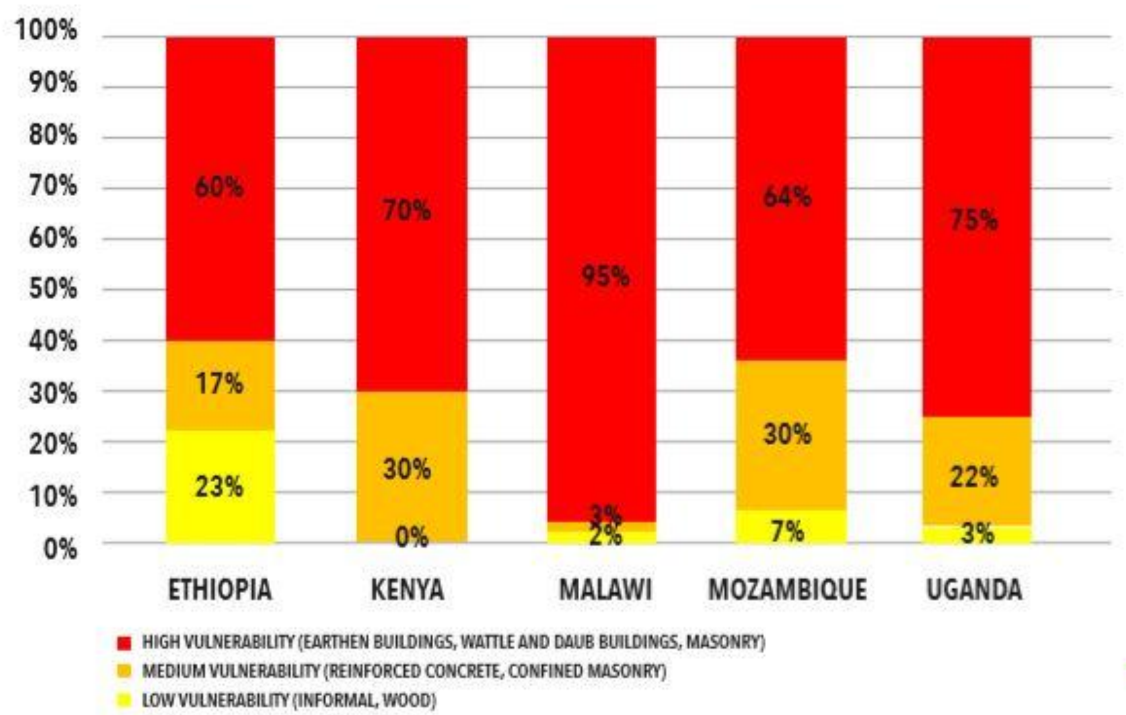


Fig: 2.1 graph of Building damage in East African rift system

Source: report on RIFT 2018 Regional seismic risk and resilience workshop, Nairobi Kenya**.**

2.2 Causes of earthquakes

2.2.1 Geological causes

Earthquake is simply represent an event that took place when ground vibrates the reason of ground vibration is due to release of energy when rock breaks. The resulting consequence of an earthquake such as total loss of life and displacement of people from homes, collapse of buildings, damage to transportation and Disruption of power and water depends on magnitude, intensity, geology, quality of existing structure and population density. The cause of earthquake is composed of geologic process and anthropogenic cases which is defined as the works of human that includes: road construction, deep well excavation, quarrying and blasting when underground mining is developed. All this human activities are considered as causes for small earthquakes.

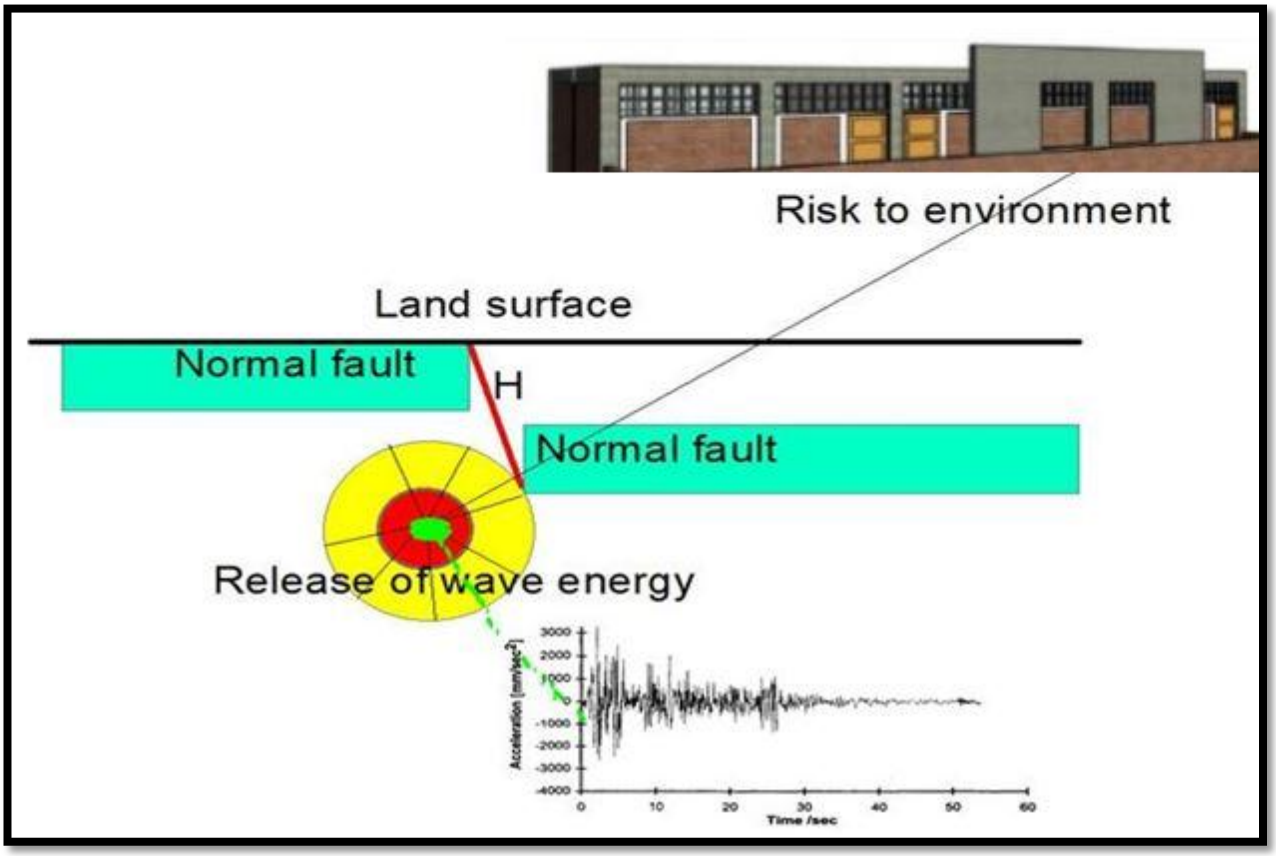


Fig: 2.2 geological causes of earthquake model

2.2.2 Tectonic plate movement

The main and primary driving force for earthquake occurrence is tectonic plate movement. Earth interior has different layers such as crust, mantle and core. Among these layers, the crust is composed of many peaces called plates. These plates are moved relative to one another as subsurface heat are generated from mantle plume and pressured by overlaying rocks. There are plates along the outer layer of the earth which are floating on the molten the crust of the earth. The convection currents originated from magma drives the plates to move inside the earth. The movement of plates causes either subduction or construction of land forms to pass over another. When the two plates meet together, they start to push and rub each other but they are not moving. As a result, development of pressure beneath plates builds up and keeps on rising. As the exerted pressure is above optimum such that it cannot hold, the pressure, it will be either brusted or expelled. This causes sudden release of energy which in turn shakes ground.

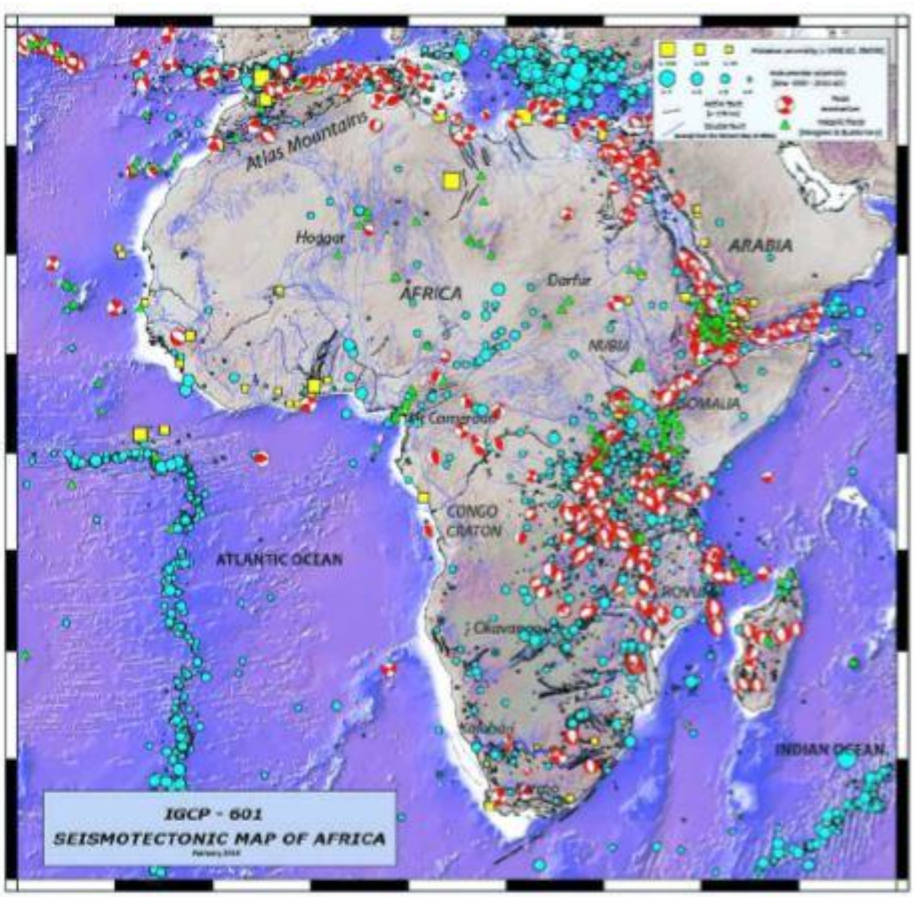


Fig: 2.3 seismo-tectonic map of Africa
Source: Professor Ataly Ayele

Subsurface of the earth has varying thickness. Earth's crust has thickness ranging from 30-40 km, tectonosphere, which extends to 400 km below the crust, mantle classes including the upper mantle (1000 km), the lower mantle (2900 km), the outer core (5120 km), and the inner core (6370 km). Geology of subsurface materials below earth's crust is known by high temperature and pressure due to weight of overlying rocks. Different fault zones are formed in tectonosphere in response of this high pressure are constantly moving. The related theory explaining the movement of rocks is called plate tectonics. As a result of this large scale movement of blocks of rocks, different fault zones and rifts are created. The size of the released energy during rock breakage depends on the size of the blocks and the amplitude of sliding between two adjacent blocks. The time required for energy accumulation before movement of the blocks occurs can range from several tens to several hundreds of years. Earthquakes are distributed mainly along the major faults. Instrumental records of earthquakes date back for about 100 years. Modern seismology is capable of instrumental recording of all kinds of earthquakes. A zone of earthquake where accumulated energy is released is called the earthquake focus or hypocenter, while its projection on the ground surface is called the earthquake epicenter. The distance between the epicenter and the hypocenter defines the depth of the earthquake. The earthquakes that occur at the depth of 0-70 km are considered as shallow, while those that occur deeper than 70 km are deep earthquakes. The size of the released energy is expressed by the magnitude and usually given in terms of the Richter scale.

2.2.3 Human effects

As vulnerability of built up environment to earthquake effect and its risk is increased due to rapid urbanization and over construction of buildings that lack building in major cities, development of earthquake effect potential map for urbanized cities become a key solution (Nwe et al, 2016). Another cause of earthquake is considered as anthropogenic factor which indicates activities of human being on natural environment such as: deforestation, construction activities, mining activities and land use land cover. Human activities that are mentioned above are capable to either being as causative factor or generating small and shallow earthquake. Most of Constructions practiced in the study area, are characterized as high rised, lacking seismic codes and weak construction materials that are not seismic proofing structures. Generally small and shallow earthquakes are produced while subsurface mining and blasting of minerals are held.

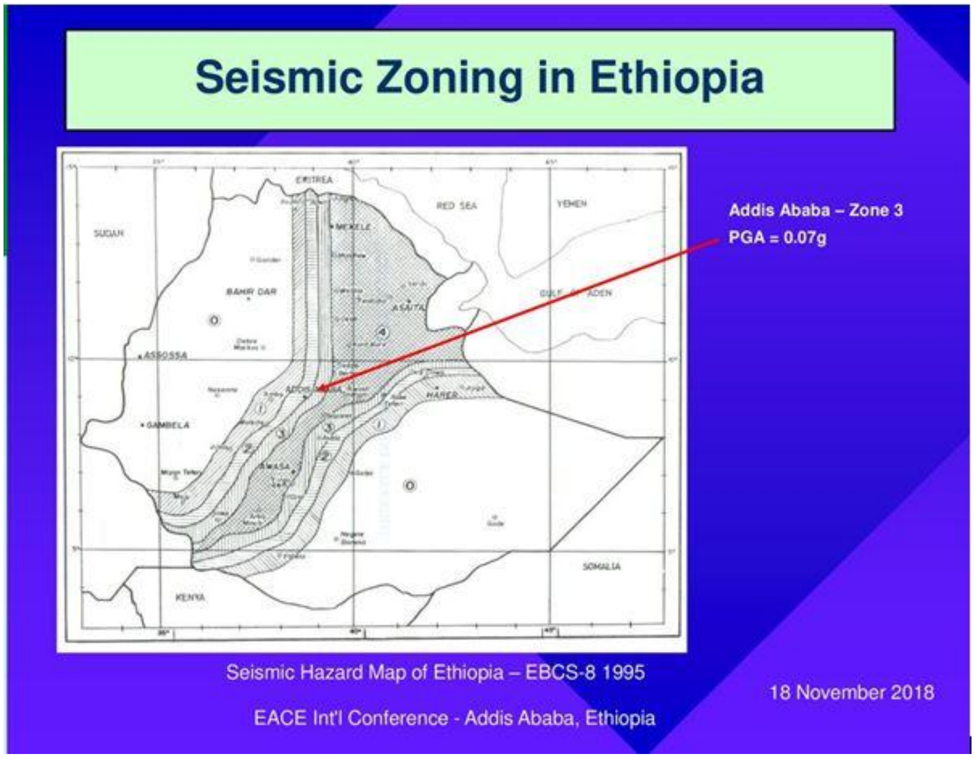


Fig 2.4 Peak ground acceleration Map of Ethiopia

2.3 Application of geospatial technology in earthquake effect potential mapping

Geospatial technologies specifically, GIS with its capability of analytical data storage allows a quick and easy method of Geohazard assessment for the given region. For this study, application of GIS technology to assess earthquake risk related spatial data that are directly or indirectly affecting the occurrence of earthquake. Nowadays, GIS has been widely used in earthquake risk vulnerability assessment (Dai, et al., 2001). Hazard zonation is the basis for any further disaster management project. GIS has strong functions for spatially distributed data processing and analysis. Using GIS gives the possibility to integrate qualitative as well as quantitative data and to collect, store, transform, analyze and display the huge amount of geographically referenced information needed for evaluation. Accordingly, Remote Sensing is defined as one part of geospatial technology as measurement and recording of electromagnetic energy reflected from or emitted by the Earth's surface and relating of such measurement to the nature and properties of surface materials including all the activities from recording, processing, analyzing, interpretation and finally obtaining useful information from the data generated by the remote sensing system.

The earthquake information extracted from remotely sensed product is mainly related to morphology, lineament, landslide area, complex road networks, Building topology and hydrologic conditions of a slope. GIS, as a computer-based system for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output, with its excellent spatial data processing capacity, has attracted great attention in natural disaster assessment. With GIS, the methods for earthquake risk vulnerability mapping can be briefly classified into three groups: qualitative methodologies, statistical methodologies and geotechnical model-based methodologies. Generally, qualitative approaches are based entirely on the judgment of those conducting the susceptibility or hazard assessment. The parameters used in these models can be determined in the field or in the laboratory. Models that consider the spatial distribution of input parameters are called deterministic distributed models. Deterministic distributed models require maps that give the spatial distribution of the input data. GIS is a tool for collecting, storing, retrieving, transforming, manipulating and displaying spatially distributed data, and therefore it is frequently used in distributed deterministic modeling. It is primarily designed for the collection, storage and analysis of objects and phenomena where geographic location is an important characteristic for analysis. A computer system for GIS consists of hardware, software and procedures designed to support the data capture, processing, analysis, modeling and display of geospatial data. GIS should satisfy the following four criteria: Data input, Data management data storage and retrieval, Manipulation and analysis, Output (Visualization) Functionalities of GIS, Collecting, storing, retrieving, transforming, manipulating and displaying spatially distributed data.

2.4 Existing GIS based Earthquake modeling methods

GIS methods for earthquake risk vulnerability mapping have been employed by different investigators throughout the world. Literature review reveals that methods for ranking earthquake risk instability factors and assigning different susceptibility levels can be divided into: qualitative or quantitative, and direct or indirect (Guzzetti, et al., 1999).

Qualitative methods are subjective, ascertain susceptibility heuristically, and portray susceptibility levels using descriptive (qualitative) terms. Quantitative methods produce numerical estimates, i.e. probabilities of the occurrence of earthquake phenomena in any susceptibility zone (Guzzetti, et al., 2005).

Direct mapping methods are those that identify the spatial distribution of instability directly from existing earthquake and/or specific knowledge of areas of potential instability. A direct method consists of the geomorphologic mapping of earthquake risk susceptibility in the field from aerial photographs or from satellite images (Nossin, 1989). Indirect mapping methods are those that use environmental factors relevant to earthquake to estimate potential instability. Indirect methods for earthquake susceptibility assessment are essentially stepwise. According to (Guzzetti et al 2005), Indirect methods of Earthquake vulnerability assessment are provided as: recognition and mapping of earthquake, Identification and mapping of the physical factors which are directly or indirectly correlated with earthquake, An estimate of the relative contribution of the instability factors in generating earthquake zonation map, classification of the land surface into domains of different levels of susceptibility and assessment of the model performance.

As most of earthquakes are naturally occurring phenomenon irrespective of time and space, it needs regular assessment of technical sets to identify environmental parameters are that are considered as earthquake input factors. These environmental parameters can be of geotechnical, geological and human activities that have direct or indirect effect on earthquake effect to build environment. Earthquake effect susceptibility of certain area is predominantly a function of combinations of Geological factors (lithology, slope, fault, ground water and soil) and human factors (Building topology, road networks, settlement).

2.5 Related works

Earthquake effect vulnerability assessment is a core process in disaster management and frequent efforts have been undertaken to address this problem. The works of researches based on seismicity of Ethiopia and Addis Ababa city (Mammo, 2005, Zest aye, 2018, Melese, 2018). A group multi criteria decision making model was proposed by (Yarian, 2020) for seismic vulnerability assessment. They assessed seismic vulnerability using a number of different MCDM methods in order to compare the results. A number of researches addressed the problem of social vulnerability which indicates the degree to which human of a specific urban area are vulnerable against earthquake. (Rashed and Weeks 2003) proposed an integrated multi criteria decision making model which is able to evaluate both social and physical vulnerabilities. Although the works of previous researchers have investigated the expected damage from future earthquake, A GIS-based Earthquake risk potentials identification of Addis Ababa city have not been assessed before.

According to (Wulfhorst, 2000), Ground motion is recorded by instruments known as seismographs. The magnitude of an earthquake is a measure of the size of seismic waves and is measured on the Richter Scale (RM) as a number between 2 and 8. Earthquake intensity is a measure of the damage caused by a quake and it is measured on an index known as the Modified Mercalli Intensity Scale (MMI). This scale is based on observation, describes the ground shaking effects on people and structures and has twelve levels of intensity (I to XII) (Wulfhorst, 2000).

Pachauri et al., 2007, have explained that, impact of natural hazards has increased due to increased population density in hazardous zones, often associated with poor human planning, and to the increase in the frequency and intensity of extreme events as a consequence of climate change. (Armas et al, 2017) revealed that, as urban vulnerability to earthquake effect is a function of human behavior, the importance to understand and define vulnerability is becoming vital. Several models of urban vulnerability have been proposed to address the various ways by which society becomes subject to hazard impacts (Menoni, 2001). Earthquake effect vulnerability implies the expected degree of damage to a given element at risk resulting from a given level of seismic hazard.

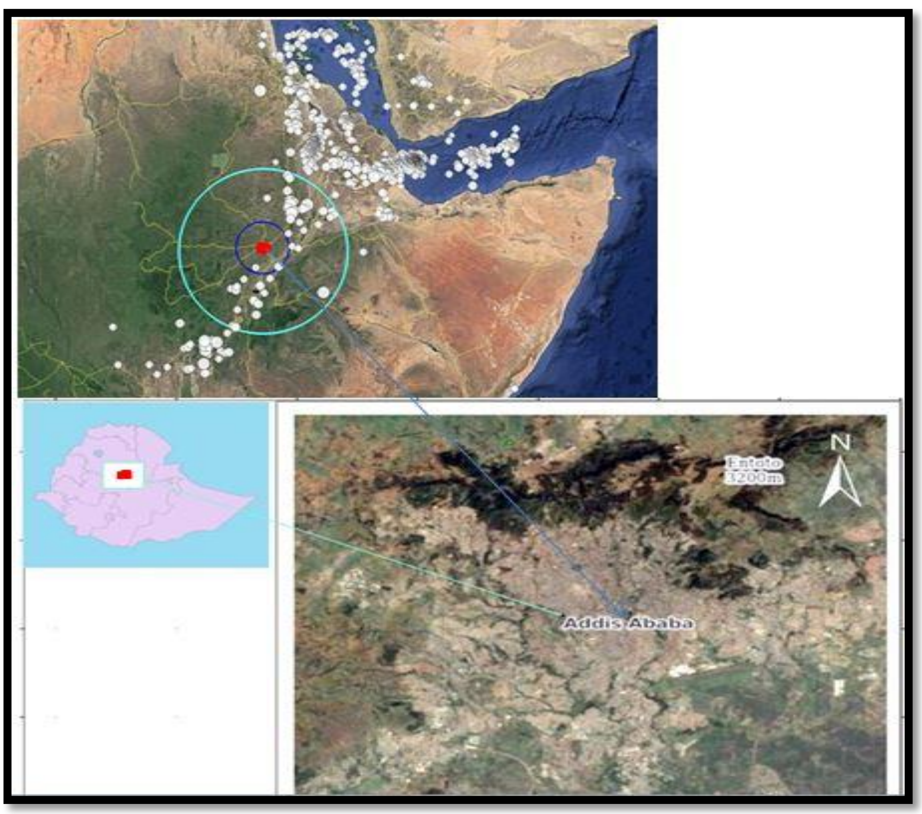


Fig: 2 .5 Alignment of Earthquake distributions along main Ethiopian rift

2.6 Concept of Vulnerability, Hazard, and Risk

According to (Müller 2012), the notion of vulnerability has now become a cornerstone of natural hazard study. Although the concept has been used in geography since the 1970s to describe human–nature interaction (White1974), it received ample attention after Timmerman's conceptualization in hazard research in the 1980s (Timmerman1981). Since then, there have been considerable efforts to understand, characterize, and map vulnerability. Literature suggest that there are several lineages on the theoretical construct of vulnerability, which may be divided into three major premises (Müller 2012; Lankao and Qin2011; Cutter et al. 2008, 2009). The first of these stems from the risk and hazard paradigm, which is based on human–nature interaction. In order to provide a systematic approach to study Earthquakes, (Varnes, 1984), defined various types of hazards, risks & vulnerability.

Natural hazard is probability of occurrence of a potentially damaging phenomenon within a specific period of time and within a given area. Hazard is defined as a threat that can potentially cause damage to people, property, or other elements. It can be natural (earthquake), technological (chemical spill), or man-made such as civil war (Godschalk 1991).

Hazards may be characterized by location, time, intensity, and frequency (Schneiderbauer and Ehrlich 2004; Wisner et al. 2004; Smith and Ward 1998).

Typical characteristics of flood hazards include area of inundation, flood depth, frequency, rainfall–runoff lag times, and geomorphologic settings

Vulnerability is the degree of loss to a given element or set of elements resulting from the occurrence of a natural phenomenon of a given magnitude.

Risk is the expected degree of loss due to a particular natural phenomenon. Hence it is a product of hazard and vulnerability. Asian Disaster Reduction Center (ADRC2005) describes risk as the overlapping areas of three factors hazard, exposure, and vulnerability that act simultaneously to generate the risk of natural hazards, which can be expressed as:

Risk = hazard *vulnerability (Kron, W., 2005)

Risk = hazard * exposure *vulnerability (Kron, W., 2002.)

Element at Risk includes the population, properties, economic activities etc. at risk in a given area. (UNDRO, 1991), have explained that vulnerability is the extent of loos to a given element at risk resulted from occurrence of natural phenomenon of certain magnitude which is expressed on scale of 0 (no damage) to 1(total damage).

Earthquake hazard is anything associated with an **earthquake** that may affect the normal activities of people. This includes surface faulting, ground shaking, landslide, liquefaction, tectonic deformation, tsunamis, and seiches.

Earthquake risk

is the probable building damage, and number of people that are expected to be hurt or killed if a likely earthquake on a particular fault occurs. Earthquake risk and earthquake **hazard** are occasionally incorrectly used interchangeably.

Earthquake Vulnerability can also be defined as the degree of loss to a given element at risk, or set of such elements, resulting from an **earthquake** of a given magnitude or intensity, which is usually expressed on a scale from 0 (no damage) to 10 (total loss).

Earthquake *Exposure*

Earthquake can be defined as the shaking of earth caused by waves moving under subsurface of the earth. Limit the risk of exposure to earthquakes by improving the quality of the built.

This theoretical construct usually answers questions relating to the nature of the hazards, the people that live in hazardous places, and the probable effects. The critical aspect in the development of this methodology is its ability to incorporate the divergent views of urban vulnerability. In the case of earthquake hazards, there are at least three basic points that different views of vulnerability would agree upon (Hewitt 1997, Kagan 1997, Bolin and Stanford 1998, Wisner 1998, Cutter et al. 2000). All vulnerability types in seismically active region include economic, social, political and environmental or physical impacts.

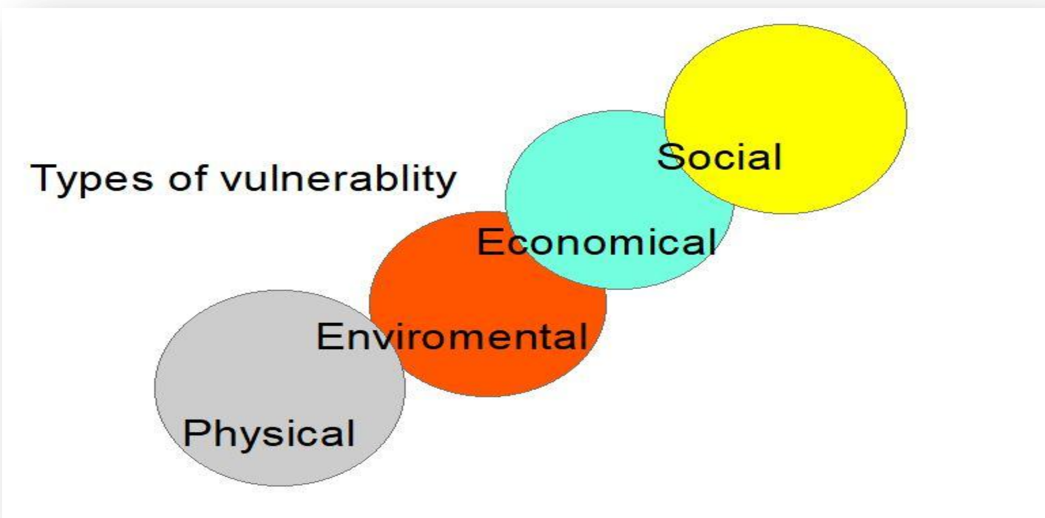


Fig: 2.6 themes of vulnerability

2.7 Approaches of Earthquake vulnerability assessment

Application of spatial multicriteria analysis method to urban vulnerability can be thought of as a process that combines and transforms spatially referenced data (input) into a resultant vulnerability score (output). The proposed process combines elements from the techniques of multicriteria evaluation (Malczewski, 1999) The AHP method is used to determine the weights of various themes for identifying earthquake effect prone areas based on weights assignment and normalization with respect to the relative contribution of the different factors to earthquake occurrence for classified into five categories Very low, low, medium, high and very high potential zone identify through integration of various thematic maps with GIS techniques (Jhariya et al, 2016).

2.8 Earthquake effect causative factors

2.8.1 Geology

Lithological conditions are one of the most important environmental parameters in earthquake events. The more geological formation of harder minerals, the lower the earthquake waves Transmission power and the weaker the destructive power of the earthquake. Also, the gaps and cracks in the geological formations are one of the most important areas for earthquake power transfer from earthquake focal point to ground level (Hosseini,et,al 2009).According to (Dai et al. 2001), main source of data related to the geomorphology of an area is determined by its lithological layers and geological properties. The seismicity of certain study area is related to the lithology and weathering properties of the material of the land (Yalcin, 2008). In the most of recent studies, such as references (Ayalew, 2005) and (Yalcin, 2008), this parameter has been considered as the most important factor in landslide susceptibility mapping.

2.8.2 Slope

The slope is one of the main factors in the slope stability analysis. As most of life is concentrated along hills, Instability of The slope angle indirectly affects earthquake risks; thus it is used in preparing Earthquake risk susceptibility maps (Lee et al., 2004a, Lee, 2005, Saha et al., 2002). The higher the slope, the greater the risk of Earthquake effect Due to the higher shears induced by gravity. Degradation in terrain with steep topography, especially at the top of hills and peaks, is greatly enhanced. According to recent studies on construction standards, a slope of 5 to 9 percent is suitable for urbanization, (Alizadeh, M et al: 2018).

2.8.3 Soil characterization

Seismic zonation of certain site is defined by Site amplification which referring response of the site between ground surface, bedrock, several factors; the composition of soil layers, S-wave velocities, soil densities, internal damping of the individual layers. Importance soil during earthquake vulnerability assessment properties on site amplification in soft soils has to be considered (Finn, 1991). Soil as influencing factor is related to, a ratio of S-wave velocity between the base layer and surface soil. Shima (1978) found that the analytically calculated site amplification is almost linearly related to the ratio of S-wave velocity of the surface top layer to that of base layer despite the difference in intermediate soil layers. Soil characteristic, strength and water holding Capacity play an important role in occurrence of landslide induced earthquake. In contrast, soft soil always amplifies shear waves. If an earthquake is strong enough and close enough to cause damage, the damage will usually be more severe on soft soils. Seismic waves travel faster through hard rocks than through softer rocks and sediments. Study of Soil as earthquake input factor play a major role in hazard map production. Variations in the seismic data are attributed to the changes in soil- moisture content of the unconsolidated material.
Classifications based on type of soil, rock and shear wave velocity of an area.

Table 2.1 site classification

Class type	characteristic
A	Hard rock (igneous rock)
B	Rock(volcanic)
C	Very dense soil and soft rock(sandstone)
D	Stiff soil(mud)
E	Soft soil(artificial fill)
F	Soil

Accessed from (https://www1.wsrb.com/)

2.8.4 Fault structures

Most of studies on geological structures such as: joints, faults and fractures are the main cause for earthquake development. The release of energy during fault breakage facilitate for generation of earthquake. faults are one of the objective forms of tectonic factors whose presence or absence can be examined in relation to the seismic hazard of diff erent areas. Other characteristics like the fault's orientation, irregularities in the rupturing fault surface, and dispersion of waves as they hit subsurface structures can create spots of significant damage, and those hot spots are unique to each earthquake. Fault distance plays a key role in resilience to earthquake hazards, as proximity to it causes high seismic risk and damage, and distance from it will reduce the risk and consequently higher resilience **(**Alizadeh, M et al: 2018**).**

According to (Gioncu, 2011), factors which influence the characteristics of the seismic waves are: type of fault depth, rupture surface, amount of fault slip, age of faulting, length of fault rupture. As a result of the rupture, the forces are transmitted in all directions, but mainly they are propagated along the direction of the rupture plan, forming predominant transmission directions. (Mortezaei, 2013) states that: "Ground motion in the near-field of a rupture fault can contain a large energy, pulse very different from far-fault earthquake and cyclic loading. Structures designed to withstand the latter will respond with higher deflection but remain ductile and absorb lower earthquake forces generally" (Gouin, 1970), also stated that the closeness of Ethiopia's major cities like; Addis Ababa, Adama, Dire dawa and Hawasa to main fault belts such as Wonji fault, Adama fault, Addis-Ambo-Ghedo fault, and Fil Woha fault lines, make them susceptible to earthquake effects. Gouin described that the quakes of 1906 with magnitude of 6.75 and estimated epicentral location of 100Km south of Addis Ababa have shocked the city and caused bells of church**.**

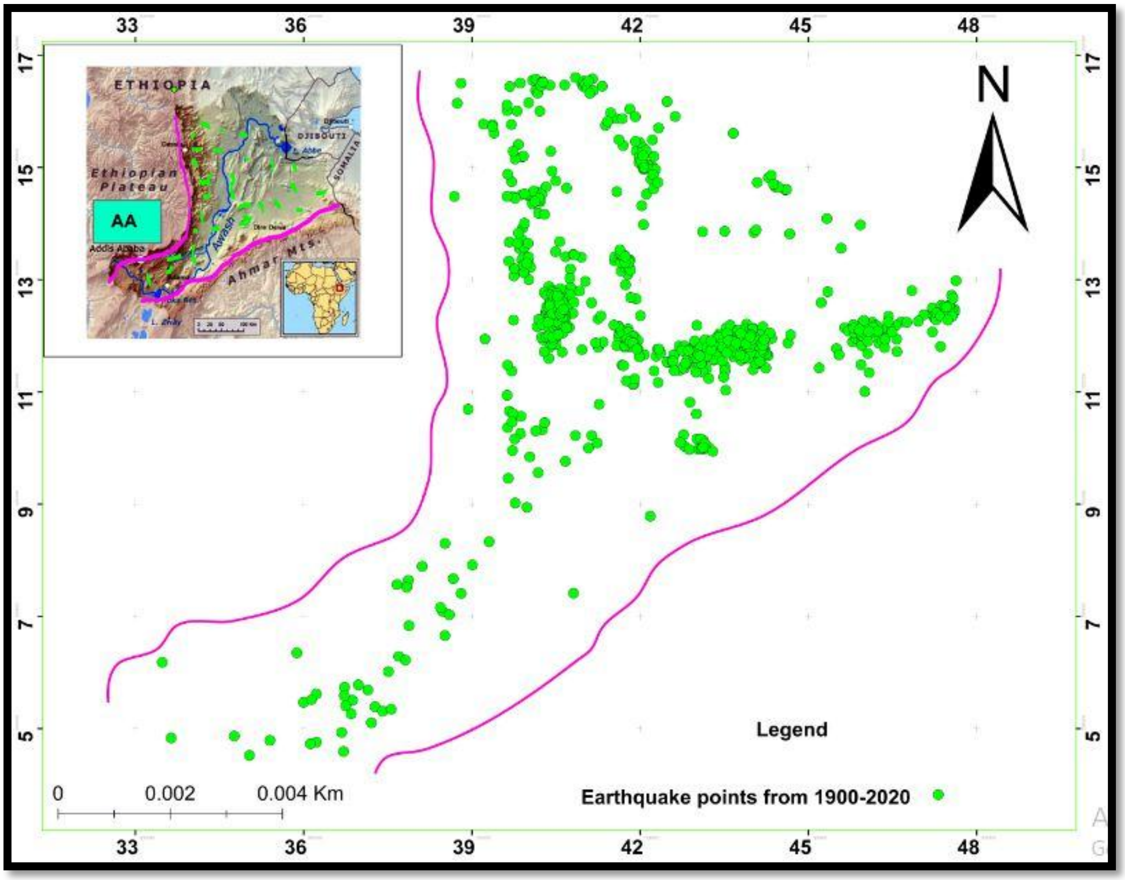


Fig: 2.7 Addis Ababa cities with respect to Great Ethiopian rift valley

Addis Ababa has witnessed a number of earthquakes in 100 years of its existence, some are: the 1906 an earthquake of magnitude 6.8 at epicentral distance of about 100 km south of Addis, the 1961 an earthquake of magnitude 6.6 occurred at a distance of 200km (Karakore Earthquake), the July 1997 an earthquake with magnitude 4.0 at a distance of 22 km to the south west of the city. Some other earthquakes of smaller magnitude and at far distance (in 1977, 1984 and 1985) were felt at upper story of high rise buildings (Asfaw, 1995). The active Great Rift Valley makes Ethiopia susceptible to two types of seismic hazard: earthquakes and volcanic eruptions. disaster databases shows that from 1900 to 2013 there were a total of 10 earthquakes and eruptions leading to a total of 93 deaths, 165 injured 420 homeless and affecting 11,000 people. These are estimated to have an economic cost of more than US$7 million (Sian Herbert, 2013).

The impact of natural hazards has increased due to increased population density in hazardous zones, often associated with poor human planning, and to the increase in the Frequency and intensity of extreme events as a consequence of climate change (Pachauri et al., 2007). Disaster is interpreted as a result of the combination of: the exposure of human life and structures to natural hazards, the conditions of vulnerability featured by the place and insufficient ability or measures to reduce or cope with the potential negative consequences (UNISDR, 2016). Addis Ababa is located close to Ethiopian Rift Valley within the seismic region of the country and has “moderate seismicity" (Haile et al, 2004). As the city is located closer to western edge of the Ethiopian Rift Valley and experienced moderate earthquake as indicated below by (Fig:2.8) is often affected by earthquakes.

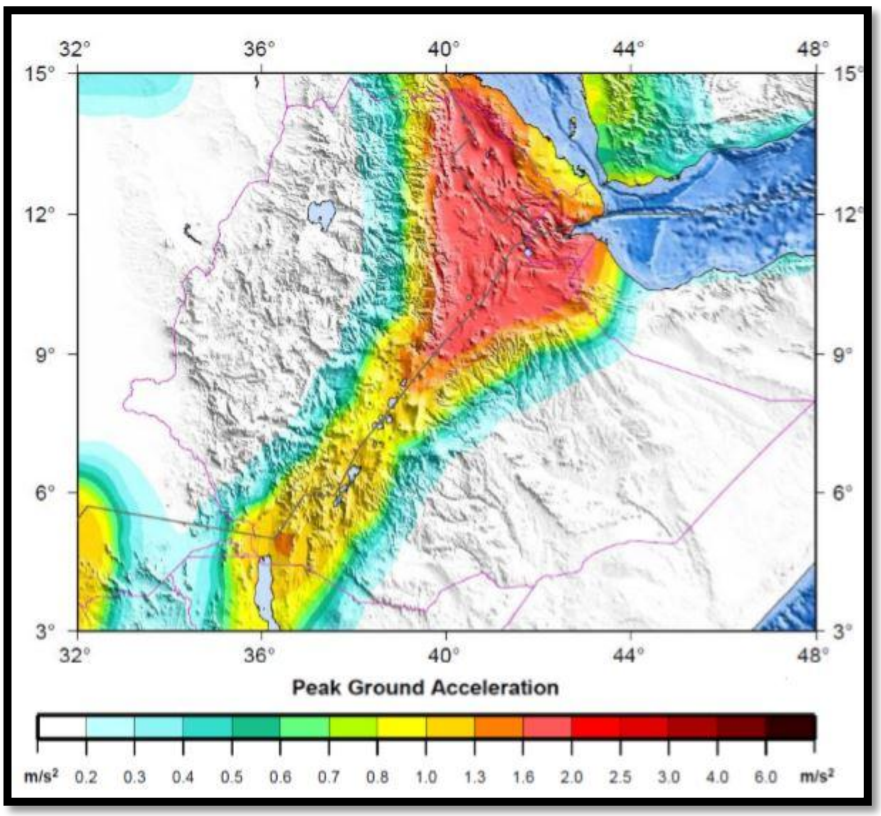


Fig: 2.8 Seismic zonation maps as per GSHAP. (After Sian Herbert.2013)

CHAPTER THREE

3.1 Materials and Methods

The preliminary data for a GIS technology and AHP method based earthquake effect vulnerability assessment for Addis Ababa was clearly based on collection of Earthquake input data such as: geology, soil strength, slope, proximity to fault, borehole depth, road networks, shear velocity at 30m and drainage density. The collected data came from different sources. Polygonal data, such as bedrock geology and surficial geology are digitized from maps to a raster format to retain their spatial accuracy. These data layers are geometrically corrected to a WGS84 datum for use of accurate map layers within a GIS. An attribute database was created for each GIS layer. Identifier numbers for each point, line, or polygon in the layer corresponds to a record in the database file. The completed GIS database will be utilized for spatial correlations such as the seismic hazard analysis. All selected factors are established, stored and managed in GIS software. After crossing the inventory earthquake vulnerability map and factor map, a cross-table was formed. In results, the 8 weight maps were formed from 8 factor maps. By combining (adding) 8 maps of weight values a weight map was created. As seismic vulnerability assessment incorporates different Earthquake input factors, AHP method and GIS technology is used to fill existing gap among factor preference. Also MCDM follows a collection of methods through which techniques and algorithms utilized to solve complex decision-making covering a wide range of choices and assessed by multiple, conflicting and incommensurable criteria as well as developing, assessing and prioritizing of decision-making alternatives can be used (Malczewski, 1999; Suárez-Vega et al., 2011).Purposely this study is to develop earthquake effect vulnerable areas in a built up environment such as Addis Ababa. The studies of Seismic vulnerability assessment have to consider all influential factors. Selection of influential factors can be done after revising earthquake effect related literatures and experiences of experts. Compiled data to develop final earthquake effect vulnerability map of the study area includes including geotechnical, structural, geological and physical distance needed facilities.

3.2 Data types and sources

Earthquake can have several causes which can be geological including (bed rock geology, lineament, morphology, hydrologic conditions) and anthropogenic activities (over construction of building, road network, bridges and urbanization. Seismic vulnerability assessment follows collection of data from remote sensing as primary data, raster and vector data from different organizations to enter them in GIS environment to produce meaningful information. The required data processing includes: Geo-referencing, digitizing, clipping, rasterizing and extraction of different features such as road networks and faults from the image. All layers will be rasterized and referenced, eventually classified into (very High, High, medium, low and very low).

Table: 3.1 data layer preparation

S. No	Data layer	Data type	Processing	Source
1	Geology	secondary	Digitizing	from AA Geological map
2	Lineaments	primary	Automatic extraction	From DEM of study area with cell size 30m
3	Bore hole depth	secondary	Interpolation	AA well construction
4	Stream density	primary	Buffering	From DEM
5	Slope	primary	Elevation deference	From DEM
6	Road networks	secondary	Line density	From AA Road Authority
7	Soil type	secondary	interpolation	AA well construction
8	Shear velocity 30m	primary	Elevation	From Global server

Topographic data

Earth Explorer offers SRTM data with a regularly spaced grid of elevation points in three file formatssuch as**:** Digital Terrain Elevation Data, Band interleaved by line and Georeferenced Tagged Image File Format. Each file or cell contains a matrix of vertical elevation values spaced at regular horizontal intervals measured in geographic latitude and longitude units in Digital Terrain Elevation Data. File size is approximately 25 MB for 1-arc-second data files and approximately 3 MB for 3-arc-second data files. Band interleaved is a binary raster format with an accompanying header file which describes the layout and formatting of the file. File size is approximately 7 MB for 1-arc-second data files and approximately 1 MB for 3- arc-second data files. Georeferenced Tagged Image File is a TIFF file with embedded geographic information.

Table: 3.2 Product Specifications of topographic data

Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Meters
Spatial Resolution	1 arc-second for global coverage (~30 meters) 3 arc-seconds for global coverage (~90 meters)
Raster Size	1 degree tiles
C-band Wavelength	5.6 cm

Source: Topographic Slope as a Proxy for Seismic Site-Conditions (Vs30) and Amplification around the Globe (USGS Vs30m map viewer)

3.3 Earthquake causative Factors

Earthquake effects depend on ground morphological attributes comprising of geology, geomorphology and geotechnical data**.** Local Site condition such as effect of soil is main earthquake input factor which have to be considered as the subsurface site effect is manifested on the surface by shaking, slipping and destruction of complex structures**.** Earthquake Risk in built up area comprises of different input factors .in risk vulnerability assessment of urban areas, two important cases should be noticed. The first one is location and exposure to hazard and the second one is identification of vulnerable elements due to poor construction practices and related human behavior such as: land degradation and deep excavation.

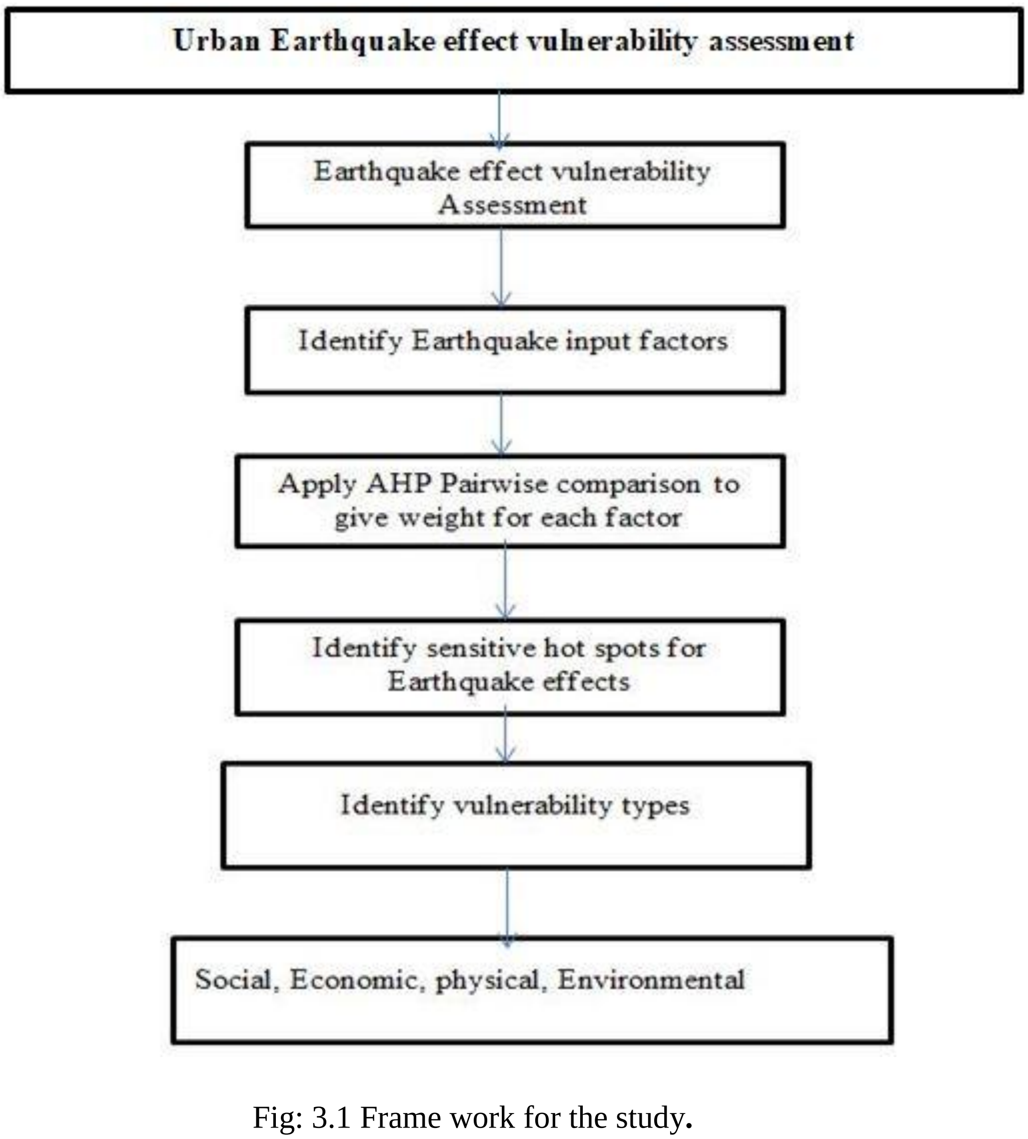


Fig: 3.1 Frame work for the study**.**

3.4 Schematic representation of the method

Seismic vulnerability assessment follows collection of data from remote sensing as primary data, raster and vector data from different organizations to enter them in GIS environment to produce meaningful information

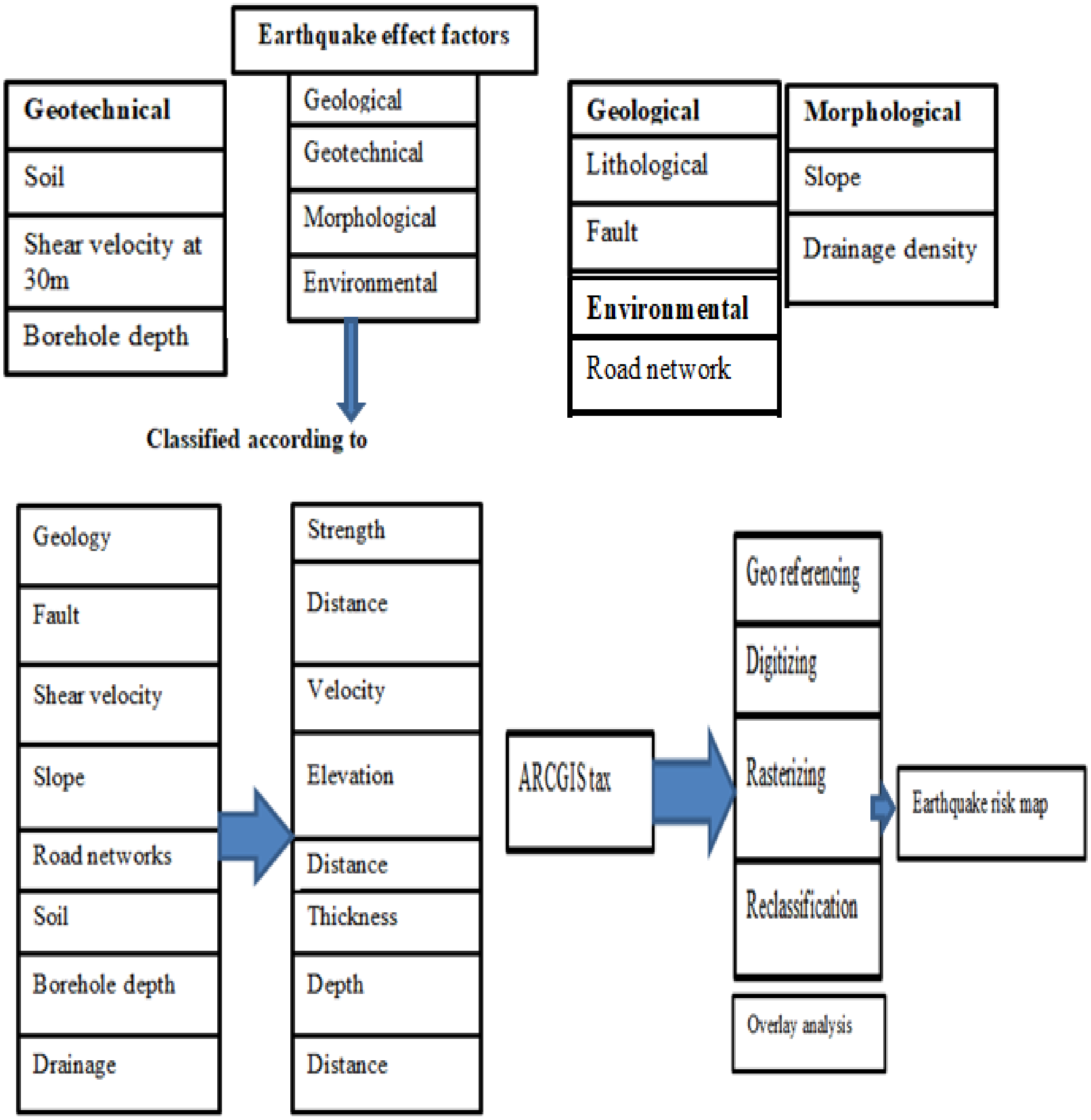


Fig: 3.2 Schematic representation of methodology.

3.5 Analytical Hierarchy process

Recently, complex decisions are analyzed by Analytical Hierarchy Process (AHP) (Saaty, 1990) based on quantifiable and tangible criteria is the. The method creates a hierarchy for the selected criteria and enables pair wise comparison to assign weight and consistency ratio to each element (Saaty 1988, Saaty 2008, Estoque 2012). AHP has been used successfully to develop seismic effect potential map in different parts of the world (Malczewski 1999, Mohanty and Walling 2008, Pal et al. 2008, Bathrellos et al. 2009, Erden and Karaman 2012, He et al. 2014, Karimzadeh et al. 2014, Panahi et al. 2014, Quadrio et al. 2015). One of the widely adopted techniques for weighing the criteria is the Analytic Hierarchy Process (AHP) developed by (Saaty, 1980). AHP breaks the problem into smaller simpler decisions and then asks respondents to rank them using pair wise comparisons, giving an organizational tool to criticize the larger problem. AHP assists the decision-making process by allowing decision-makers to organize the alternative solutions to a specific problem in a Hierarchical decision model (Erden and Karaman, 2012). AHP calculates the required weights, assigning a weight to each criterion against each of the other criteria. The higher the weight of a criterion, the more important it is in the decision Analytic Hierarchy process (AHP) model, one of multi criteria decision making method that was originally developed by Prof. Thomas L. Saaty, is used.

Table: 3.3 the fundamental scale (Saaty, 1980)

Scale	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Moderate importance	One factor is strongly favored over another
5	Essential or strong importance	One factor is strongly favored over another
7	Very strong importance	The dominance of one factor is practically demonstrated and strongly favored
9	Extreme importance	The evidence of favoring one factor is highest
2,4,6,8	Intermediate importance	When compromise is needed

Note: If factor A is assigned one of the numbers above (1-9) and to be compared to B, factor B will be assigned the reciprocal value of A (i.e. 1 / (value for A)

AHP is one of the most well-known and popular algorithms used for compiling different parameters during decision making as it follows formulizing hierarchy in complex problems**.** According to (Chen et al., 2008), AHP method is accepted in worldwide as there is the possibility of considering different quality and quantity criteria simultaneously. In Earthquake effect vulnerability assessment, different input factors are combined together and studied simultaneously by using multi-criteria decision-making (MCDM) techniques which can be used to fill existing gaps. MCDM follows a collection of methods through which techniques and algorithms utilized to solve complex decision-making covering a wide range of choices and assessed by multiple, conflicting and incommensurable criteria as well as developing, assessing and prioritizing of decision-making alternatives can be used (Malczewski, 1999; Suárez-Vega et al., 2011). AHP method assigns weight for the criteria and quantified for zoning. The method was common and accepted for seismic effect potential zonation. The assigned weight of factors is computed by ARCGIS based calculations. The complied input data layers were selected based on the nature of geomorphology, geology and seismology. ArcGIS software with extension 10.4.1 (ESRI, 2014) was used for calculating and analyzing the spatial data (Childs 2004, McCoy 2004). Eventually, weighted overlay analysis was computed on arc toolbox extension of ArcGIS software to develop seismic potential zone of the study area (Wilson, 2014).

3.6 Approaches in seismic vulnerability assessment:

3.6.1. Definition of objectives

The main objective of current study is to develop earthquake effect susceptible areas in case of Addis Ababa city. In meantime this study also addresses specific objectives such as:

- Outlining the main approaches used for earthquake effect Vulnerability assessment for cities.
- Understanding the types of earthquake effect vulnerable themes.
- Identification of causative factors in earthquake effect assessment.
- Proposing a link between of the causative factors and severity of seismic effect

3.6.2. Selection of earthquake triggering factors

Purposely this study is to develop earthquake effect vulnerable areas in a built up environment such as Addis Ababa. The studies of Seismic vulnerability assessment have to consider all influential factors. Selection of influential factors can be done after revising earthquake effect related literatures and experiences of three experts. Compiled data to develop final earthquake effect vulnerability map of the study area includes including geotechnical, structural, geological and physical distance needed facilities. Earthquake can have several causes which can be geological including (bed rock geology, lineament, morphology, hydrologic conditions) and anthropogenic activities (over construction of building, road network, bridges and urbanization. All selected earthquake input factors play their own role during ground shaking. Effect earthquake to human life and structure is a function of these causative factors. Most of areas probably affected since occurrence of earthquake is areas with faulty structures, massive lithological layers, highly dense drainage patterns, complex roads, high slope areas, dense and complex faults, soft and thick soils and highest values of Vs30m.

Table: 3.4 List of selected earthquake input factors

S.no	Input factors	Remark
1	Litho logical layers	Geological
2	Fault structures	Geo-structural
3	Soil thickness	Geotechnical
4	Drainage density	Hydrogeological
5	Shear velocity at 30m	Geotechnical
6	Road networks	Physical-structural
7	Slope	Geomorphologic
8	Borehole depth	Geotechnical

3.6.3. Data transformation into GIS environment.

The complied input data layers were selected based on the nature of geomorphology, geology and seismology. ArcGIS software with extension 10.4.1 (ESRI, 2014) was used for calculating and analyzing the spatial data (Childs 2004, McCoy 2004). Eventually, weighted overlay analysis was computed on arc toolbox extension of ArcGIS software to develop seismic potential zone of the study area (Wilson, 2014). As all selected spatial data are characterized by different format, data transformation should be processed to bring them together. Each of the criteria is brought to datum of WGS1984 to attain same geographic position system. If the extent of selected data is more than the study area, one of the reprocessing tools such as: clipping and extractions are used. All forms of data in shape files such as points, lines and polygons are converted into raster formats. All rasterized pixel values are reclassified according to natural breaks classification system. Earthquake effect Vulnerability assessment of the study area is classification of each rasterized factor layer into five classes. Accordingly, the area classified as Very low, low, medium, high and very high referring regions of minimum pixel values to regions of maximum pixel values respectively. But the classification was based on sensitivity of the criteria in amplifying the effect of earthquake. As a Pixel in each data layer represents the smallest and building block of an image, the maximum number of pixels in each factor layer represent sensitive areas in future earthquake.

Table: 3.5 data transformation

S.No	Data layers	Data category	Base of classification	Final input data
1	Geology	Geological	Rock mass strength	Geological map
2	Fault	Structural	Fault density	Fault density map
3	Shear velocity	Geotechnical	Shear velocity value	Shear velocity map
4	Road	Physical	Road density	Road density map
5	Borehole	Geotechnical	Depth	Borehole depth map
6	Slope	Geomorphological	Elevation values	Elevation map
7	Drainage	Hydrogeological	Density	Drainage density map
8	Soil	Geotechnical	Thickness	Soil thickness map

3.6.4. Applying Analytical Hierarchy Process

Analytical Hierarchy Process is the most effective method in compiling different criteria that has different degree in multicriteria decision making. In this study, earthquake effect potential identification is the main objective to be addressed. Accordingly, all layers are compared to them themselves and each other. If one criterion is compared with its self, the value is 1.

In Table (3.6), each factor is compared to another and assigned a judgment value.

Table: 3.6 Assignment of importance value for each layer

Criteria	Geology	Fault	Soil	Road	Shear v30m	Bore hole	Drainage	Slope
Geology	1	3	2	3	2	3	2	2
Fault	1/3	1	2	3	3	2	2	3
Soil	1/2	1/2	1	3	2	3	2	3
Road	1/3	1/3	1/3	1	2	3	2	5
Shear v30m	1/2	1/3	1/2	1/2	1	2	3	3
Bore hole	1/3	1/2	1/3	1/3	1/2	1	2	3
Drainage	1/2	1/2	1/2	1/2	1/3	1/2	1	2
Slope	1/2	1/3	1/3	1/5	1/3	1/3	1/2	1

Table: 3.7 Analytical Hierarchy Process based ranking of each factors

Criteria	Geology	Fault	Soil	Road	Shear v30m	Bore hole	Drainage	Slope	
Geology	1	3	2	3	2	2	2	2	**2.03**
Fault	0.33	1	2	3	3	2	2	3	**1.72**
Soil	0.5	0.5	1	3	2	3	2	3	**1.50**
Road	0.33	0.33	0.33	1	2	3	2	2	**0.98**
Shear v30m	0.5	0.33	0.5	0.5	1	2	3	3	**0.96**
Bore hole	0.5	0.5	0.33	0.33	0.5	1	2	3	**0.73**
Drainage	0.5	0.5	0.5	0.5	0.33	0.5	1	2	**0.58**
Slope	0.5	0.33	0.33	0.5	0.33	0.33	0.5	1	**0.42**
Total sum									**8.9**

Table: 3.8 Analytical Hierarchy Process based on Matrix generation

Criteria	A1	A2	Consistency check A3=A1*A2	A4=A3/A2
Geology	2.03	2.03/8.9=0.228	0.44	=2
Fault	1.72	1.72/8.9=0.193	0.32	=1.68
Soil	1.5	1.5/8.9=0.168	0.24	=1.5
Road	0.98	0.98/8.9=0.11	0.10	=0.9
Shear Velocity	0.96	0.96/8.9=0.107	0.09	=0.89
Bore hole	0.73	0.73/8.9=0.082	0.05	=0.62
Drainage	0.58	0.58/8.9=0.065	0.03	=0.5
Slope	0.42	0.42/8.9=0.047	0.01	=0.25
				= **Ʌma**x=8.34

Measurement of inconsistency will be calculated based on the following formula. To define the deviation or degree of consistency, a consistency index (CI) can be computed as (Saaty 1988, Saaty 1990):

Consistency index=λmax-n/n-1……………………….2

A high Consistency index value indicates a matrix of low consistency. To determine the satisfactory consistency level of a matrix, the consistency ratio (CR) is normally computed as (Saaty 1988, Saaty 1990):

CR=CI/RI………………………………………….3

8.34-8/8-1=0.339/7=0.048

0.048/1.4=0.034<0.1

Random inconsistency indices (RI) for n=1, 2... 12 (Saaty, 1980, 2000).

Table: 3.9 standard RI values

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Combining the raster factors and constraints datasets

Now that the weighting allocations have been calculated in Table (), the factors and constraint data sets can be aggregated by multiplying each factor by its associated weighting.

The formula to perform the Weighted Linear Combination is as follows:

S = Σwixi x Πcj

Where: S – is the composite suitability score

Xi – factor scores (cells)

wi – weights assigned to each factors

cj – constraints

Σ -- Sum of weighted factors

Π -- Product of constraints

The final results of AHP include the weight of each criterion and an inconsistency measure indicating whether the judgments are consistent to be 0.034. The maximum acceptable level of inconsistency measure is 0.1; if consistency ratio (CR) exceeds 0.1, the preferences assignment needs should be revised. In this study, AHP is used to weigh the selected criteria and the inconsistency score is computed for the criteria weights obtained through the AHP approach. The algorithm of weighted linear combination follows summation of each index layers multiplied by their weights.

Each criterion has equal importance when compared to its self. If one of the criteria is compared with another criteria, the value is assigned values from 1-9 by the researcher based on the importance of the criteria to the objective. For example: if criteria A is to be compared to criteria B and assigned 3, the value of B should be inverse of A which is 1/3. All factors are filled accordingly and weight can be generated by calculating the given values. All criteria are assigned individual weights based on importance of the criteria on the vulnerability assessment.

3.7 Earthquake causative factors and Attenuation relation

Earthquakes are among the most and well known geohazard types that are resulted from complex geological process such as: volcanism, structural geology, tectonics and deformation of rocks and partly man-made Earthquake triggering factors. Most of recent study reveals that any study on environmental effect of earthquake should consider the relationship between the selected criteria and severity of the earthquake around the sensitive area. Attenuation is a term used in seismicity to refer the effect of subsurface material on propagating wave energy. Accordingly, all selected layers have certain region in which wave energy is either amplified or attenuated. The main Earthquake input factors that have directly or indirectly strongest influence on the impact of earthquakes on certain region includes: Slope, Lineaments, Bore hole depth, Shear velocity at 30m, Geology, Road networks, Stream density, Soil thickness (Ateş, A, et al, 2019).

Causes of Earthquake can have several factors. It can be geological including (bed rock geology, lineament, morphology, hydrologic conditions) and anthropogenic activities (over construction of building, road network, bridges and urbanization). . In addition to these geologic processes that activate Earthquake effects, there are also man-made Causative factors such as: construction of buildings without following seismic code, deep excavations, unpracticed land use, rapid urbanization, over population and complex infrastructures. The prime criteria selected as inputs into the AHP and GIS models, based on the attenuation relation. Eight parameters, which were obtained for developing earthquake susceptibility map. Even though earthquake related studies are complex and difficult to analyze, selection of prime input factors are basis in vulnerability assessment. Any geohazard assessment including earthquake should consider other factors that related to topography, source from site distance, soil classification, and liquefaction potential. These criteria are crucial for modeling the earthquake hazard effects in a investigated region, as the effect of the topography magnifies the seismic energy with regard to the height and slope angle; the earthquake results reduce with improving distance from the source.

3.7.1 Geology

Geology of the study area was considered as important criteria for seismic ground motion depiction at a site of interest (Power et al. 2004). Most slope failures are shallow, involving deposits near the surface; particular attention must be given to the geology of an area. At present, geological and faults density are by far the most commonly used information sources for earthquake analysis in Addis Ababa. Seismic waves travel faster through hard rocks than through softer rocks and sediments. The softer the rock or soil under a site is, the larger the wave. Softer soils amplify ground motion. Rock mass strength of lithological layers of the study area is provided below.

Rock mass strength classification of the study area

Furthermore, the Geological Survey classifies rocks of the region into engineering geological rock units based on rock mass strength evaluated from field observation, field tests and laboratory tests (Tsehayu and Mariam, 1990).

Rocks with very high mass strength: Includes basalts situated mainly in the central part and outcrops (porphyritic olivine, porphyritic feldspar and aphanitic) in the south-eastern part of the city.

Rocks with high mass strength: This unit consists of trachybasalts, trachyte, rhyolite and more jointed basalts. Young trachyte in south-west and southern part and rhyolite and trachyte of Entoto silicic outcropping in the northeast of the city are rocks with high mass strength.

Rocks with medium mass strength: Includes the widely spread ignimbrite throughout the city (outcropping mainly in southern and eastern part) and some narrowly spaced jointed rocks of rhyolite and trachyte.

Rocks with low mass strength: Tuff and agglomerate and tuff which are available in the north-west, north-east and south-eastern part and all highly weathered jointed rocks have low mass strength. They are highly weathered and changed into soils in places they outcrop. Seismic waves travel faster through hard rocks than through softer rocks and sediments. The softer the rock or soil under a site is, the larger the wave. Softer soils amplify ground motion.

Note - Seismic waves travel faster through hard rocks than through softer rocks and sediments.

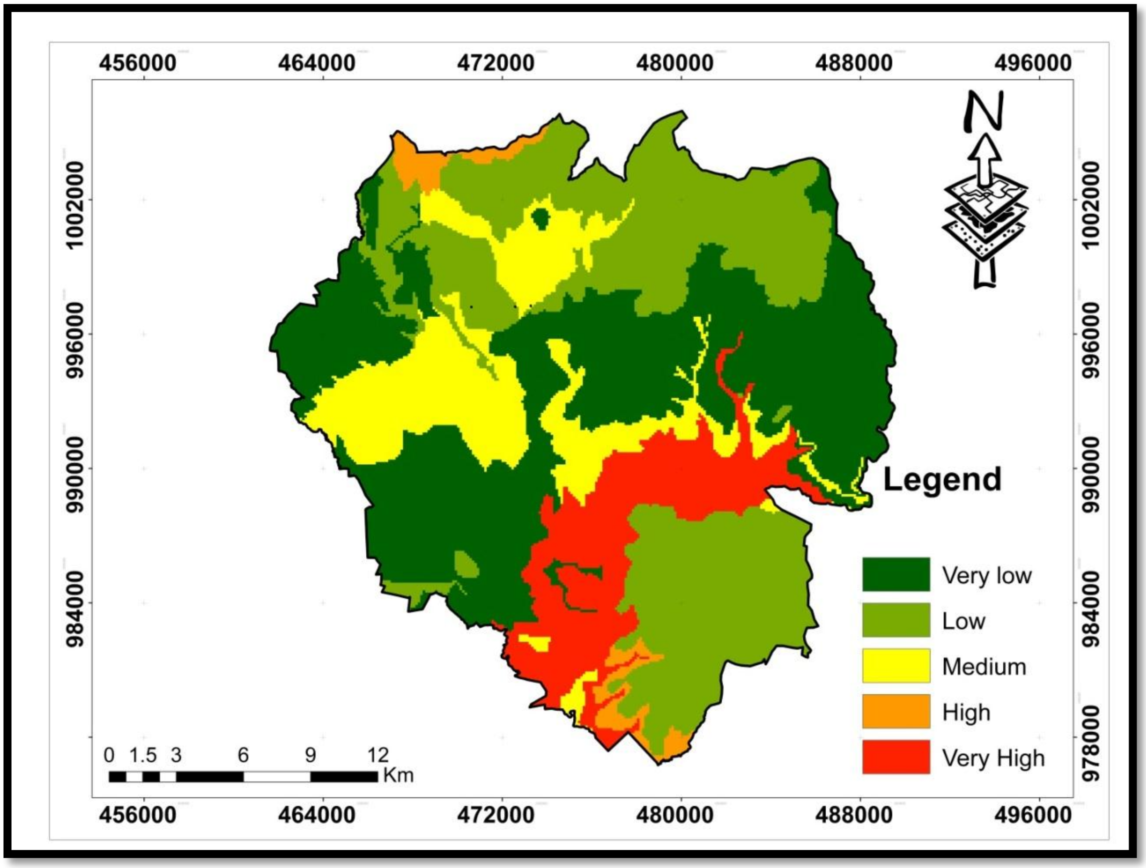


Fig: 4 .1 Earthquake effect susceptibility of Geology

Table: 4.1 Seismic effects of Litho logical classes

S.no	Major Litho logical layers	Rock mass strength	Seismic response	Degree of Vulnerability
1	Basalts	Very High	Very low	Very low
2	Trachyte, Rhyolite	High	Low	Low
3	Ignimbrite	Medium	Medium	Medium
4	Tuff and agglomerate	Very low	High	High
5	Scoria cones	Low	Very High	Very High

3.7.2 Fault

Lineaments are the linear morph-tectonic features of the terrain which include faults, fractures, ridges, major discontinuities. In this work, lineaments were interpreted from Geological map**.** Especially, neo tectonics contributes to slope instability by fracturing, faulting, jointing and deforming foliation structures. The close relationship between tectonically active zones and earthquake points in the central part of Main Ethiopian rift was discussed in a previous work. Hence, fault density is taken into account as a causative factor for earthquake in the research area.

S.no	Fault line density in (km^2)	Degree of vulnerability
1	0 - 0.078	Very low
2	0.078 - 0.156	Low
3	0.156 - 0.234	Medium
4	0.234 - 0.313	High
5	0.313 - 0.391	Very High

Existing earthquake map identifies the definite and probable areas of existing earthquake, and is the most basic requirement for an earthquake risk vulnerability assessment. The product of an existing earthquake map is a spatial distribution of earthquake as points. Earthquake inventory maps can be and often are used as a basis for other earthquake hazard zonation techniques or for an elementary form of a hazard map. A typical earthquake inventory map is based on aerial photograph interpretation, ground survey or a database of historical movements within the area. These maps, however, only provide information for a short period of time, and they provide no insight into temporal changes in earthquake distribution.

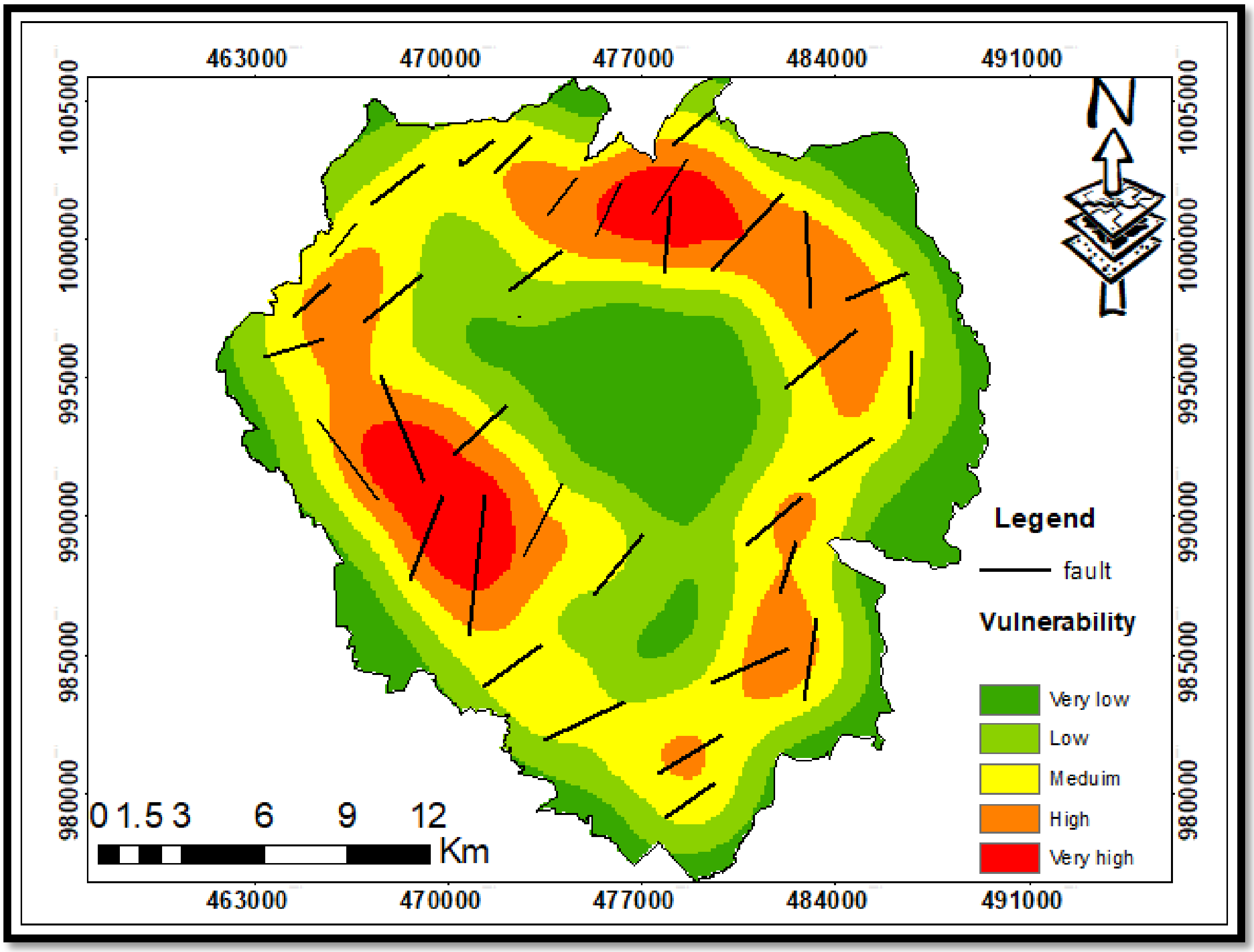


Fig: 4.2 Earthquake effect susceptibility of Fault structures

3.7.3 Shear velocity at 30m/s

An alternative method has recently been proposed for evaluating global seismic site conditions, or the average shear velocity to 30 m depth (VS30), from the Shuttle Radar Topography Mission. The extracted shear wave velocity distribution down to a depth of 30 m of Addis Ababa city. Seismic amplification shaking levels at a site may be increased, or amplified, by focusing of seismic energy caused by the geometry of the sediment velocity structure, such as basin subsurface topography, or by surface topography. Seismic waves travel faster through hard rocks than through softer rocks and sediments. As the waves pass from deeper harder to shallow softer rocks they slow down and get bigger in amplitude as the energy piles up.

The Vs30 distribution of the study area has direct impact in seismicity. Shear velocity is an indication of effect of sub surface material during earthquake occurrence. Shear velocity of the study area was extracted global server which is a global available on SRTM and globally accepted being a source of shear velocity at 30m/s for all regions on the world. In overlaying critical structures of the city on shear velocity of the study area, high and medium shear wave values correspond to the hill zone and transition zone while lower ones correspond to the basin. Hilly Land regions are characterized by unstable slope and landslide induced earthquake. Classification of the study area based on shear velocity will enable to identify vulnerable land regions.

The softer the rock or soil under a site is, the larger the wave. Softer soils amplify ground motion. The second primary earthquake hazard, ground shaking, is the result of rapid ground acceleration. Ground shaking can vary over an area as a result of factors such as topography, bedrock type and the location and orientation of the fault rupture. These all affect the way the seismic waves travel through the ground. Shear velocity at 30m of the study area was extracted from global server as scientifically accepted by Bulletin of Geological society of America.

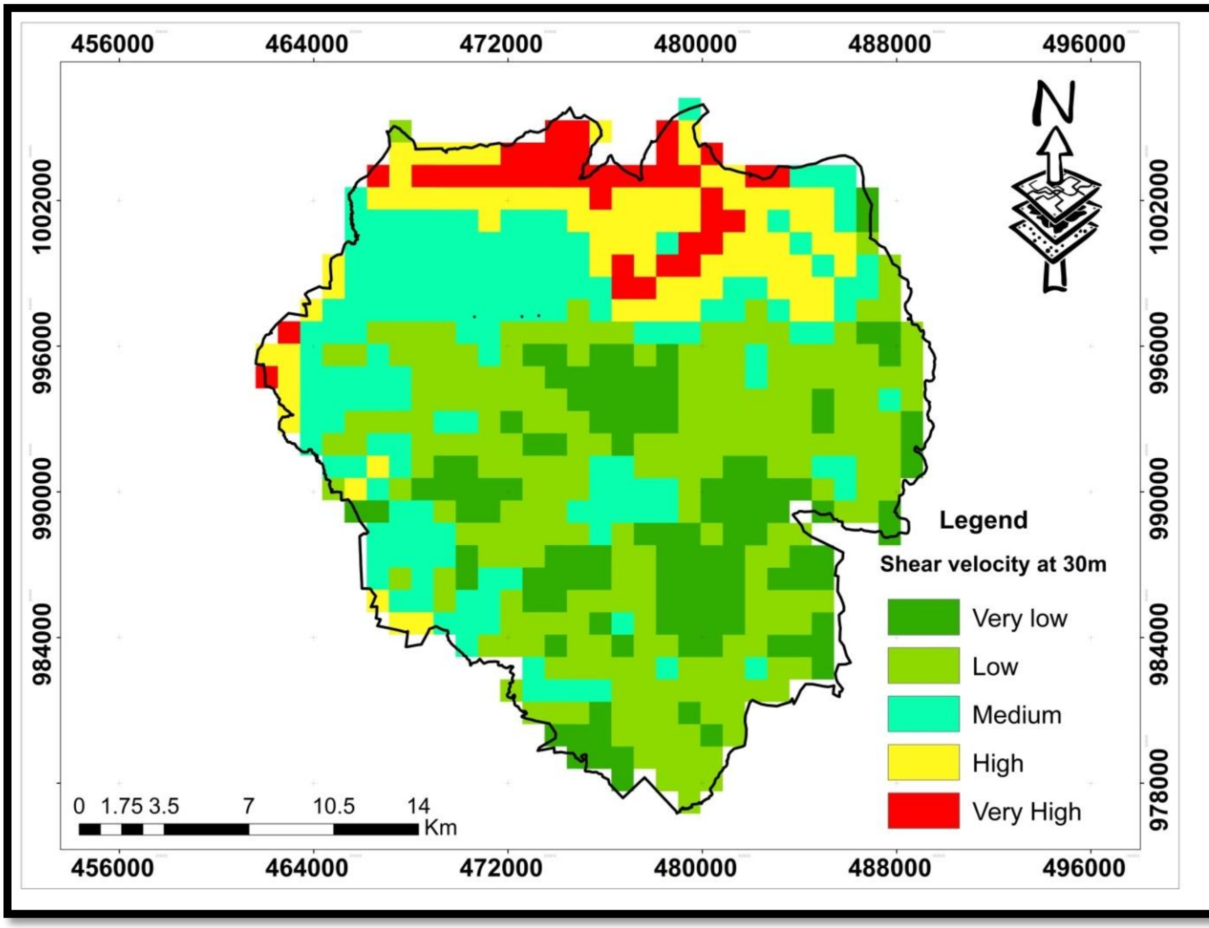


Fig: 4.3 Earthquake effect susceptibility Shear velocities at 30m/s

Shear velocity at 30m in (m/s-2)	Seismic effect vulnerability
211 - 355	Very low
355- 431	Low
431- 518	Medium
518- 632	High
632- 824	Very High

Table: 4.3 Earthquake effect susceptibility of Shear velocities at 30m/s

3.7.4 Drainage density factor

Drainage density is defined as the ratio of sum of the drainage lengths in the cell and the area of the corresponding cell. Seismic effect is amplified more a long course of rivers due to faults termination with respect to drainages. The under-cutting action of the river may induce instability of slopes. Hence, some of the major drainage segments were digitized to include the effect of this causative factor. Most of drainage patterns are controlled by fault orientations that are following weak zones of subsurface materials.

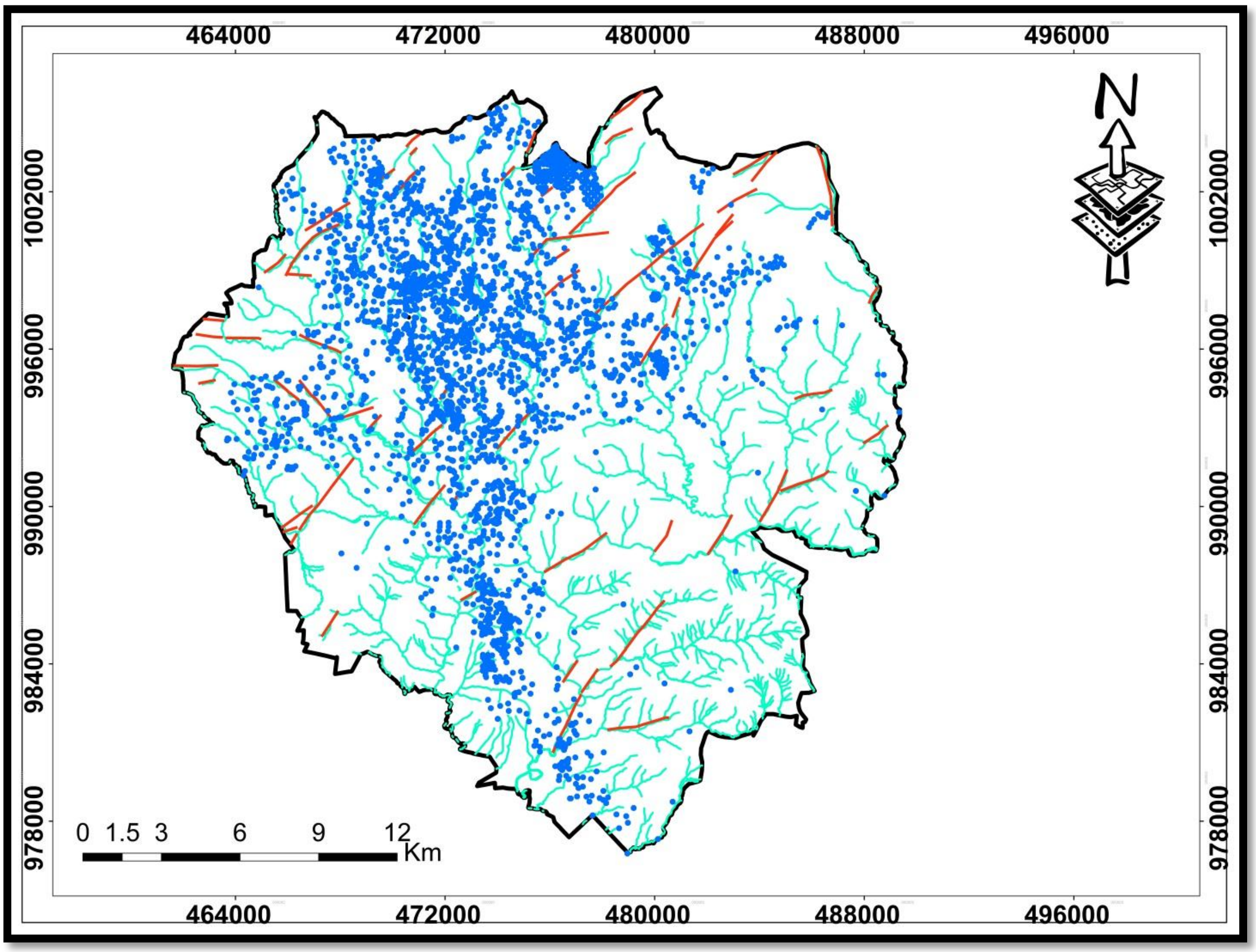


Fig 4.4 Drainage patterns with fault systems

Table: (4.4). Earthquake effect susceptible Drainage classes

Drainage density in (km^2)	Seismic vulnerability
0 - 0.505	Very low
0.505 - 1.011	Low
1.011 - 1.516	Medium
1.516- 2.022	High
2.022 - 2.52	Very High

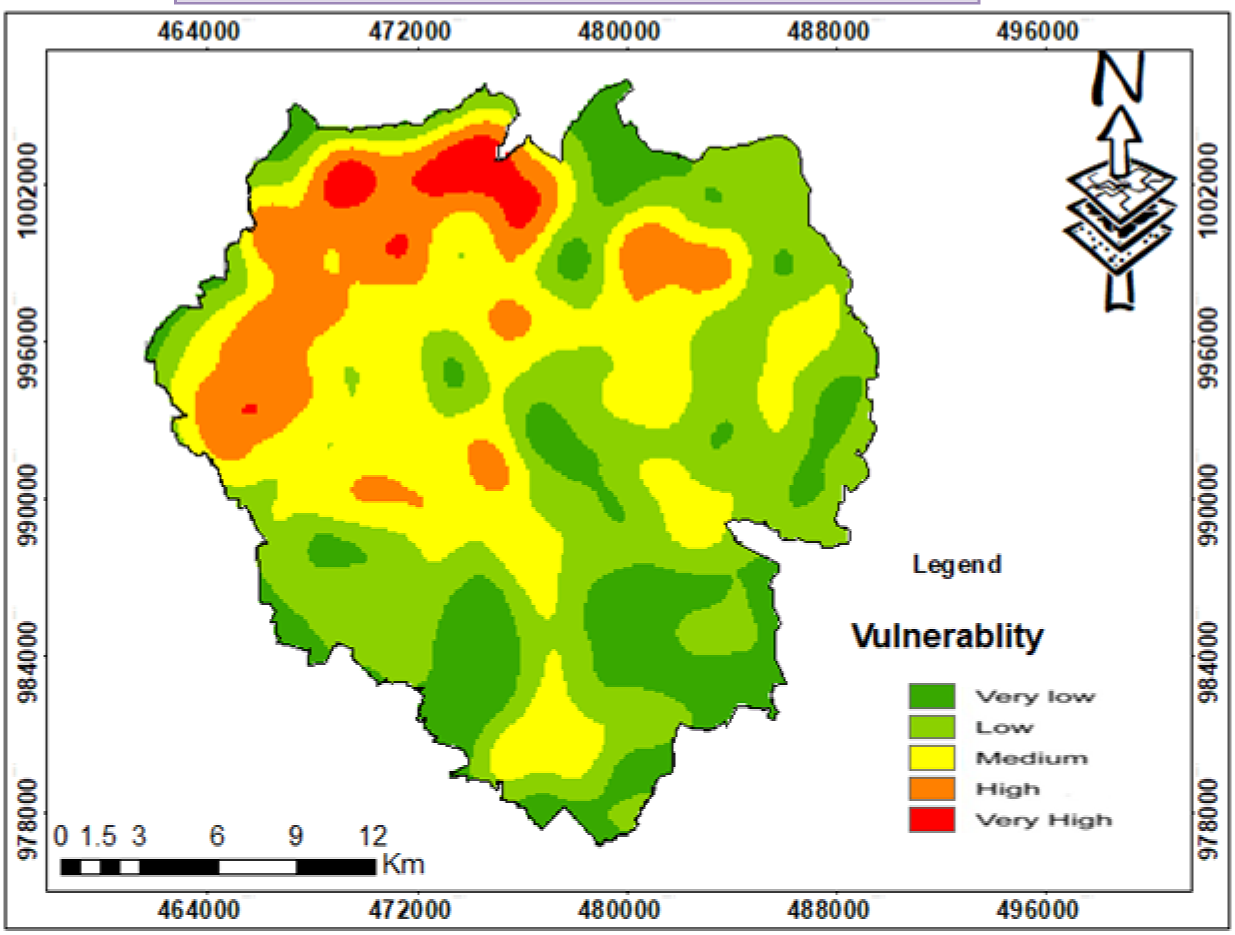


Fig: 4.5. Earthquake effect susceptibility of drainage density

3.7.5 Road networks

It is known that effect of earthquake to build up environment is sever where Roads, bridges and electric utilities exist. Particularly exist and substandard ones are particularly vulnerable to strong ground motions being the weakest components of a road network. Structural and foundation damages in bridges lead to a significant loss related to both repair and a prolonged traffic disruption, which in turn results in large indirect loss in the affected area. Previous Damage from earthquakes has shown that roads, bridges and electric utilities particularly exist and substandard ones are particularly vulnerable to strong ground motions being the weakest components of a road network. Along these lines, the estimation of the overall loss related to earthquake-induced damage in highway bridges and overpasses must be based on a wider network analysis rather than on a single structural assessment (Kilanitis et al, 2019). Most of the roads are constructed by cutting the slope of the mountains and located near the river side. The expansion of roads is increasing year by year. Which has increased the susceptibility of slope failures and often responsible for the slide of soil or debris in the city.

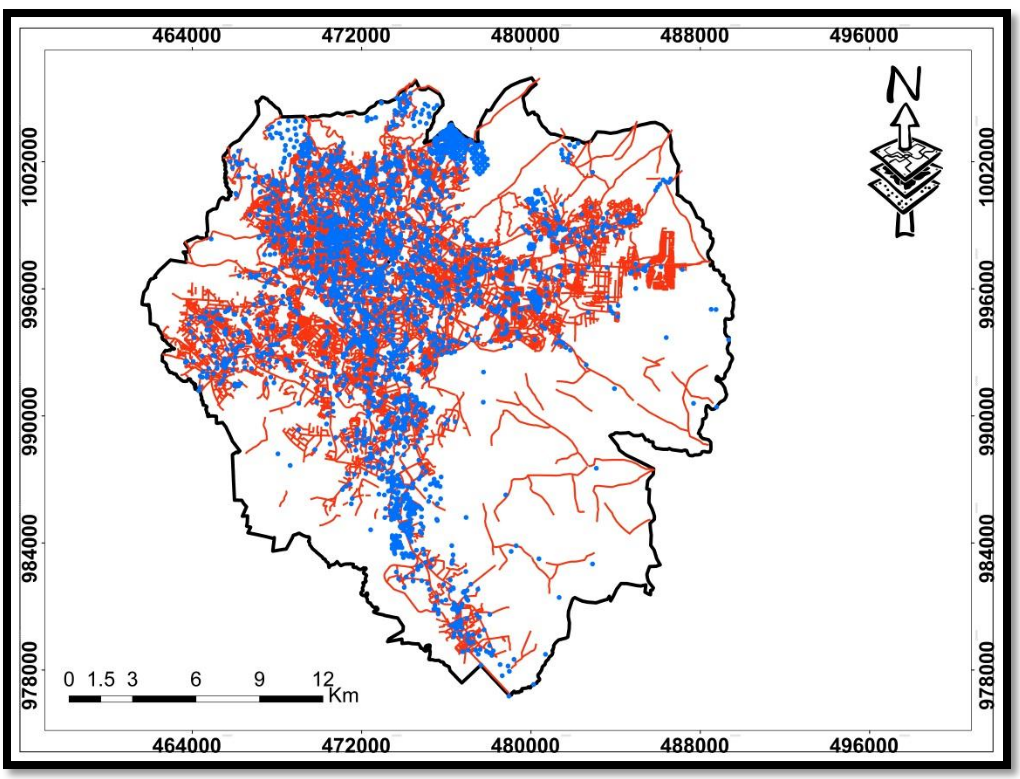


Fig: 4.5 critical structures with respect to road networks

Table: 4.5 Earthquake effect susceptible road classes

Road networks density in (m)	Value	Seismic effect vulnerability
0 - 291	1	Very low
291- 583	2	Low
583 - 875	3	Medium
875- 1,167	4	High
1,167- 1,458	5	Very High

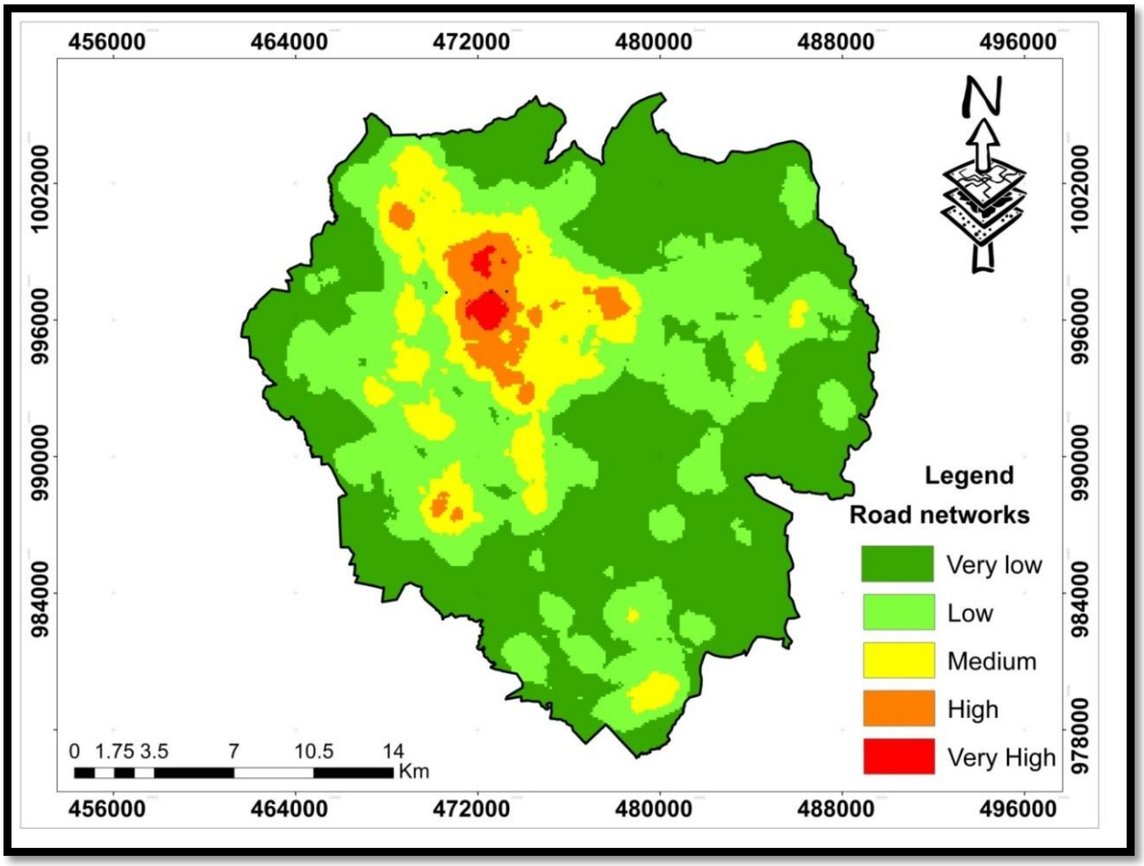


Fig: 4.5 Road networks vulnerability

3.7.6 Ground water borehole depth

As depth increases downward, the weight of overlaying rocks increases formation of faulting structures are distributing through the borehole points. Earthquake has significant impact on unstable environment which was developed due to quarrying, borehole development, mining activities and construction activities. as bore hole is logged, and the underlying rock or lithology is being unstable and get collapsed. When Earthquake has occurred on such unstable environment, the risk will be more than expected. As depths of ground water bore hole increases, faulting, fracturing and joints also facilitate the way of seismicity .the life lines found near the vulnerable zone will be damaged due to the risk. Over logging and subsurface mining will increase the weak zones in the form of faults and subsidence.

Groundwater-level responses to earthquakes have been investigated for decades, and have been documented close to and far from earthquake epicenters. The most common groundwater-level response is a water-level oscillation. These step changes can be large enough to make a well flow at land surface, or to cause a well to go dry near an earthquake. Typically, however, the water-level changes are several feet or less. Recovery to the pre-earthquake water level can be nearly instantaneous, or it may take as long as days or months, or may not recover at all. Step changes in groundwater levels occur 'near field' of an earthquake because the earthquake subjects the earth's crust, including its aquifer systems, to stress and permanent strain (deformation).

Table: 4.6 Earthquake effect susceptible Borehole depth classes

Borehole depth in (m)	Degree of Seismic effect vulnerability
0 - 55	Very low
55- 90	Low
90- 146	Medium
146- 232	High
232- 368	Very High

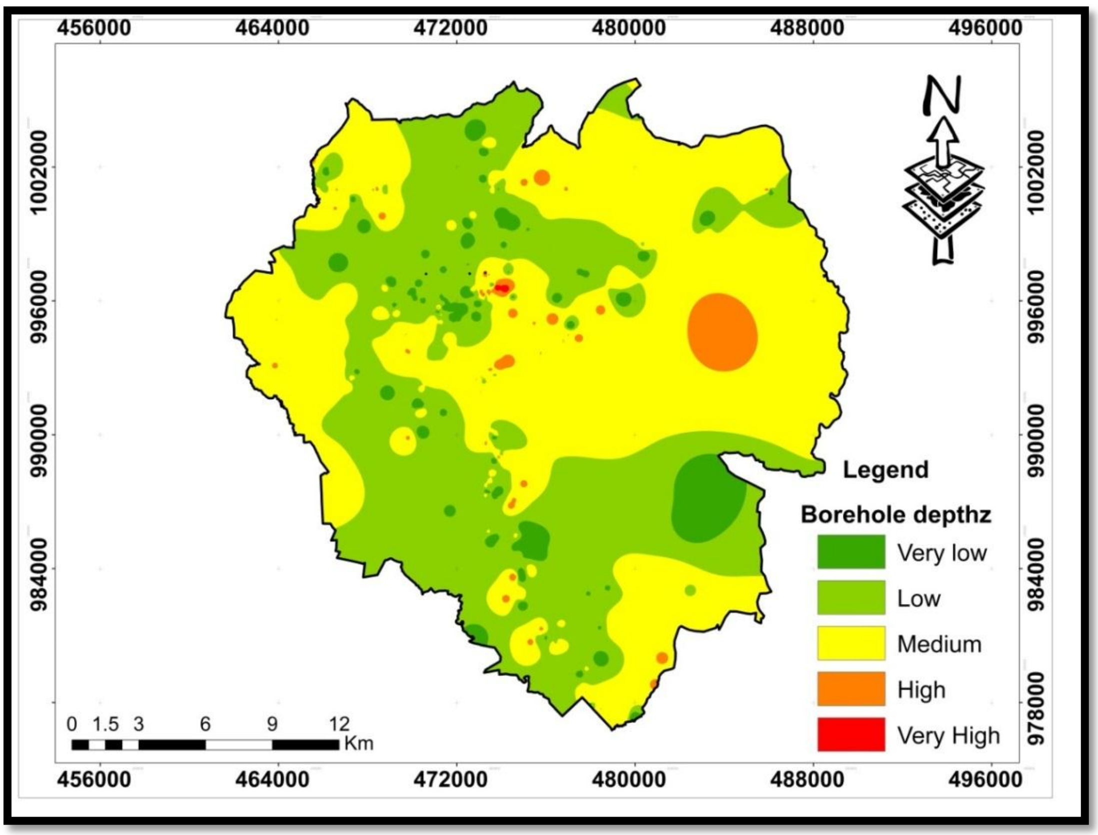


Fig: 4.6 Earthquake effect susceptibility of Borehole depth classes

3.7.7 Soil thickness

Repeated shallow- seismic experiments were conducted at a site on days with different near-surface moisture conditions in unconsolidated material. Variations in the seismic data are attributed to the changes in soil- moisture content of the unconsolidated material. Soil characteristic, strength and water holding Capacity play an important role in occurrence of landslide induced earthquake. In contrast, soft soil always amplifies shear waves. If an earthquake is strong enough and close enough to cause damage, the damage will usually be more severe on soft soils. Seismic waves travel faster through hard rock's than through softer rocks and sediments. Study of Soil as earthquake input factor play a major role in hazard map production. Variations in the seismic data are attributed to the changes in soil- moisture content of the unconsolidated material. Soil characteristic, strength and water holding Capacity play an important role in landslide occurrence these factors vary from earthquake to earthquake.

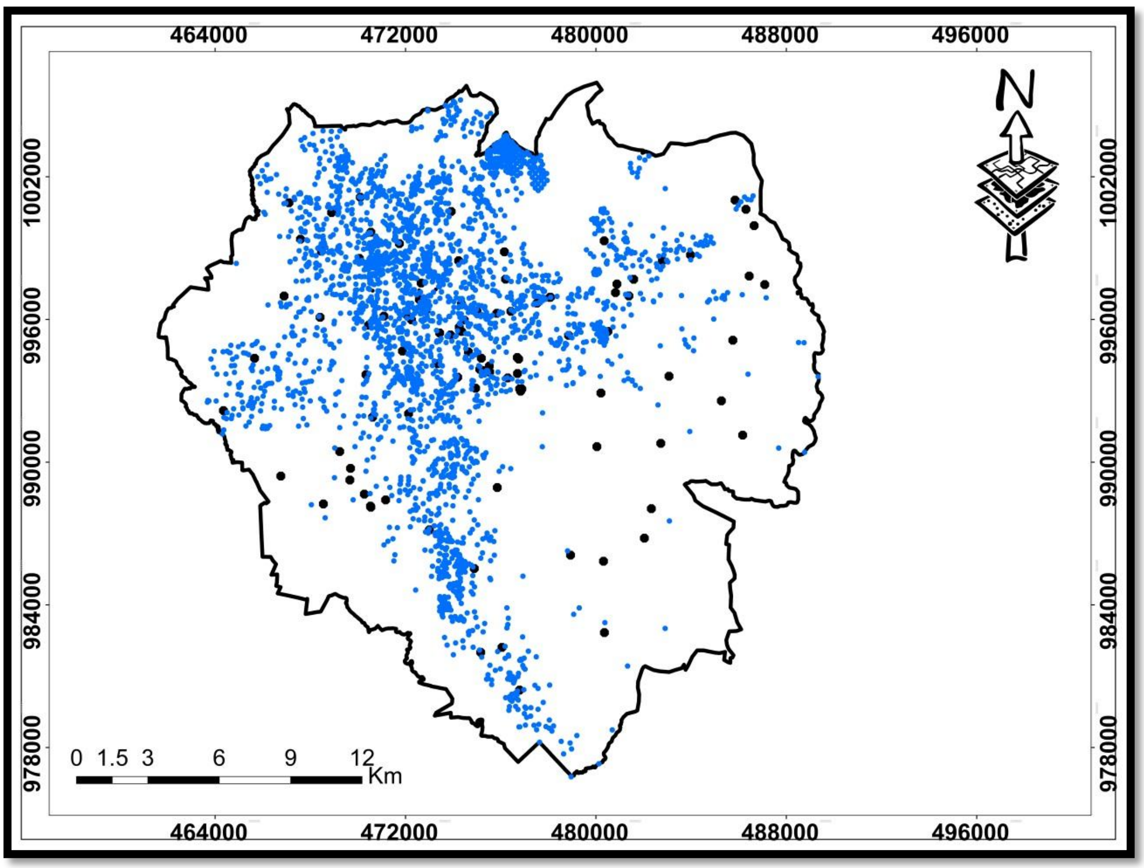


Fig: 4.7 Borehole distribution

Table: 4.7 Earthquake effect susceptible Soil thickness classes

Soil thickness in (m)	Value	Seismic vulnerability
0.3 - 8.6	1	Very low
8.6 - 17.04	2	Low
17.04 - 25.4	3	Medium
25.4 - 33.76	4	High
>33	5	Very High

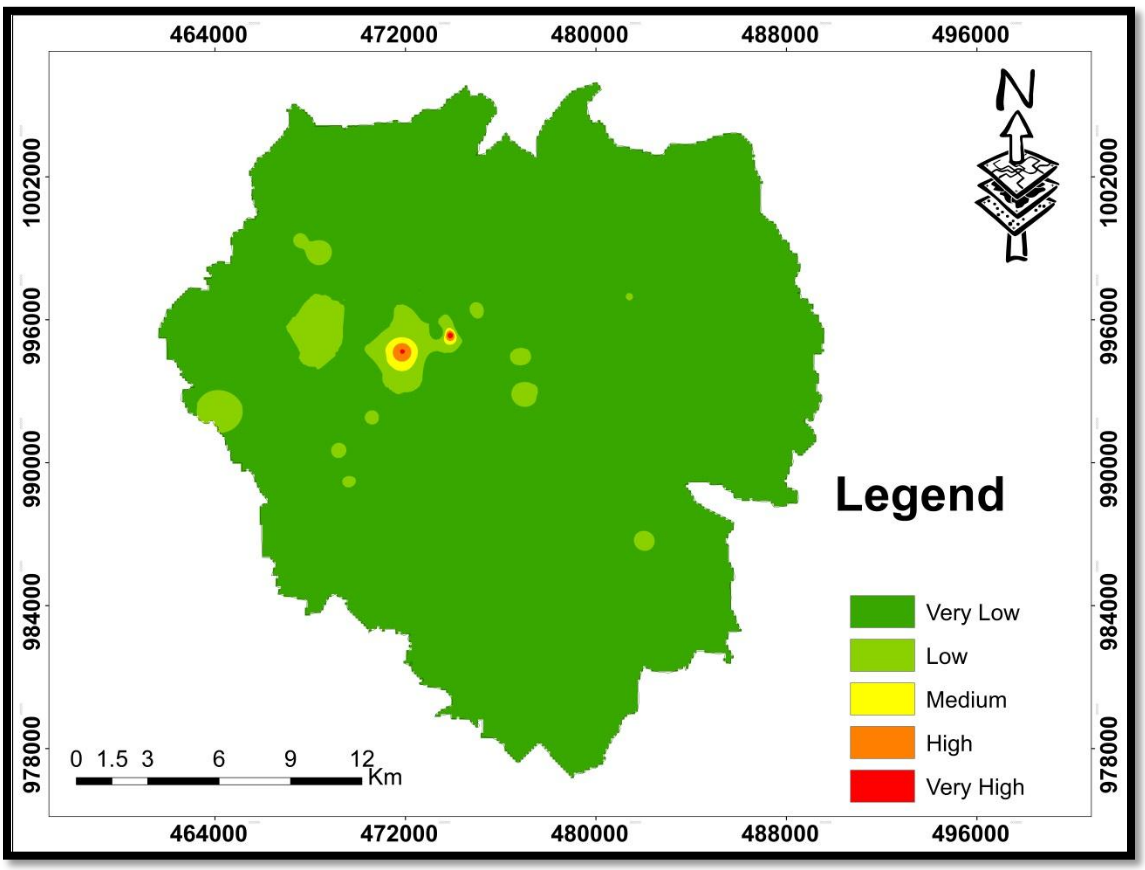


Fig: 4.8 Soil thickness map of the study area

3.7.8 Slope

Slope is a very important factor for earthquake study. If the slope is higher then there is a chance of earthquake occurrence. Earthquake frequency is mostly found at mountainous and hilly regions where forests have been severely destroyed due to the deforestation of ethnic people. This observation of Earthquake could be possible as forest still exists at high elevations and steep slopes where inhabitants have been prevented from logging as well as cultivating on scattered plots of hills; the southern and south-eastern part is predominantly flat. After that the slope values were divided into 5 main classes with natural breaks classification method. Accordingly, the study area has hilly regions which are strongly dissected, steeped and characterized by scattered settlements around the mountains.

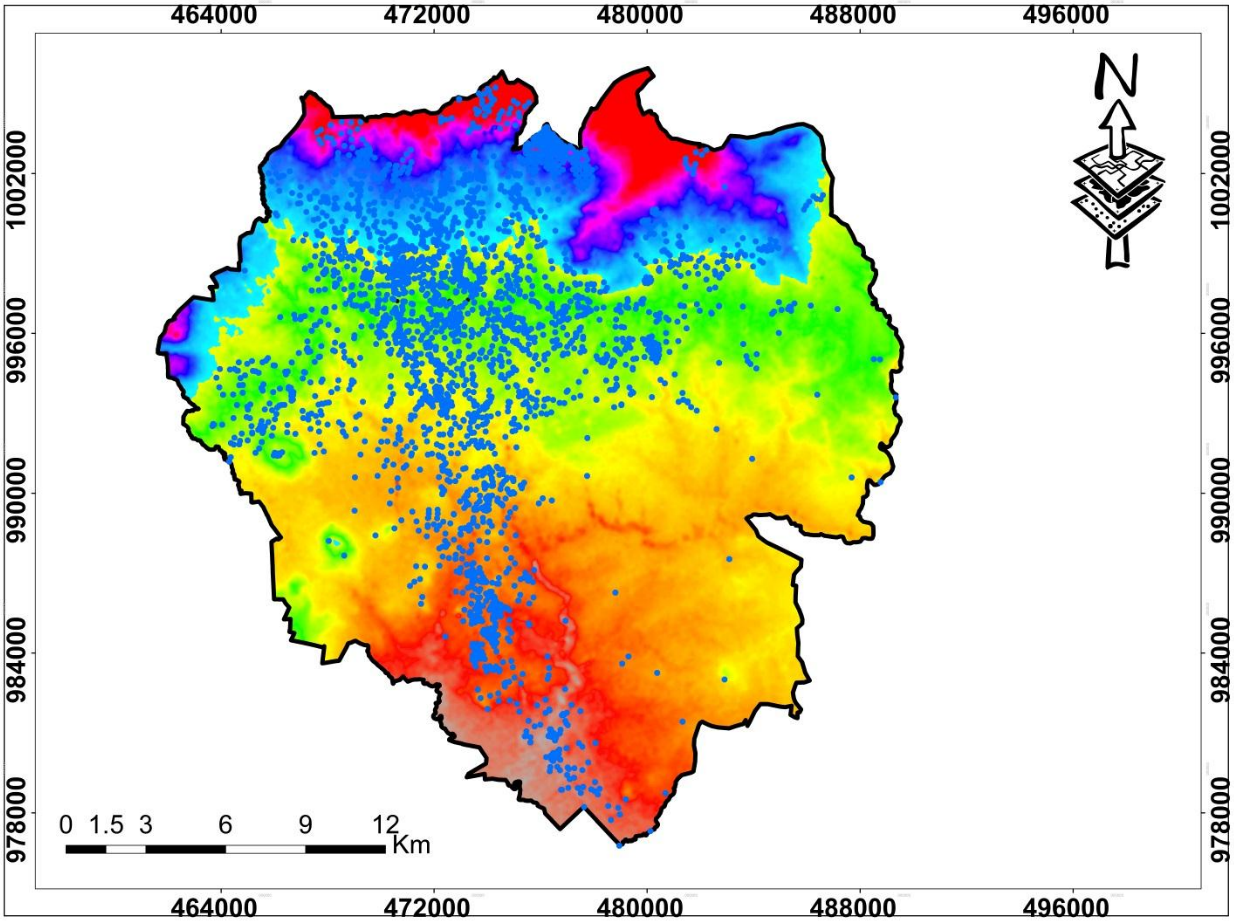


Fig: 4.9 critical structures with respect to topography

Table: 4.8 Earthquake effect susceptible Slope classes

Slope in degree	value	Seismic vulnerability
0 – 1.87	1	Very low
1.87- 3.64	2	Low
3.64- 6.01	3	Medium
6.01- 9.27	4	High
9.27- 25.15	5	Very High

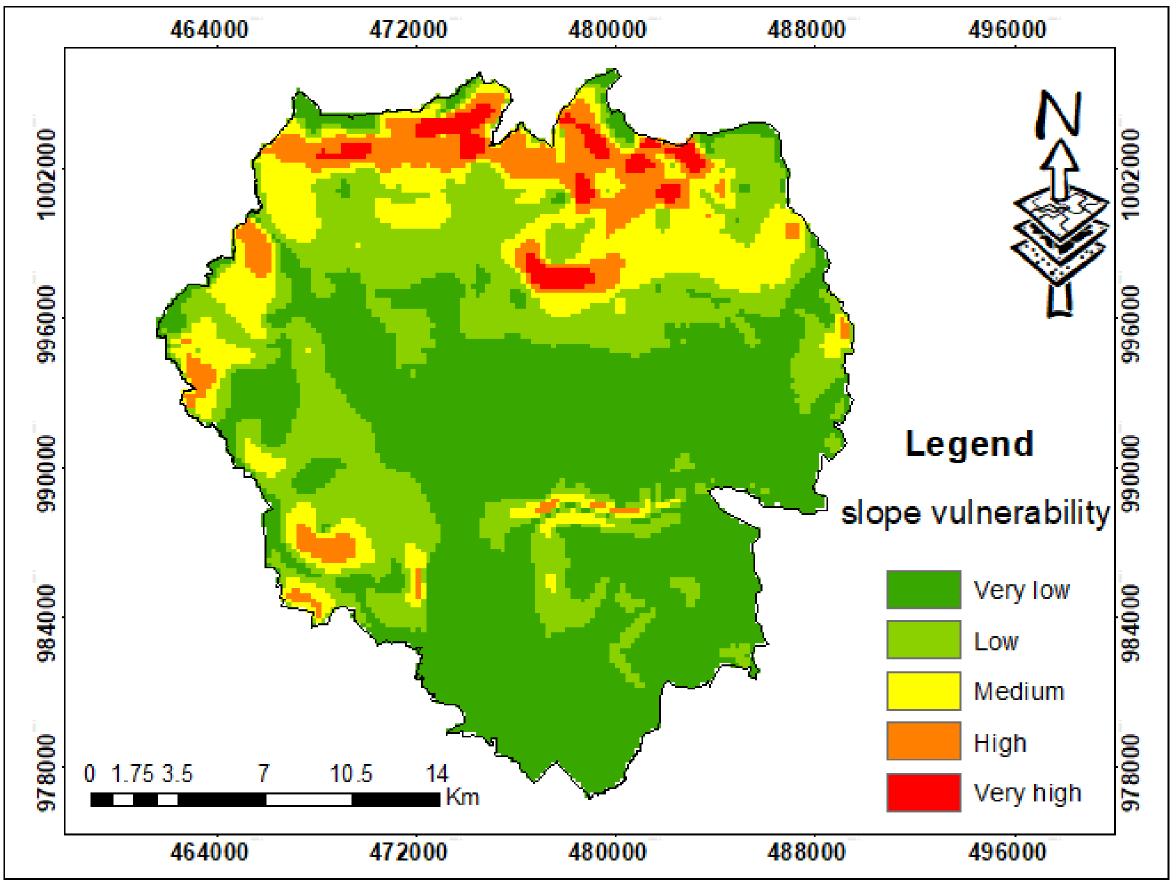


Fig: 4.9 Earthquake effect susceptibility of Slopes

CHAPTER FOUR

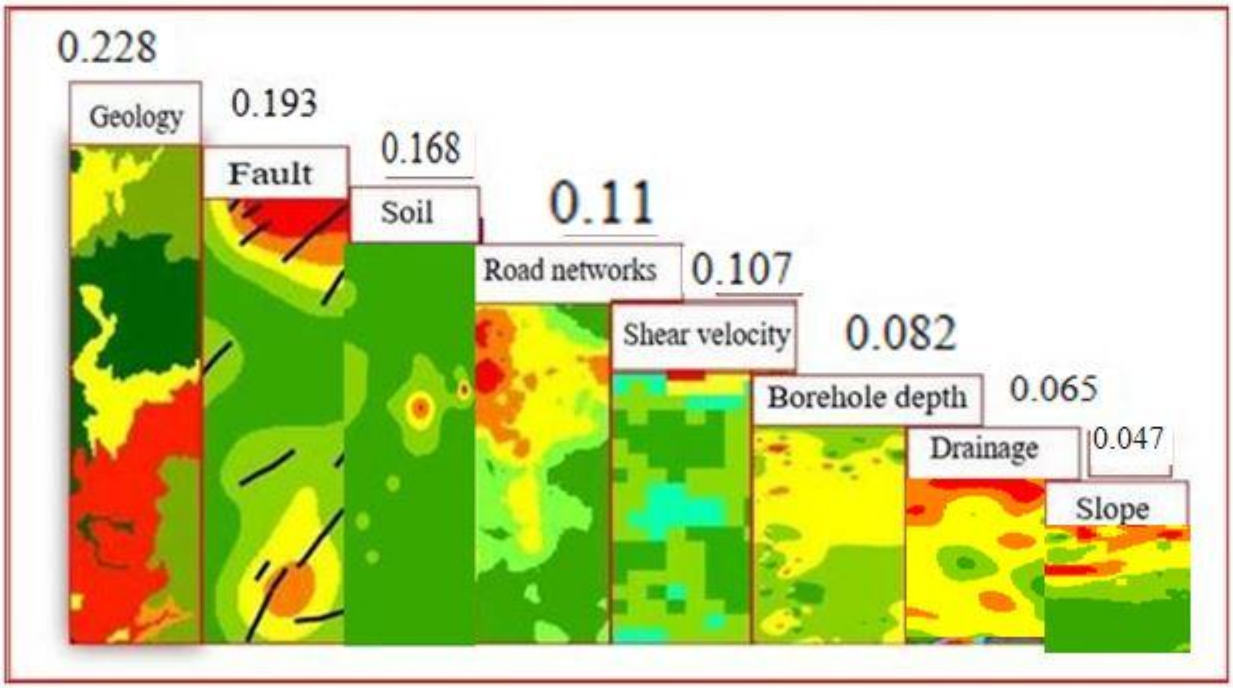
RESULTS AND DISCUSSION

4.1 RESULTS

Geohazard refers to natural phenomenon that can operate at different geological periods that has an impact on human life and built up environment. Recently, an Earthquake is one of the major existing Geohazard that requires detail analysis of its causative factors. To develop Earthquake effect vulnerability map in the research area, geology, soil, drainage density, slope, shear velocity at 30m, fault, borehole depth and road networks were selected as Earthquake input factors. Earthquake risk potential identification of the study tries to evaluate and estimate the earthquake risk vulnerable areas in relation with naturally different elements of natural conditions such as geology, geomorphology, engineering geology, tectonics, hydrology, etc. The earthquake vulnerability map supplies the assessment and prediction with information about expected risk. The quantitative classification of geological setting of the study area is shown in fig (4.1).Accordingly the study area was classified into 5 main litho logical layers namely: Quaternary and tertiary basalts, ignimbrites, trachyte, sediments and scoria. Seismic response of these lithological layers was classified as very low, low, medium, high and very high respectively based on their rock mass strength (Tsehayu and Mariam, 1990). The second Earthquake effect factor was fault lines. Density of fault lines in the study area was considered and classified by density as very low, low, medium, high and very high 0 - 0.078Km^2, 0.078 - 0.156k m^2 , 0.156 - 0.234 km^2 , 0.234 - 0.313 $m^2$0.313 $-$ 0.391Km^2 respectively.Studies demonstrated that ground that encounters high fault activity is severely damaged due to the concentration of Earthquake hot spots near faults. The quantitative classifications of faults are shown in fig ().Soil thickness was another index layer to be considered. The importance of soil thickness for seismic analysis was described as thick soils amplify wave propagation due to quantization of energy during their movement (mamo, 2005). Soil thickness map of the study area was classified into very low, low, medium, high and very high: 0.3 - 8.6m, 8.6 - 17.04m, 17.04 - 25.4m,25.4 – 33.76m, >33m respectively. Shear velocity at 30m was an alternative method that has been recently proposed for evaluating global seismic site conditions, or the average shear velocity to 30 m depth (VS30), from Shuttle Radar Topography Mission.

Five different velocity zones were extracted from global server and overlaid on the study area indicating Five classes of shear velocity zones classified as very low, low, medium, high and very high from 211 – 355m/s, 355- 431m/s, 431- 518m/s,518 – 632m/s,>632m/s. drainage density that has direct link with fault orientation is another factor in risk assessment. This can be best explained by the fact that hydrogeological system where there are more drainage density, the more fault lines are expected and with the highest probability risk. The drainage density map was produced by classifying into very low, low, medium, high and very high with class value of 0 - 0.505 Km^2, 0.505 - 1.011 Km^2, 1.011 - 1.516 Km^2, 1.516- 2.022 Km^2, 2.022 - 2.52 Km^2respectively. Borehole depth was analyzed for the study area .during borehole development, other earthquake causative factors such as slope instability, faults, fractures and joints increase with depth. For existing boreholes, depth to surface was interpolated and classified as very low, low, medium, high and very high with corresponding depths from 0 – 55m, 55- 90m, 90- 146m, 146- 232m, 232- 368m. Slope is another Earthquake input factor selected for the study area. Slope is very crucial parameter in landslide induced earthquake assessment. Land irregularities have an amplifying effect in seismic wave propagation. The study area was classified into five elevation differences. These are also classified for seismic effect as very low, low, medium, high and very high with degrees from 0 – 1.87, 1.87- 3.64, 3.64- 6.01, 6.01- 9.27, 9.27- 25.15 respectively. Road networks are another human induced earthquake effect factor to be considered in vulnerability of built up environment. As majority of life lines including buildings, electric power lines, water reservoir, movement of cars and people are concentrated along roads, road network density should be classified to identify the vulnerable areas (Kilanitis et al, 2019). Road density map of the study area was prepared and expected risk of this map was classified into very low, low, medium, high and very high with 0 – 291m, 291- 583m, 583- 875m, 875- 1,167m, 1,167- 1,458m respectively. The AHP method with GIS technology could produce the final Earthquake effect vulnerability map by integrating all layers together. The researcher used assigned weights for the individual factor map to assess which factors are important for the prediction. Therefore, it is necessary to make sure that the output tables with the weights can be linked to the factor maps. All individual index Weights are added to each together to develop final composite layer.

All earthquake input factors are given different weight based on their importance in earthquake effect vulnerability assessment. The overall vulnerability map is the cumulative summation of all selected layers as per AHP which is accepted in different literature reviews. Hence the final vulnerability map is produced from overlaying of those individual input factors. The impact of preexisting geological structures on the way earthquake rupture has already been suggested several times (Dokka et al, 1990), explained that propagation of rupture occurred through set of fault segments that show two dominant directions consistent with directions of major structures. Where the history of earthquakes due to seismic activity is present in an area, the faults associated with the activity can frequently be identified on satellite imagery. The density of the energy that the seismic waves diffuse in the areas near fault lines will Increase the amount of the damage.



Fig; 4.1 All earthquake input factors overlaying

Themes and its weights for GIS integration

Weight of Index layers	subclass	Degree of seismic vulnerability
Geology	Quaternary and tertiary basalts,	Very low
(0.228)	Ignimbrites	Low
	Trachyte	Medium
	Quaternary Sediments,	High
	Scoria,	Very high
Soil thickness (m)	0-9m,	Very low
(0.168)	9-18m,	Low
	18-27m,	Medium
	27-36,	High
	>36	Very high

Weight of Index layers	subclass	Degree of seismic vulnerability
Shear velocity at 30m (m/s)	211-355,	Very low
(0.107)	355-431,	Low
	431-518,	Medium
	518-632,	High
	>632	Very high
Fault density (Km^2)	0 - 0.078	Very low
(0.193)	0.078 - 0.156	Low
	0.156 - 0.234	Medium
	0.234 - 0.313	High
	0.313 - 0.391	Very High
Drainage density (km^2)	0-0.505	Very low
(0.065)	0.505 - 1.011	Low
	1.011 - 1.516	Medium
	1.516- 2.022	High
	2.022 - 2.52	Very high

Weight of Index layers	subclass	Degree of seismic vulnerability
Road networks (Km^2)	0 – 291	very low
(0.11)	291- 583	Low
	583- 875	Medium
	875- 1,167	High
	>1,167	Very High
Borehole depth (m)	0 – 55	Very low
(0.082)	0.0555- 90	Low
	90- 146	Medium
	146- 232	High
	232- 368	Very high
Slope (degree)	0-1.87	Very low
	1.7- 3.64	low
0.01	3.64- 6.01	Medium
	6.01- 9.27	High
	9.27 – 25.15	Very High

Generally Developed earthquake risk potential map predicting the Earthquake hazard in the research area based on the GIS system have been successfully built with 5 levels of classification: zonation of Very high, High, medium, low and Very low having an aerial extent of 30.34Km^2, 71.74Km^2,97.36Km^2, and 219.34Km^2 and, 108.46Km^2respectively. The areas of Earthquake probability of the different Earthquake susceptibility classes were also accurate and very reliable. This result is relatively high with model predictions, so the partition results of disaster Earthquake risks are relatively accurate and can be applied to practical research areas in order to prevent and alleviate damages due to crashes Earthquake can cause.

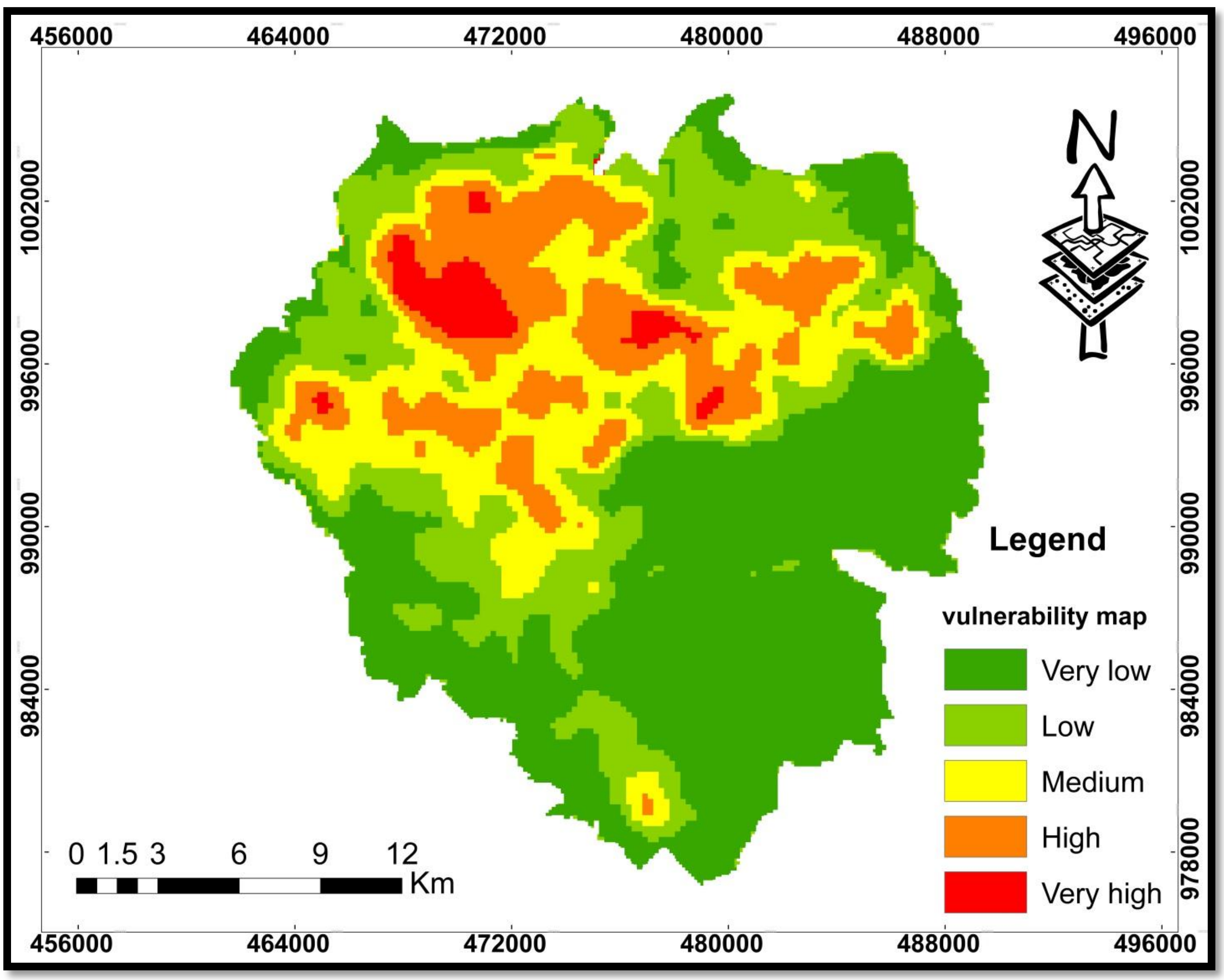


Fig: 4.2 Earthquake effect susceptibility map

All selected input factors are integrated with GIS software and AHP method to produce final earthquake effect vulnerability map of the study area. Earthquake vulnerability assessment of built up environment will enable city planners and policy makers to mitigate and minimize risk of earthquake. Earthquake susceptibility zonation of Very high, high, medium, low and very low having 5.75%, 13.6%, 18.47%, 20.58% and 41.62% respectively.

4.2 DISCUSSTION

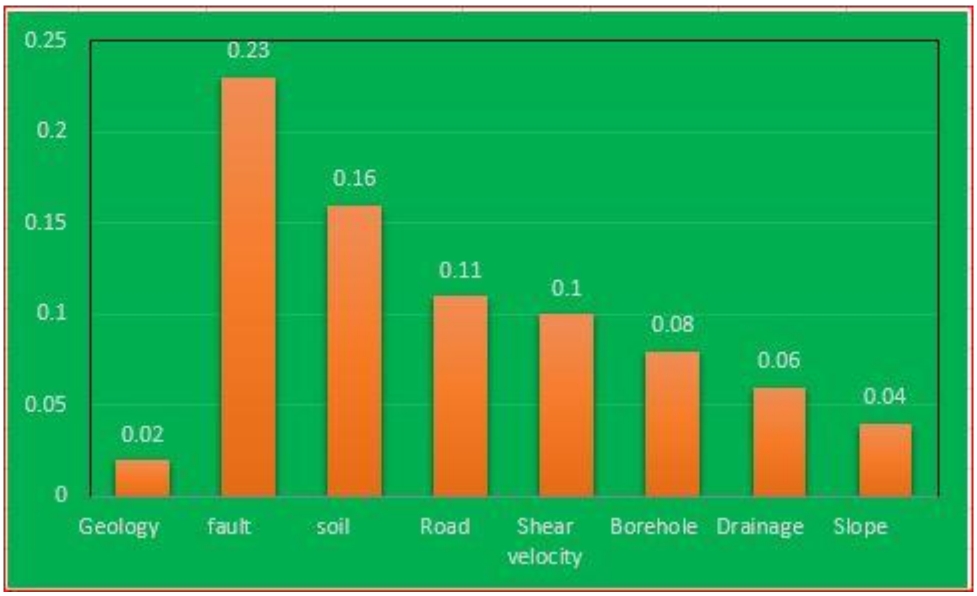
In this study, I have developed GIS-based Earthquake risk prone area identification based on the integration of AHP methodology and expert opinion techniques, involving the geographic information system (GIS), to identify urban Earthquake vulnerable areas. Since the determination of seismic vulnerability requires exploiting geophysics, civil engineering, urban development, programming, and GIS, this multidisciplinary knowledge required the cooperation of various experts. Earthquake input factors selected for environment has their own significant figure and the resulting findings showed that the highest and lowest effective factors in this study area was geology (0.228) and slope (0.047) respectively. The result of our study is consistent with prepared seismic zonation based on Peak ground acceleration where the study indicated that a higher PGA results in a higher probability of liquefaction occurrence is, and hence a higher seismic vulnerability of that area.

The final Earthquake risk map is compared to existing hazard map. Even though there is no specific hazard map produced, the current study is compared to hazard map prepared based on Peak ground acceleration. Earthquake is a complex process that requires understanding of different input factors. However ,The previous study was based on only one Earthquake factor as this research incorporates different Earthquake input factors .In order to validate current study, existing hazard map is required. Some criteria are considered for the evaluation of the results. In most Earthquake studies, the observed Earthquake in different Earthquake susceptibility classes are always considered the key factor for result evaluation. Even though there is no Hazard map which incorporates all involved factors, the prepared map will be serve as a base for hazard map. As per AHP, the calculated consistency ratio is used as validation.

Validation

Requirements validation is concerned to check the requirements document for consistency, completeness and correctness", and in states that the requirements should be checked to: validate, understand, consistent, traceability, completeness, realism and verifiability.

According to different researches conducted yet, validation is an important means of verification either by practical observation or any related researches conducted before. for current research study validation was based on consistency measurement .As Earthquake is very complex process that can be occur at unknown time and place, these selected factors are consistent and common in earthquake risk assessment projects. there is no hazard map prepared with respect to all triggering factors included in this study, measure of inconsistency is used to validate the current study.



Fig; 5.3 weight based Bar graph representation of all layers

Elements at risk

In urban areas the population, structures, utilities, systems, and socio-economic activities constitute the "Elements at Risk". Buildings and lifeline systems are generally termed “Built Environment”. The physical losses to elements at risk that would result from a specified earthquake scenario necessitate an extensive and comprehensive collection of their inventories. Preparation of urban earthquake damage/loss scenarios encompass involve compilation of information on: Demographic structure for different times of the day; building stock and its types; lifeline and infrastructure (major roads, railroads, bridges, over passes, public transportation, power distribution, water, sewage, telephone, and natural gas distribution systems) including their nodal points (stations, pumps, switch yards, storage systems, transmission towers, treatment plants, airports, marine ports etc.).

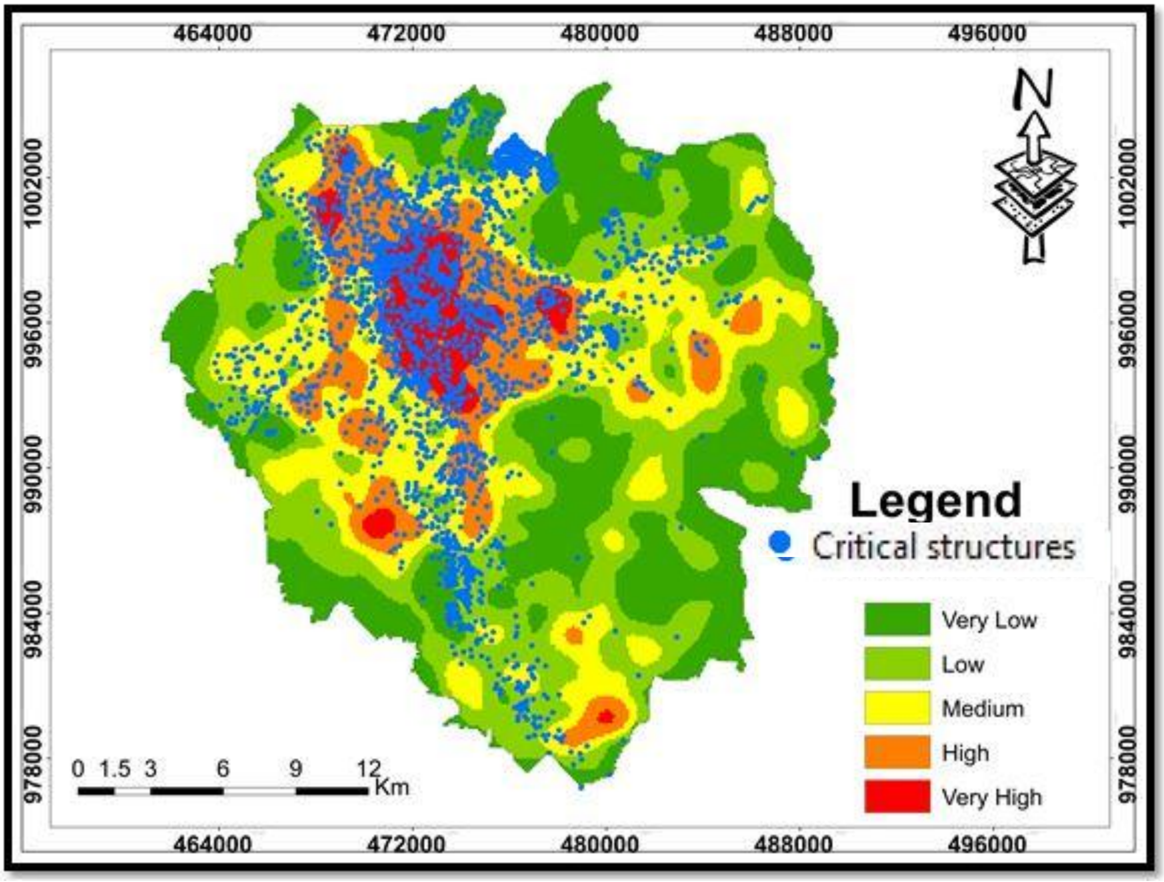


Fig: 4.4 Vulnerability of critical structures

Geotechnical indicators

Assessment of earthquake effect suscestiplity conducted on the basis of geotechnical parameters such as soil, shear velocity and borehole depth has put the city in vicinity seismically vulnerable zones. Previous studies revealed that if the faults along Main Ethiopian rift become active, Addis Ababa city will experience the PGA of 0.07g. According to (Fig:4.4) indicated above, the future earthquake to be occurred due to movement of active faults, indicators of the geotechnical vulnerability in parts northern, north western and southern part of the city are highly vulnerable. As small faults are developing along central part of the city, most of structures found along northern districts of the city are highly crowded; these areas are prone to direct effect of future earthquake. Geotechnical indicators of earthquake effect vulnerability are resulted from vulnerability classes found in borehole, shear velocity and soil.

Structural indicators

Direct effect of Geohazard can bring disruption of all life lines. Other secondary effects are related to falling of blocks, collapse of buildings and risk of power banks. Assessment of seismically vulnerable areas in built up environment can easily identify vulnerable elements such as roads, bridges, buildings, power lines, water towers and all transportation accessibilities.

Socio-Economic indicators

Population density and economic development of any country is directly related with vulnerability to existing geohazard. High population density is highly vulnerable to effect of earthquake. Economic aspects are other vulnerable elements in earthquake effects. Demographic context of a society during an earthquake occurrence or after is very important since these factors have a direct relationship with the increase or decrease in tolls and facilitation of relief operations. Unfortunately, during recent years earthquake experts have not paid enough attention to this issue and not enough studies have been conducted with this viewpoint on the last earthquakes.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Finally, this study results allowed identification earthquake effect susceptible areas of built environment. I have identified Earthquake effect susceptible areas based on selected input factors in context of built up environment. Different earthquake triggering factors are combined to produce the final earthquake effect susceptible regions of the study area. Analytical methods such as AHP and geospatial technologies including GIS were used as methodology. Earthquake related studies require collection of different data type from different sources. Each of earthquake triggering factors plays a major role in earthquake occurrence. The importance of each index layer in seismic effect study is analyzed by pair wise comparison and weight generation. Current findings are consistent with the empirical knowledge of the study area and are crucial elements to define seismic risk mitigation policies and emergency planning by the local authorities. Environmental studies includes regular observation and frequent assessment of existing geohazard. As effect of earthquake is huge and destructive for built-up environment and loss of human life, investigation of an environment is a key in risk mitigation strategy. This study includes different index layers from geotechnical, geological, hydrogeological, structural and geomorphologic fields of study. Generally eight earthquake effect causative factors were selected and used as an input to develop the final earthquake risk map. Each individual layers are mapped to represent risk map of the study area. However, Earthquake is known by its complex process which includes either natural causes or manmade. The contribution of each layers in vulnerability assessment is well reflected if they combined. Five different velocity zones were extracted from global server and overlaid on the study area indicating five classes of shear velocity zones classified as very low, low, medium, high and very high. Future infrastructure projects are not only designed with Earthquake risks in mind, but also to ensure that the few development projects that are built are not “wasted” by future, predicted Commercial, industrial or residential land-use plans for these areas should be reexamined in light of Earthquake risk and vulnerabilities. Existing infrastructure and human settlement should be examined with the potential for the need of mitigation planning.

5.2 RECOMMENDATIONS

On the basis of current studies on earthquake effect potential identification, the result of the study area indicates that different land regions of vulnerable classes. Potential Effects of earthquake of the study area has been identified. Accordingly, earthquake is a complex geological process that requires consideration of different environmental input factors. Previous studies indicate that seismic activity of the study area could bring significant damages on life of human being and structures. Current study has put a solution in effect of seismic activity by identifying vulnerable zones. Accordingly, the result of this study serves as a base for risk mitigation and reduction policy. City planners and engineers should have to consider degree of vulnerability in these classes while constructions are developed. Land use land cover should have to consider the risk map. Generally, Geospatial technologies are applicable for any geohazard assessment in integration with popular analytical methods. Application of ARC-GIS Software integration with, AHP method is used to reduce time for analysis and Techniques/ map preparation. Current scientific research support application of powerful soft wares and new available methods in assessment of geohazard. Source of data for Earthquake vulnerability assessment are of different forms and geographical location, combination of these data together requires basic knowledge on seismicity and causative factors. As built up environments are composed of different elements with different responses during geohazard, regular monitoring and understanding our environment is very essential in risk mitigation.

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York

Appendix I

Earthquake catalog downloaded from 1900 to 2020 from USGS

Latitude	Longitude	Depth	Magnitude
12.213	40.26	27.5	3.7
12.396	40.441	10	3.7
12.122	41.784	10	3.7
12.799	40.922	10	3.8
11.772	43.19	10	3.8
12.162	40.167	10	3.9
12.514	40.333	14.3	3.9
12.88	40.374	4	3.9
12.628	40.396	21.7	3.9
12.158	40.502	10	3.9
12.535	40.535	10	3.9
12.456	40.574	10	3.9
12.542	40.591	10	3.9
11.712	40.611	10	3.9
12.286	40.618	10	3.9
12.233	40.623	10	3.9
12.705	40.632	10	3.9
12.726	40.7	10	3.9
13.4	40.953	10	3.9
12.589	41.135	10	3.9
10.034	42.788	10	3.9
12.465	40.453	10	4
12.579	40.465	10	4
12.673	40.526	10	4
12.601	40.576	10	4
12.513	40.597	10	4
12.367	40.606	10	4
12.382	40.693	10	4
12.148	40.736	10	4
10.223	41.138	10	4
11.797	41.254	10	4
12.91	41.74	10	4
13.669	39.666	10	4.1

13.553	39.854	10	4.1
12.296	40.191	10	4.1
10.327	40.257	10	4.1
12.42	40.319	10	4.1
11.597	40.375	10	4.1
12.384	40.404	10	4.1
12.377	40.423	10	4.1
12.169	40.426	10	4.1
12.636	40.468	10	4.1
12.05	40.509	10	4.1
12.046	40.579	10	4.1
12.64	40.678	10	4.1
12.206	40.682	10	4.1
10.239	42.775	10	4.1
13.221	40.046	33	4.2
11.929	40.272	10	4.2
12.408	40.324	10	4.2
11.97	40.328	10	4.2
12.045	40.413	0.1	4.2
11.998	40.446	10	4.2
12.643	40.472	10	4.2
11.947	40.491	10	4.2
13.499	40.494	10	4.2
11.846	40.5	10	4.2
12.197	40.619	10	4.2
12.59	40.622	10	4.2
13.189	40.759	10	4.2
12.863	40.762	10	4.2
12.3	41.25	10	4.2
12.172	41.613	10	4.2
11.974	40.244	10	4.3
12.202	40.251	10	4.3
11.8	40.396	10	4.3
11.999	40.426	10	4.3
11.859	40.432	10	4.3
12.601	40.44	10	4.3
12.281	40.475	10	4.3
12.199	40.511	10	4.3
12.237	40.526	10	4.3
12.286	40.545	10	4.3
12.383	40.55	10	4.3

12.616	40.566	10	4.3
12.331	40.568	10	4.3
12.566	40.586	10	4.3
12.679	40.629	10	4.3
12.691	40.637	10	4.3
10.001	41.079	10	4.3
12.356	41.303	10	4.3
5.781	36.976	10	4.4
7.57	37.665	10	4.4
7.643	37.868	10	4.4
13.572	39.929	10	4.4
13.336	39.963	33	4.4
13.409	39.991	10	4.4
11.978	40.323	10	4.4
12.357	40.378	10	4.4
12.271	40.419	10	4.4
12.603	40.422	10	4.4
12.386	40.426	10	4.4
12.815	40.44	10	4.4
11.936	40.449	10	4.4
12.429	40.461	10	4.4
12.214	40.465	10	4.4
12.1	40.472	10	4.4
12.187	40.472	10	4.4
12.08	40.474	10	4.4
12.518	40.485	10	4.4
12.638	40.489	10	4.4
12.391	40.498	10	4.4
12.238	40.512	10	4.4
12.595	40.516	10	4.4
12.654	40.527	10	4.4
12.578	40.545	10	4.4
12.448	40.552	10	4.4
12.553	40.585	10	4.4
12.572	40.6	10	4.4
12.45	40.63	10	4.4
12.352	40.651	10	4.4
16.469	40.653	10	4.4
9.765	40.669	10	4.4
12.482	40.704	10	4.4
16.482	40.967	10	4.4

10.091	41.233	10	4.4
9.843	40.032	33	4.5
16.551	40.083	10	4.5
14.562	40.167	10	4.5
9.563	40.181	10	4.5
12.468	40.34	10	4.5
12.148	40.365	10	4.5
12.236	40.37	10	4.5
12.694	40.375	21.5	4.5
12.437	40.39	10	4.5
12.607	40.404	10	4.5
12.569	40.418	10	4.5
12.46	40.449	10	4.5
12.681	40.463	10	4.5
12.695	40.474	33	4.5
12.146	40.492	10	4.5
12.655	40.494	10	4.5
12.726	40.505	10	4.5
12.099	40.51	10	4.5
12.322	40.511	10	4.5
12.127	40.524	10	4.5
12.315	40.54	10	4.5
12.643	40.562	10	4.5
12.094	40.588	10	4.5
12.316	40.59	10	4.5
12.498	40.643	10	4.5
12.461	40.646	10	4.5
12.304	40.656	10	4.5
12.625	40.659	10	4.5
12.546	40.666	35	4.5
13.4093	40.6697	9.97	4.5
14.632	40.69	33	4.5
12.749	40.691	10	4.5
12.519	40.71	10	4.5
13.029	40.748	10	4.5
12.727	40.754	10	4.5
12.598	40.822	10	4.5
16.602	40.846	10	4.5
16.451	40.982	10	4.5
12.969	41.023	10	4.5
10.779	41.27	10	4.5

16.449	41.326	10	4.5
11.976	41.614	10	4.5
12.775	40.289	10	4.6
11.717	40.289	10	4.6
12.002	40.37	10	4.6
15.288	40.407	37	4.6
12.411	40.418	10	4.6
11.985	40.441	10	4.6
12.153	40.455	10	4.6
12.423	40.462	10	4.6
12.486	40.475	10	4.6
12.323	40.483	10	4.6
12.669	40.49	10	4.6
12.213	40.493	10	4.6
12.193	40.498	10	4.6
12.514	40.507	10	4.6
12.69	40.516	10	4.6
12.711	40.527	10	4.6
12.223	40.547	10	4.6
12.606	40.568	10	4.6
12.341	40.595	10	4.6
12.638	40.605	10	4.6
12.053	40.626	10	4.6
12.399	40.801	10	4.6
13.452	40.806	10	4.6
16.467	41.02	10	4.6
16.345	41.121	10	4.6
12.044	41.626	10	4.6
12.096	41.648	10	4.6
12.072	41.68	10	4.6
11.197	41.754	10	4.6
11.807	41.813	10	4.6
5.47	35.998	10	4.7
5.107	37.209	10	4.7
6.018	37.513	10	4.7
6.289	37.697	10	4.7
16.112	39.627	10	4.7
9.463	39.648	10	4.7
13.201	39.755	33	4.7
12.719	40.343	10	4.7
16.462	40.392	33	4.7

12.323	40.396	10	4.7
12.6	40.401	10	4.7
12.486	40.423	10	4.7
12.777	40.445	10	4.7
12.291	40.452	10	4.7
12.345	40.453	10	4.7
12.253	40.463	10	4.7
12.348	40.495	10	4.7
12.499	40.518	10	4.7
12.55	40.556	10	4.7
12.389	40.578	10	4.7
12.532	40.579	10	4.7
12.837	40.579	33	4.7
12.215	40.63	10	4.7
12.15	40.687	10	4.7
12.164	41.611	10	4.7
12.063	41.794	10	4.7
13.351	40.011	33	4.8
13.001	40.015	33	4.8
12.514	40.361	10	4.8
12.732	40.427	10	4.8
12.65	40.446	33	4.8
12.501	40.461	10	4.8
12.416	40.466	10	4.8
12.575	40.472	10	4.8
12.545	40.499	10	4.8
12.627	40.499	10	4.8
12.699	40.539	10	4.8
12.423	40.578	10	4.8
12.55	40.598	10	4.8
12.669	40.613	10	4.8
12.436	40.617	10.3	4.8
12.447	40.621	10	4.8
12.386	40.662	10	4.8
16.404	41.059	10	4.8
16.539	41.076	10	4.8
16.371	41.166	10	4.8
15.82	41.423	34	4.8
12.193	41.532	10	4.8
5.266	36.849	34	4.9
5.314	37.411	10	4.9

6.837	37.878	18.6	4.9
8.301	38.524	33	4.9
13.334	39.657	11.1	4.9
8.946	39.982	10	4.9
13.308	39.984	33	4.9
13.649	40.001	10	4.9
12.26	40.513	10	4.9
12.02	40.537	10	4.9
13.678	40.565	10	4.9
12.62	40.607	10	4.9
12.386	40.613	10	4.9
12.335	40.646	10	4.9
11.992	41.891	10	4.9
10.94	39.629	38	5
11.373	39.712	10	5
13.129	39.927	52.2	5
12.239	40.359	33	5
12.535	40.465	10	5
12.441	40.495	10	5
12.366	40.505	10	5
12.754	40.515	10	5
12.447	40.603	10	5
12.338	40.617	10	5
13.439	40.828	10	5
10.224	40.846	10	5
11.754	40.964	10.3	5
7.521	37.839	10	5.1
7.03	38.599	10	5.1
12.279	39.744	10	5.1
12.543	40.389	10	5.1
12.398	40.442	10	5.1
12.458	40.538	10	5.1
12.421	40.578	10	5.1
12.443	40.634	10	5.1
11.825	41.583	10	5.1
10.817	42.888	10	5.1
11.52	43.097	5.3	5.1
5.347	37.561	10	5.2
10.617	39.732	33	5.2
12.697	40.461	10	5.2
12.674	40.519	10	5.2

12.617	40.535	10	5.2
12.702	40.553	10	5.2
12.386	40.578	10	5.2
12.429	40.602	10	5.2
11.896	41.764	10	5.2
11.898	41.884	10	5.2
6.35	35.88	10	5.3
6.223	37.814	10	5.3
7.671	38.6682	10	5.3
8.331	39.308	12.4	5.3
13.263	39.925	33	5.3
12.572	40.569	10	5.3
11.8	41.721	10	5.3
5.518	36.143	10	5.4
10.305	40.138	20	5.4
12.707	40.526	10	5.4
11.478	39.638	15.2	5.7
10.364	39.638	20	5.7
13.654	39.813	10	5.7
13.83	39.83	15	5.7
11.985	41.87	10	5.7
5.74	36.73	10	6
5.691	37.145	15	6
10.162	39.764	20	6
11.884	41.338	15	6.1
11.886	41.341	10	6.1
11.942	41.769	9.7	6.1
11.884	41.812	10	6.1
11.904	41.824	11.7	6.1
11.88	41.88	10	6.1
11.374	42.609	15	6.1
10.466	39.717	25	6.2
11.875	41.208	10	6.2
5.409	36.751	12	6.3
10.453	40.301	15	6.4
11.874	41.87	15.8	6.4
5.589	36.724	15	6.5
7.415	40.813	15	6.5

Northing	Easting	Thickness in (m)
993754	477194	18.5
993768	477200	15
994637	476281	30
996894	477063	30
99429	476526	25
994302	476541	27
994320	476561	25
991826	475183	11
99183	475194	10
991826	475183	11
99183	475194	10
993317	476615	30
993296	476618	30
993301	476616	30
986243	474312	10
986233	474329	10
985942	473483	10
985965	473477	10
985943	473484	10
985870	473480	10
985862	473461	10
980768	479986	8.4
980767	479998	10
994653	476471	20
994645	476492	20
99466	476486	25
994672	476484	20
994670	47649	20
992744	47427	8
99275	475291	3.8
982875	474686	15
982868	47470	15
982901	474660	10
982919	474689	10

982887	474670	7
982908	474700	7
99426	475896	10
994268	475884	10
986178.5	478140.7	10
986197.3	478187.1	10
986197.3	478187.1	10
986244.2	478265.2	10
986262.8	478280.7	10
986209	478159	10
986229.2	478193.1	10
986249.8	478227.4	10
986216	478114	10
986247	478165	10
986277.9	478216.6	10
986301.8	478256.5	10
986243	478107	10
986263.4	478141.5	15
994014	476452	12
994033	476454	12
99400	476453	12

Appendix II

Soil thickness variations

Easting (X)	Northing(Y)	Soil thickness in (M)
468470	998870	10
472055	996188	12
472863	996385	5.5
472750	996752	2
476798	993085	12
476835	992987	9.8
476889	993078	10
473887	995350	43
471871	994671	35
472580	996839	2.2
472750	996752	5
472252	995989	10
474359	995495	2
476705	993728	3.5
471094	996141	6
474231	998472	2.5
474471	995977	4
474351	996652	8
476696	994402	10
476754	994337	11.8
472657	997534	5
477525	996690	2.5
481589	997691	1.2
473005	987156	2.5
480822	997130	2
478090	996939	7

475158	982005	1.5
475122	993909	9
475238	993851	3.5
475520	994040	3
478851	995332	8
475837	996262	2
478062	996928	3
486442	997826	7
476794	980414	3
473921	1000541	1
470100	1001140	5.6
475004	996342	12
476296	993543	1.5
475855	988933	5.5
482330	988045	0.6
474643	994640	1
480886	997491	2
483977	998713	1.5
480347	999309	3.5
485849	1001021	3
476203	997695	2.5
475537	993793	1.3
480357	982833	0.6
476054	982212	4.5
473436	995433	1.6
487096	997467	3.8
469691	989741	2
470447	995755	5
475186	994374	1.5
482797	998475	3
480503	995498	5.8
474890	985530	2
476157	998845	1.4
469661	989250	12
470528	988152	0.6
474193	993571	2.8
480212	992908	0.5
476428	996341	1.2
473349	994146	0.9
474944	993109	1.7
481385	996991	10

474944	993109	0.7
475186	994374	1.2
474257	995675	2.8
482797	998475	1.3
471741	999192	0.4
468549	988245	0.3
470270	988658	1.2
486306	1000634	3
486650	999945	2.5
467104	1000909	4.5
467586	999375	9
466897	996986	8
468412	996091	11
465659	994370	5
464351	992168	10
469237	990447	10
470614	991893	9
471165	988412	8
466760	989415	3
470545	988107	7
470339	993682	3
472128	992038	4.5
483071	993613	3
485756	995128	6
485274	992581	3
482727	990792	5.5
480043	990654	3
486169	991136	2.5
478935	986092	2
480318	985836	8
482039	986805	10
468893	1000496	5.5
470063	998569	6
470545	999670	4

D E C L A R A T I O N

I hereby declare that the thesis entitled "GIS-based Earthquake effect vulnerability assessment of Built-up environment, in case of Addis Ababa City, Ethiopia" has been carried out by me under the supervision of Dr. K.V. Suryabhagavan, Associate Professor, School of Earth Sciences, College of Natural and Computational Sciences, Addis Ababa University, Addis Ababa during the year 2018−2020 as a part of Master of Science program in Remote Sensing and Geo-informatics. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Kaleb Tarfa

Signature: ___________________

Addis Ababa University

Addis Ababa

Date: June, 2020

C E R T I F I C A T E

This is certified that the thesis entitled "GIS-based Earthquake effect vulnerability assessment of Built-up environment, in case of Addis Ababa City, Ethiopia" is a work carried out by Kaleb Tarfa under my guidance and supervision. This is the actual work done by Kaleb Tarfa for the partial fulfillment of the award of the Degree of Master of Science in Remote Sensing and Geo-informatics from Addis Ababa University. Addis Ababa, Ethiopia.

Dr. K. V. Suryabhagavan

Associate Professor

Signature: __________________

School of Earth Sciences

Addis Ababa University

Addis Ababa

Date: June, 2020