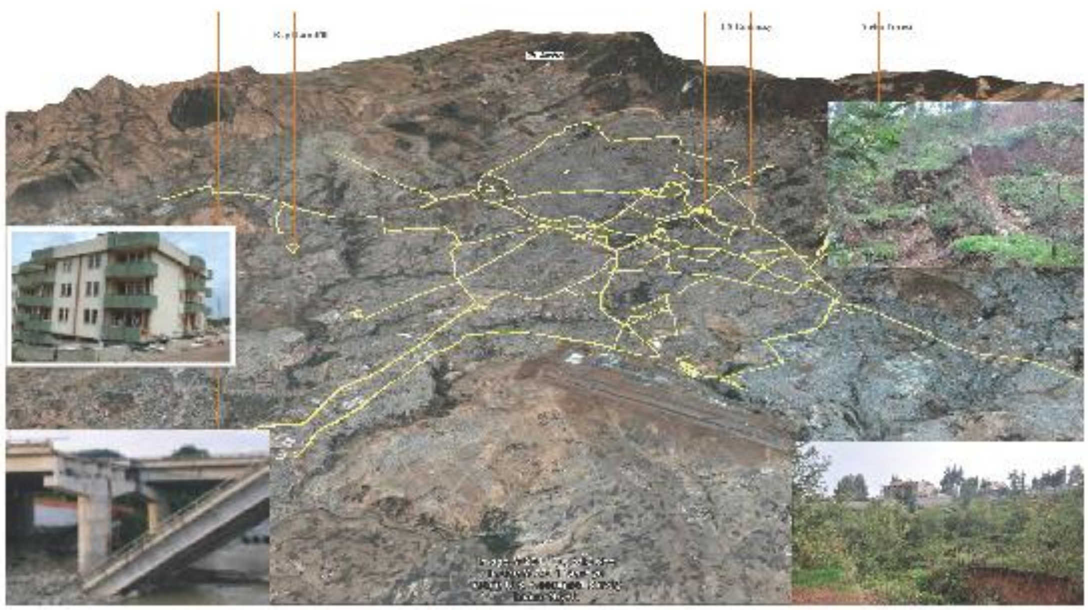
ADDIS ABABA UNIVERSITY
School of Graduate Studies
Faculty of Science

CHARACTERIZATION OF THE TREND OF URBANIZATION AND ASSOCIATED NATURAL HAZARD ASSESSMENT AND ANALYSIS: LANDSLIDE AND EARTHQUAKE PROBLEMS ALONG HILL SLOPE AREAS IN THE CASE OF ADDIS ABABA CITY, ETHIOPIA

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 Environmental Geology



Temesgen Assefa
June 2012

Acknowledgements

A great many of people have contributed to the development of this research work.

Firstly, I express my gratitude to Packard foundation, especially to W/ro Yemisrach Belayneh (country director of Ethiopia) and Dr. Hailu Chaneyalew who provided me financial support at the preliminary stage of this research work, in 2010.

I express also my deepest gratitude to Dr. Asefawossen Asrat, my research advisor, for his thoughtful suggestions and professional comments. His critical advice and comments made after long patience made me to pay more effort and be attentive on my research work.

The following organizations and companies whom I am indebted have provided me valuable data: PHE-Ethiopia, Ethiopian Mapping Agency, (EMA); Ethiopian Red Cross Society (ERCS); Central Statistics Agency (CSA); the Geological Survey of Ethiopia (EGS); Addis Ababa City's manager office; the International Livestock Research Center (ILRI); Addis-Geo-systems; AG Consult; Gondwana Engineering Plc., Ethiopian Railway Corporation (ERC); and National Metrology Agency (NMA).

I express my sincere thanks to Ato Matewos Assefaw, (town planner and director of the A.A and the surrounding oromiya integrated development planning project office) and Ato Sahele Fersha (Dept., Head of A.A planning and information institute): they offered me constructive advice and valuable data.

I am especially indebted to my friends who offered me their valuable advice and help: Berta Solomon, Habtamu Solomon, Netsanet Mengistea, and all others too many to list here.

Last, I express my deep gratitude to Prof. Gezahegne Yirgu, Dr. Bekele Abebe, Dr. Atalay Ayele, Dr. Tilahun Mamo, and Dr. Agizew Nigusie for their enthusiasm and professionalism; without which successful completion of this work would have been impossible.

My family has been supportive of this research work. Any remaining shortcomings are, of course, my responsibility.

Table of Contents

List of tables

List of figures

List of plates

Abbreviations

AA: Addis Ababa

AAWSA: Addis Ababa water and sewerage authority

Alt: Altitude

asl: Above sea level

CLUVA: Climate change and urban vulnerability in Africa

CSA: Central statistics agency

DPPC: Disaster Prevention and Protection Commission

Dr: Doctor

e.g: Example

E: East

EARS: East African rift system

EGS: Ethiopian geological survey

EMA: Ethiopian mapping agency

EQ: Earthquake

ERC: Ethiopian rail-way Corporation

ERCS: Ethiopian Red Cross society

Ev: Evaporation

EvT: Evapo-transpiration

FAO: Food and agricultural organization

Fig.: Figure

GIS: Geographic information system

Ha: Hectar

ILRI: International live stock research institute

JICA: Japan international cooperation agency

K/Ar: Potassium/ Argon

Km: Kilo meter

LU/LC: Land use land cover

M^3: meter cube

MER: Main Ethiopian rift

mm: mili meter

mt: meter

N: North

NMA: National metrology authority

NPDPM: National Policy on Disaster Prevention and Management

PHE: Population Health and Environment

PRB: Population reference bureau

RRC: Relief Rehabilitation Commission

S: South

W: West

Abstract

Every year, in most urban areas, millions of people lost their lives due to natural hazards. The deadliest natural hazards in urban regions have been landslides, earthquakes and floods. In geologically unique regions where plates diverge, converge or sub duct, hazard intensity increased and huge losses resulted.

In previous years, with similar repeated events (earthquakes, floods and landslides) hundreds of residents of Addis Ababa were inflicted to deaths and properties damaged. Notably, Addis Ababa is geologically dictated by the activities of the Afar plume magmatic rifting and the African magmatic up-wells.

In two separate parts, this paper aims to identify and evaluate landslide and earthquake hazard prone areas and generate hazard risk maps. Yeka, Gullele, Kolfe Keraniyo, and Nefas Silk Lafto are sub-cities of Addis Ababa selected for this research work. While considered the population and land mass proportion, the selected areas encompass 34% and 46% respectively. Most of them have more or less dissected mountain upland morphology characterized by highly to moderately weathered volcanic lava products (basaltic and rhyolitic rocks; mostly cenezoic in age) associated with tectono-siesmic controlled structures (faults and dykes) potential to develop natural hazards.

Current research evidences indicates that, on the rugged up-land hilly regions of Yeka, Gulele, Kolfe Keraniyo and some parts of Nefas Silk Lafto area; affected by the urban sprawls have been significantly marked as vulnerable areas to landslides and earthquake hazards. More often, significant portion of the south western zones where abundant condominiums constructed, i.e. Jemmo, Nefas Silk Lafto sub-city fall under high to moderate landslides and seismic vulnerability values.

Key words:

Natural hazards, Afar plume, magmatic processes, magmatic up-wells, tectono-seismic, Addis Ababa, vulnerability, risk

Chapter I
General Introduction and Description of the Study Area

1 Introduction

1.1 Background

Every year, related to natural disasters, large numbers of people lost their life and huge properties damaged. Factors for these hazard occurrences might be anthropogenic and/or geologic or both. Some places in the globe have a unique geological setting (they are tectonically active regions where either divergent, convergent, or subduction takes place); thus have an adverse effect on natural disaster occurrences and hazards intensively developed.

At Global scale, urban areas than rural have been affected by frequent catastrophes and as a result huge losses of human lives and property damages were recorded every year. Currently, most cities in developing countries suffer greatly with challenges of population pressure (see table 1.1). Besides, majority are found in geologically active zone hence high human death tolls were recorded.

Table 1.1: Most populous countries in the world: 2011 and 2050

Year, 2011		Year, 2050	
Country	**Population**	**Country**	**Population/Proj.**
China	1,346 Mil.	India	1,692 Mil.
India	1,241 Mil.	China	1,313 Mil.
United States	312 Mil.	Nigeria	433 Mil.
Indonesia	238 Mil.	United States	423 Mil.
Brazil	197 Mil.	Pakistan	314 Mil.
Pakistan	177 Mil	Indonesia	309 Mil.
Nigeria	162 Mil.	Bangladesh	226 Mil.
Bangladesh	151 Mil.	Brazil	223 Mil.
Russia	143 Mil.	Ethiopia	174 Mil.

Source: Population Reference Bureau data sheet, *2011(PRB, 2010).*

As population projections (PRB, reports 2009) revealed, significant numbers of the major cities in the world (most are in developing countries) will transform into mega cities; having twenty million people and more (see table 1.1 the projected population).

Amazingly, in most developing countries, large numbers of their urban population settled in marginal lands, quite unplanned (unsafe to human settlement) and often illegal squatter colonies. These squatter colonies, pushed to live on marginal lands, have been poor communities and thus unable to coop-up with natural hazard extremes. Due to this fact, large death toll recorded from this group.

For instance, in the year 2010, in Port-au-Prince's (Haiti), a single earth quake incident killed over 250,000 people; most victims were poor societies. As geo scientists reported, this hazard changed to catastrophic because of the thick sediment base where the city was laid on, thus play an amplification role while seismic waves propagated. (Source:http://WWW.oxfam.org/haitiquake)

In the same period (2010), landslides killed 350 people when Mountain Baduda, (North western Uganda, east Africa) collapsed. This incident was also attributed to geologic and climatic factors.

Addis Ababa, the capital city of Ethiopia and home for more than 3.7 million people, is located in the margin of the Main East African Rift zone (MER). Research evidences showed that the region have been geologically controlled by tectono-siesmic activities of the magmatic processes of the North-West plateau and the East African Rift (D. Bastow, et.al. 2008; Derek Keir, et al., 2009).

As past disaster records revealed, earth quake and landslide hazards repeatedly affected many of the towns and the city itself and consequently more people deceased and properties damaged (Samuel Kindu, 2002); (Pierre Gouin, 1997). The increased rate of disaster was obviously reported from areas that have been more affected by urban sprawls (unplanned urbanization) and factors related to geology and climatic conditions satisfy.

Therefore, this paper tries to tease out land slide and earthquake hazard problems on the up-land urban areas of Addis Ababa city specifically, Yeka, Gulele, Kolfe Keraniyo and Nefas Silk Lafto sub-cities.

1.2 Objectives of the study

1.2.1 General Objectives

- Considerations given to the geological setting of the study area, characterize effects of the urban sprawl/ urbanization, and identify its trend along the selected up-land areas in relation to landslide and earthquake hazard intensification;
- Asses and analyze associated potential landslide and earthquake hazard threats on the urban areas.

1.2.2 Specific Objectives

- Organize and develop questionnaires, conduct interviews, arrange focused grouped discussions so as able to know effects of mountain upland urban sprawls, in regard to landslide and earthquake hazard.
- Collect relevant satellite imageries, aerial photographs, geological, engineering geological, hydrogeological, seismic and topographic maps and perform preliminary desk study.
- Perform field observations and collect primary data on geological features and units: take measurements, capture photographic data and try to trace ground signatures related to landslide and earthquake hazard.
- Based on desk and field study and experts knowledge, assign parameters/ controlling factors which dictate landslide and earthquake hazard occurrence specific to the study area. This includes investigation of susceptible slops to failures of all kind, differentiation of fault zones, and weak zones which may increase vulnerability.
- Collect rock and soil specimens; conduct in-situ and/or laboratory tests, and /or assess secondary data, identify the chemical and mechanical characteristics (engineering geologic and seismic behaviors) of rocks and soils found in the study area.
- By applying GIS facilities, conduct a multi criteria discriminate tool; AHP method (a GIS based method) and made analysis and interpretations.
- Generate vulnerability / risk maps on landslide and earthquake hazards.

1.3 Statement of the problem

Throughout the human history, environmental/natural disasters inflict deaths to many more million humans and properties were damaged. These hazards can be either geologic or anthropogenic/human induced or both.

Currently, most developing countries including Addis Ababa, Ethiopia, suffered by alarming population growth. Rural-urban shifts considered to be the major factor. In these dense urban societies, still the rate of natural increase and fertility rate has been at a higher level which creates stresses on the urban environment; population pressure effect (PRB, 2009).

Reliable economic data reveals that majority of the urban population of these regions live under poor economic conditions that could not withstand stresses due to natural extremes (FAO, 2009 world report). Furthermore, majority of the community is mainly natural resource dependants. This situation may have adverse effects on the natural environment and hence trigger natural hazard events. In regions where unique geologic activities dominate, like for example, Addis Ababa; dictated by the east Africa magmatic rifting; hazardous events would be even more complex and severe thus population at-risk is so large and development will be un-sustained.

More importantly, governments are responsible to safeguard their own citizens from any natural hazard challenges.

Therefore, assessments and identification of prone areas to natural hazards at urban planning scale must be a priority.

1.4 Significance of the study

At present, fast population growth is apparent in most urban centers of the developing countries. At the same time, due to natural hazard occurrences great losses of human lives were exhibited. The most known deadly killers have been landslides, floods, and Earthquakes. Each year, their severity increased. Besides, most are located in geologically active zone, hazards posed are complex and even some have experienced worst catastrophes. While population greatly increased, it is obvious that infrastructural developments like road, bridge, houses, e.t.c., also increased. Where ever intense human actions present, the natural environment mostly abused. Moreover, marginal lands including very steep terrains and river sides will be affected thus natural/ environmental hazard occurrences escalate.

In a given society, governments should be committed to satisfy community needs, maximize their benefits and ultimately, insure citizen's safety. Especially, in areas where mainly tectonic activities predominate, great concern should be paid to decrease human life losses due to natural disaster occurrences. Accordingly, potential environmental / natural hazard assessment and evaluation must be carried out. If clearly identified, help full to devise the necessary preventive and mitigation measures that would possibly minimize human life losses prior or after any occurrences of natural hazard.

Therefore, this research study will provide valuable information on potential landslides and earthquake hazards to planners/development professionals and decision makers.

1.5 The scope of the study

Currently, in Addis Ababa city, population pressure creates challenges on the urban natural environment. Further, the tectono-seismic conditions prevailed in the area (effect of magmatic rifting activities), the rugged morphology constructed by volcanic materials associated with climatic factors; intense weathering and significant precipitation aggravate the occurrence of landslide and earthquake hazard. In the past periods, landslide and earthquake hazards repeatedly occurred and killed large numbers of humans.

For the following two reasons, this research work strongly focused on the city's most prominent natural hazard events, i.e. landslides and earthquake.

Firstly, associated with the effects of urban sprawls i.e., mainly unplanned squatter colonies often settled on the up-land region and impact of the prevailed geological factors (tectono-seismic activities) landslides and earthquake hazards have been current urban community threats.

Secondly, based on statistical reports, at a global scale, landslides and earthquake hazards are deadly killers and still pose sever challenges and treats to most urban societies. Even though their fatality rate increased, it is less addressed and more work has been required. Therefore, this study was aimed to assess, and analyze landslide and earthquake hazard and generate usable vulnerability/ risk maps for the selected sub-cities of Addis Ababa (Yeka, Gullele, Kolfe Keraniyo, and Nefas Silk Lafto), which cover forty six percent of the total land mass and thirty six percent of Addis Ababa city's population.

1.6 Choice of the Study Area

In addition to the current fast urban population growth effect, spread of urban sprawls along mountain up-land regions critically, contribute natural hazard developments. Considering this fact, sample areas were selected based on the following criteria:

- Population numbers at risk (density) and spatial location and settlement pattern: The selected areas have been comparatively the most densely populated and pushed to live on marginal lands/poor as well; widely **v**ulnerable to environmental/natural hazard extremes often unable to coop-up disaster strategies
- Effects of geology, topography and climatic factors: Most of the area has been dictated by tectono-siesmic activity of East African magmatic rifting. The rugged morphology and dissected volcanic mountains owned a tropical climate as a result showered by significant precipitation thus intense weathering activated consequently, prone to various environmental/natural hazards.

1.7 Description of the study area

1.7.1 Location of the study area

Addis Ababa is located at latitude 09° 02' and longitude 38° 44'. It has a total area of 51,948.89ha (Parcel-sheet of Addis Ababa May, 2012).The city has been sub divided into ten sub-cities. The target area where this research focuses has been mainly contained the higher relief areas (the mountain region of the upland areas) of the city. It encompasses the four most densely populated sub-cities namely, Yeka, Gulelea, Kolfe Keranyo, and Nifas Silk Lafto sub-cities. Specifically, the target area covers 35% of the total area. In general, the city overlies at the western margin of the Main Ethiopian Rift and is part of the North, and north western mountain highland regions of Ethiopia, which comprises the mountain ridges of Entoto, Wochecha, and Furi. The city has been mainly in-circled by these neogene volcanic mountains and in addition at the far Eastern side by Yerer Mountain. These mountains are found in the North and North east, West, South-West, and East of the city respectively. To a large extent, the city has been sporadically stretched along these particular high relief areas so significantly impacted by urbanization.

The altitude ranges from the highest peak on mt Wochecha that exceeds 3400 m a.s.l and the lowest part which is 1850 m a.s.l found in south of the city i.e., Abasamuel lake. (BCEOM and Seureca, 2000)

The study areas have been specifically enclosed between altitudes of 2,200ma.s.l.in Nifas Silk Lafto area and 3,000m a.s.l., in top of Entoto mountain uplands. Out of the total land mass of the city, this research covers forty six percent.

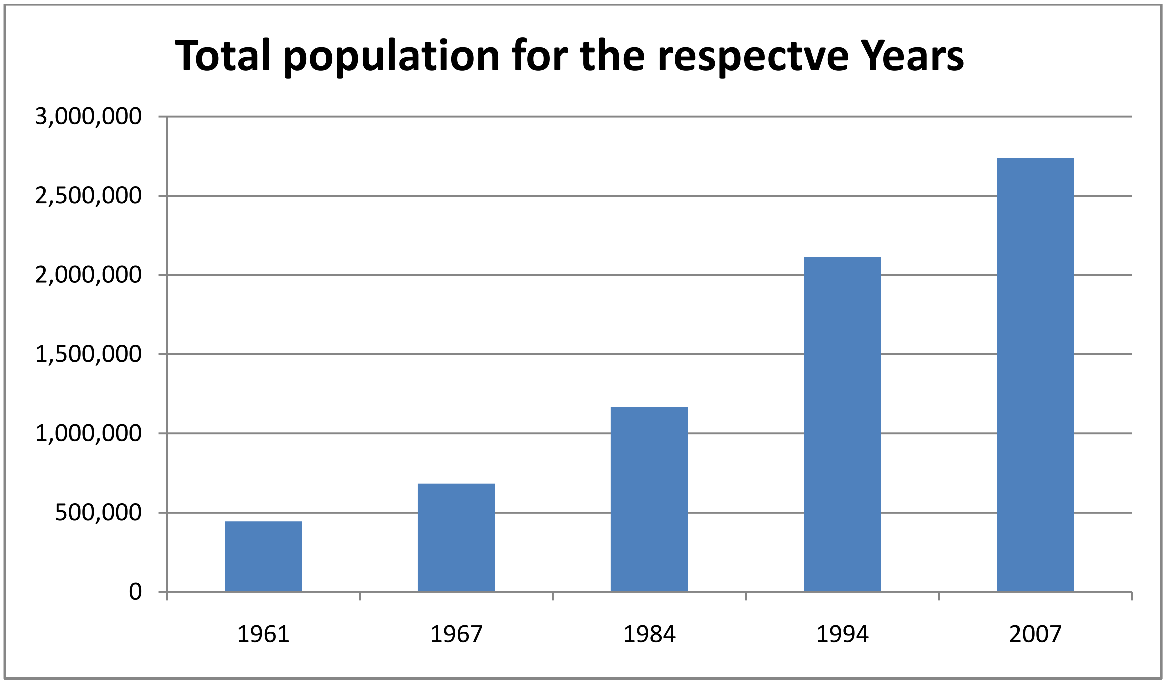
1.7.2 Population of the study area

Current population of Addis Ababa City is over 3 million with an annual growth rate of 3.8 percent (CSA, 2007).

Out of the city's total population nearly half it resides in the study areas (1,358,623 people). Compared to the others, they are the most populous sub-cities (CSA, 2010).

While it was infant (at the regime of emperor Menilik), the population was estimated about 100,000. Within the time span of 100 years population increased dramatically and current is 3.7 million (see Table 1.2).

Table 1.2: Total number of population in the respective years, Source: central statistics agency, 2009



As population increased wider areas of the near-by farm lands have been transformed to developed urban lands. Consequently, total area of Addis Ababa city greatly increased from 222.04 km^2 in 1984; to 530.21 km^2 in 1994, and at present reached 636 Km^2.

The population density of Addis Ababa is 3984 persons per km^2. The densities of population in urban and rural sectors of the city are 7008 and 121 persons per Km^2 respectively.

The annual population growth for Addis Ababa city is 2.1 percent (CSA, 2010).

1.7.3 Land use Land cover

Importantly, the urban land mass have been classified as green areas (encompassing forests, grass lands, buffer zones); settlement areas, industrial zones, public services and amenities, cultural heritages. Industrial zones have been dominantly found in the southern and south western parts (e.g., Nefas Silk Lafto and Akaki sub-cities) of the city. Major economic sectors (market and business areas), and cultural heritages have been placed in the main central city part (see Fig 1.1 bellow).

The huge expanse of the research project area, significantly, the high relief mountain upland regions constitute forest, grass land, agricultural lands, residential areas (squatter settlements highly pronounced), and significant numbers of small and medium industries. Industries and highly populated condominium houses are found especially in areas of Nifas Silk Lafto sub-sity.

Ruminant indigenous forests like Juniperus Procera and Ficus vasta species on highly degraded soil profiles have been observed in the higher relief areas of Entoto and Wochecha Mountain which is an implication to the past vegetation cover types (see Plate1.1).

In those mountain upland areas, even on the face of the hilly steeper slops; traditional agriculture has been intensively practiced. On the embankments of little Akaki and Bantyiketu rivers, urban agriculture (vegetable producer cooperatives) has been widely established and intensive vegetable farming practices have been carried out (JICA, 1998).

Plate 1.1: Indigenous forests species cleared for human settlement, farming and quarry activities. The plate shows one of highly degraded mountain parte in Yeka sub city,AA

In addition, following the major rivers/ streams embankments, animal husbandry has been also widely practiced. Large portion of the city's land have been used as residential area (Fig.1.1). Within and around the study areas, intense unplanned constructions (like housing, Road, and other infrastructures) have been greatly carried out, and hence lead to develop various potential environmental and natural hazard problems including flood, landslides, and pollution. (City development plan, 2010).

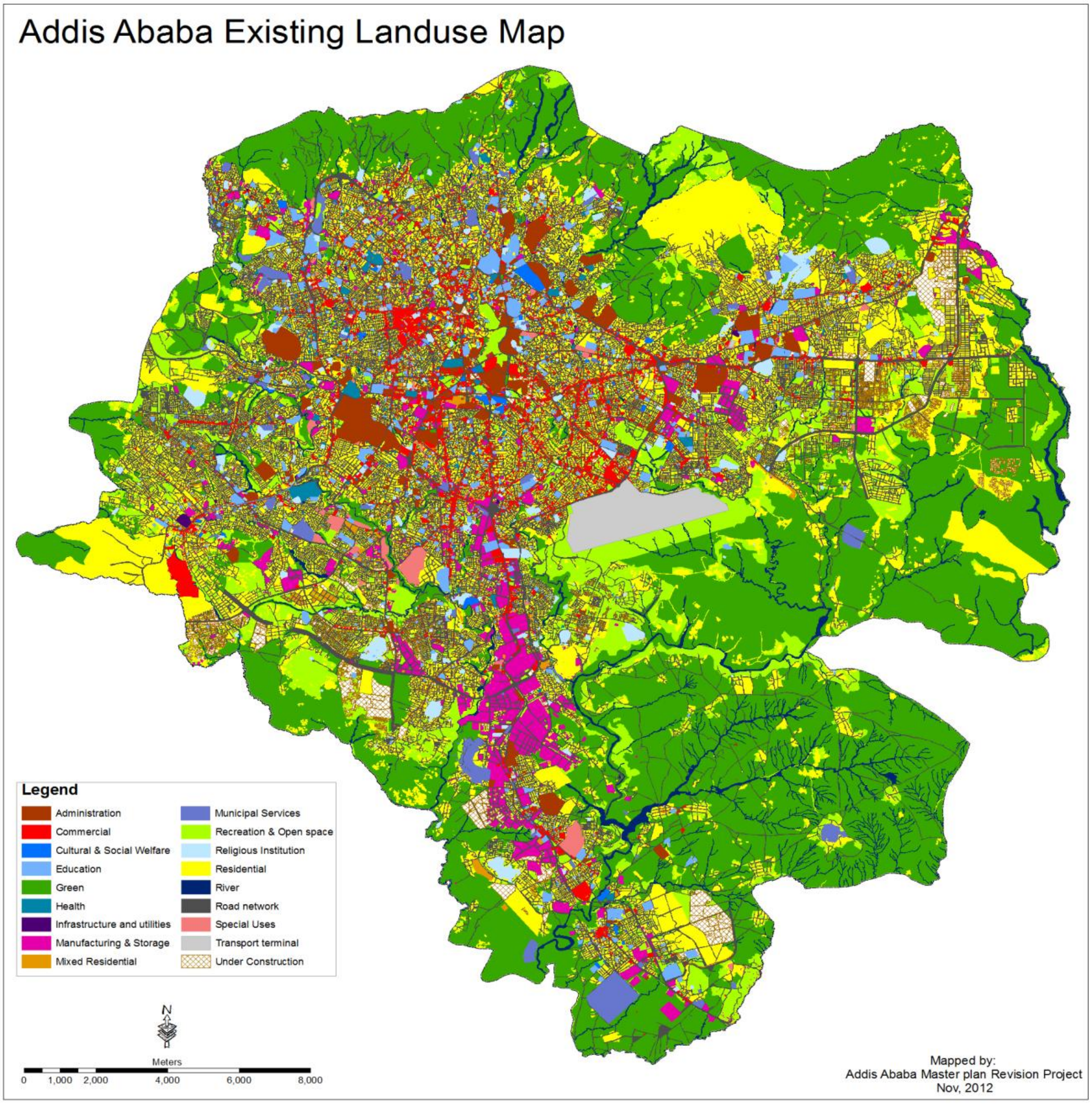


Figure 1.1: Existing land use map of Addis Ababa. Source: AAOIPPO, 2012

Table 1. 3: Current land use classification/type, Source: AAOIPPO

Layer	Gross Area (Ha)	Gross%	Net Area(Ha)	Net %
Administration	902.30	1.74	902.30	3.39
Commercial	736.34	1.42	736.34	2.77
Cultural & Social Welfare	114.38	0.22	114.38	0.43
Education	855.45	1.65	855.45	3.22
Green	19916.62	38.33		38.4
Health	185.76	0.36	185.76	0.70
Infrastructure and utilities	23.34	0.04	23.34	0.09
Manufacturing & Storage	1724.15	3.32	1724.15	6.48
Mixed Residential	812.81	1.56	812.81	3.06
Municipal Services	502.09	0.97	502.09	1.89
Open space	4362.16	8.40		8.38
Recreation	105.02	0.20	105.02	0.20
Religious Institution	612.28	1.18	612.28	2.30
Residential	12270.34	24.58	12270.34	48.03
River	1090.08	2.10		0.2
Road network	5233.94	10.07	5233.94	19.68
Special Uses	345.73	0.67	345.73	1.30
Transport terminal	529.34	1.02	529.34	1.99
Under Construction	1135.23	2.18	1135.23	4.27
Total	51957.94	100	26589.09	100

Table 1.4: Land use classification of AA city, 1988

	Description/Layer	Area(ha)	Distribution
1	Built-UP Residential area	8054	15.7%
2	Residential Expansion	10445	20.4%
3	Party & government Institution	2617	5.1%
4	Higher Education & Research centers	247	0.5%
5	Commercial & business center	303	0.6%
6	Transport related activities	1759	3.4%
7	Zonal office/administration	324	0.6%
8	Industrial	2269	4.4%
9	Embassies	238	0.5%
10	Green area	14580	29%
11	Wood land	1662	3.2%
12	Functional green for permitted uses	8518	16.6%
	Total	**51016**	

Figure 1.2: Former scene of AA city at its infant stage (1915).The plate shows the western part of the grand palace (Yeduro Kera)and its vicinities.Formerly, areas were covered by grass lands and tall indigenous tree species like Accacia, Juniperus and etc

Figure 1. 3: Intensive quarrying and traditional agricultural practices carried out on the very degraded mountain uplands i.e., 2874mt a.s.l (Entoto Mountain) trigger soil erosion, flood hazard, and hinders rain water infiltration hence hydrological system haults.

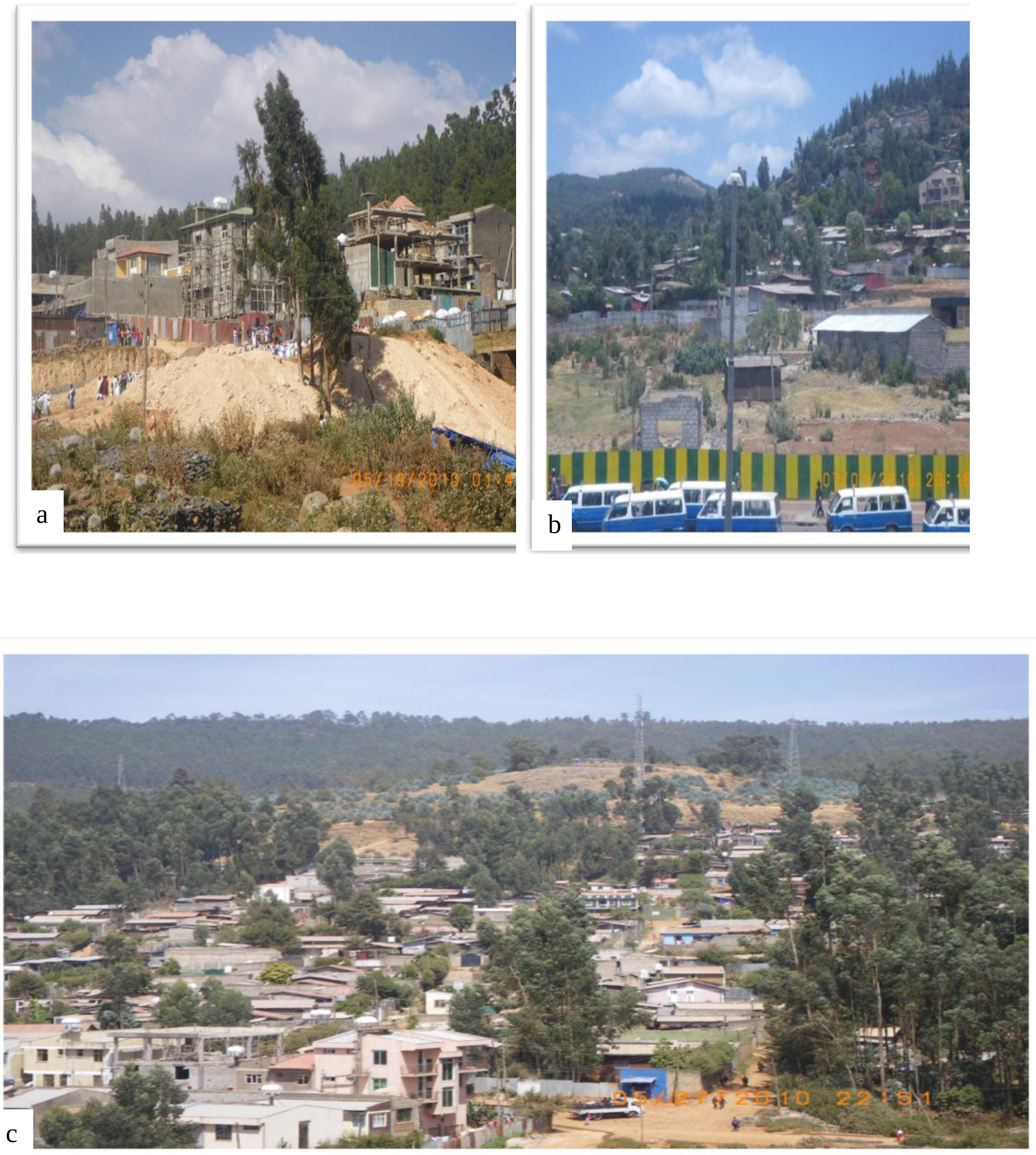


Plate 1.2: The steeper mountain areas (a,b,and c) of Megenagna, Egziabhere-Abe and Shegole (Entoto mountain ridges) respectively impacted by dense residential buildings; major triggering factors for erosion, landslides and flood problems to occur.

1.7.4 Climate and weather in the study area

The climate of the country is dominated by altitude. The same is true in the case of Addis Ababa.

National Atlas of Ethiopia (1981) defined five climatic zones: "Kur" (Alpine), 3000 m and above mean sea level; "Dega" (temperate), 2300 m to about 3000 m; "Weina Dega" (Sub tropical), 1500 to about 2300m; "Kolla" (Tropical), 800m to about 1500m and "Bereha" (Desert), less than 800m,a.s.l.

According to Daniel Gamachu,(1977) there are various climatic zones. Javier Gozalbez and Dulce Cebrian, (2008) also defined the climatic zones of the country as high wurch, (Alt. 3,700m.a.s.l. and T^o below 5 C^o); Wurch(Kur), Alt. 3700-3,200m,a.s.l.,and T^0 5-10 ^oC; Dega, Alti. 3,200-2,300mt a.s.l., and T^0 10-15 ^0C; Weina Dega, Alt. 2,300-1,500, and T^0 15-20C0; Kolla, Alt. 1,500-500mt, a.s.l., and T^0 >30 C^0; and Bereha, Alt. below 500m a.s.l.; and T^0 of above 40 C^0. The study area has a maximum and minimum elevation range of 3,200mt a.s.l, and 2,200m, a.s.l., on tip of Entoto and Ertu-Mojo area/Furi respectively. Most part of Addis Ababa falls under the Weina Dega (Sub tropical) category. According to the above classification, major part of the study area falls under category of Dega, and relatively its small portion fall under Weina-dega, and Wurch climate.

Accordingly, the climate of Addis Ababa as a whole is typically characterized by two distinct seasonal weather patterns: the wet season which extends from June to September, contributing about 70% of the annual rainfall, and the dry season which covers the period from October to May with a minor rainy season in March and April (Belg), and it is well known for its frequent failure. Such climates which are characterized by alternating wet and dry seasons may favor weathering.

1.7.5 Temperature

Highest temperature in the region was observed for the months of March, April, May and June. While the months October, November and December had the lowest temperatures. The maximum temperature varies on average between 20° C in the wet season and 25° C in dry season, while the variation of minimum temperature falls in the range of 7° C to 12° C throughout the year. Daily variation in temperature is more pronounced than the annual variation.

Table 1.5: Long year temperature records in the study region

Parameter	Station	Period	Month												Total
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Temprature	Entoto	1989-2004	19.1	19.7	19.9	19.4	20.1	17	15.9	15.9	15.8	16.8	18.6	17.5	1115.2
	AA Obs	1980-2005)	23.9	24.9	25	24.5	25.1	23.4	21	20.9	21.7	22.7	23.1	23.2	279.6
	AA Bole	1980-2004)	23.8	23.8	26.3	24.8	25.3	23.5	21.2	21.1	21.8	22.9	23.2	23.2	280.8
	Akaki	1997-2004)	26.3	27.3	27.4	27.3	28	26.3	24.3	23.8	25.3	25.8	25.9	25.9	313.6
Mean			**23.3**	**24**	**24.7**	**24**	**24.6**	**15.9**	**20.6**	**20.4**	**21.2**	**22.1**	**22.7**	**22.5**	265.8

Data Source: National Metrological Agency, 2010.

1.7.6 Rain fall/precipitation

The Ethiopian territory is divided into four zones marked as **A**, **B**, **C**, and **D**; each of them with different precipitation patterns. The seasonal classification and precipitation regimes of Ethiopia (after NMSA, 1996) are characterized in Table 1.7.

Table 1.6: Long year rain fall records in the respective recording stations, Data Source: EMA

Parameter	**Station**	**Period**	**Month**												**Total**
			Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun**	**Jul**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	
Rain fall	Entoto	1989-2004	15.6	38.3	61	87.2	43.2	102.2	265.3	317.1	138.4	27.2	9.9	9.8	1115.2
	AA Bole	1980-2004	11.8	33.6	68	93	71.1	122.5	235.9	240.3	133.5	30.9	3.2	4.9	1248.8
	AA Obs	1980-2005	14.2	39.1	68.9	91.5	83.7	136.2	262.4	272.9	168.7	34.9	5.8	9.2	1187.4
	Akaki	1975-2004	14.1	29.8	76.7	86.1	68.5	115.2	255.4	258.5	118.8	25.1	3.6	3.2	1055
Mean		1975-2004	**23.3**	**24**	**24.7**	**24**	**24.6**	**15.9**	**20.6**	**20.4**	**21.2**	**22.1**	**22.7**	**22.5**	265.8

1.7.7 Zone Precipitation pattern

Table 1.7: Classification of country's zonal precipitation pattern, Data source NMSA,1996.

Zone	Classification Criteria
A	This region mainly covers the central and central eastern part of the country. It is characterized by three distinct seasons, and by bimodal precipitation patterns with small peaks in April and the main rainy season during mid June to mid September with peaks in July.
B	This region covers the western part of the country. It is characterized by a single precipitation peak. Two distinct seasons, one being wet and the other dry, are encountered in this region. The analysis of mean monthly precipitation patterns shows that this zone can be split into southwestern (b1) with the wet season during February/ March to October/November, western (b2) with the wet season during April/May to October/November, and northwestern (b3) with the wet season during June to September.
C	This region mainly covers the southern and southeastern parts of the country. It has two distinct precipitation peaks with a dry season between. The first wet season is from March to May and the second is from September to November.
D	The Red Sea region in the extreme northeastern part of the country receives diffused precipitation with no distinct pattern; however precipitation occurs mainly during the winter.

The mean annual rainfall at Addis Ababa Observatory is about 1248 mm. Table 1.6 shows the monthly distribution of rainfall as observed at rain-gauge stations in Akaki, Bole, and Entoto.

Generally, the annual rainfall value is observed to increase with elevation. Temporal variation of annual rainfall about the mean from 1980 to 2005 at Addis Ababa Observatory is represented by Table 1.5.

Latitude, altitude, winds and humidity, with varying magnitude have significant impacts on temperature conditions in Ethiopia.

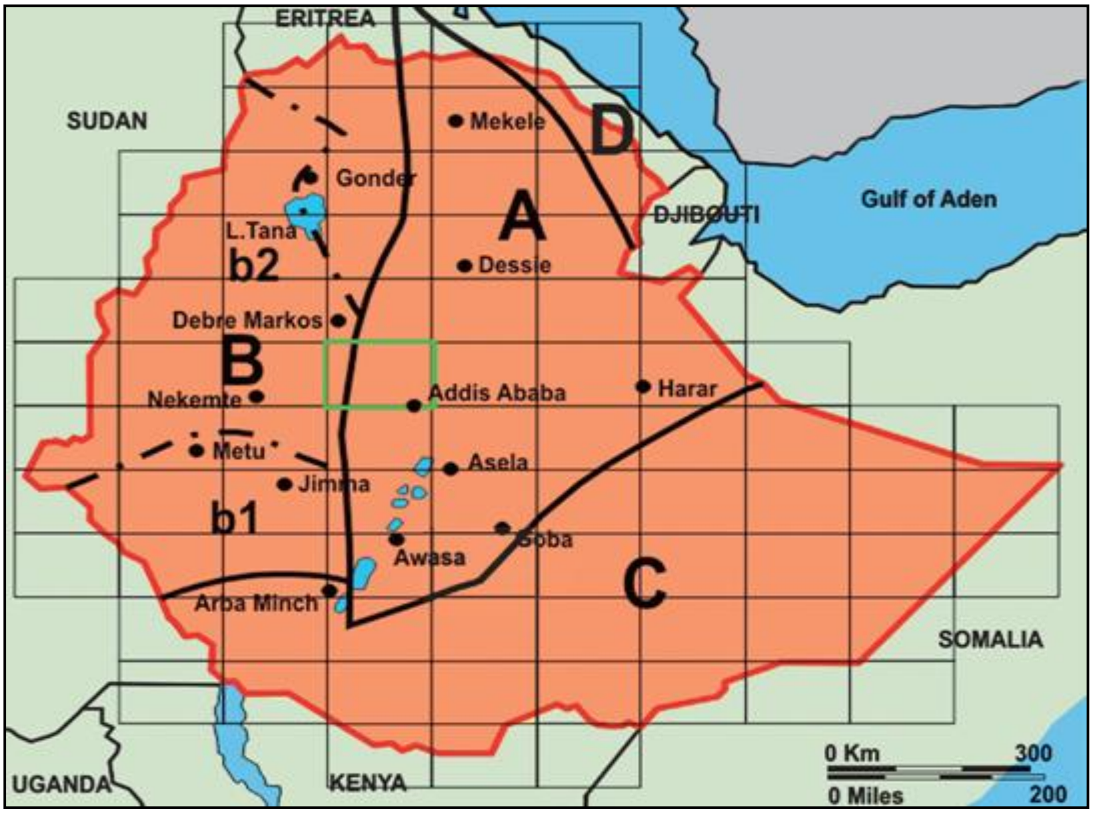


Figure 1.4: Climate classification of Ethiopia, Data Source: Geological Survey of Ethiopia (GSE), (2010)

1.7.8 Relative humidity

The relative humidity of the area determines the rate of evaporation. The mean relative humidity of the area recorded at the Addis Ababa (Akaki) station is 58.5 % and reaches its peak in the rainy season from July to September, while the minimum relative humidity is registered in March and December (Fig. 1.5). The annual range of relative humidity is about 40 %.

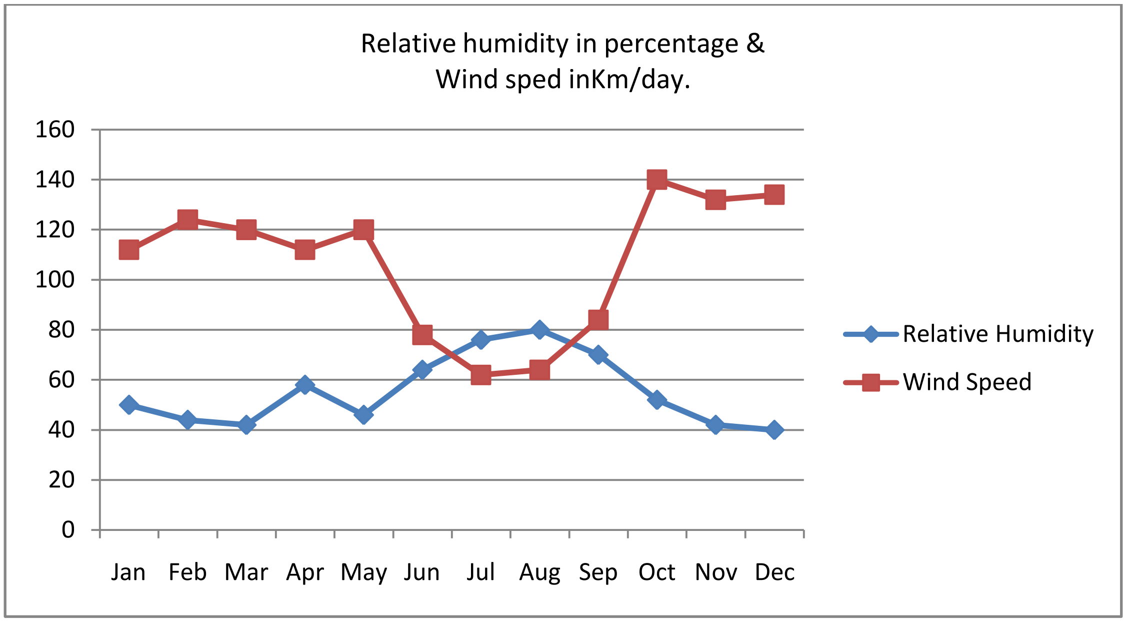


Figure 1.5: Relative humidity in percentage and wind speed in Km/day, Data source: National Meteorology Agency, (2009).

1.7.9 Sun shine Hours and Radiation

The total daily evapo-transpiration rate is dependent on the total daily sunshine hours. It can be noted from Fig. 1.6 that the mean maximum number of sunshine hours is recorded in November and December whilst the mean minimum is registered in July and August. Average daily sunshine hours as high as 9.5 hours are observed in November and December; and this figure dropped to 3 hours or less in July and August.

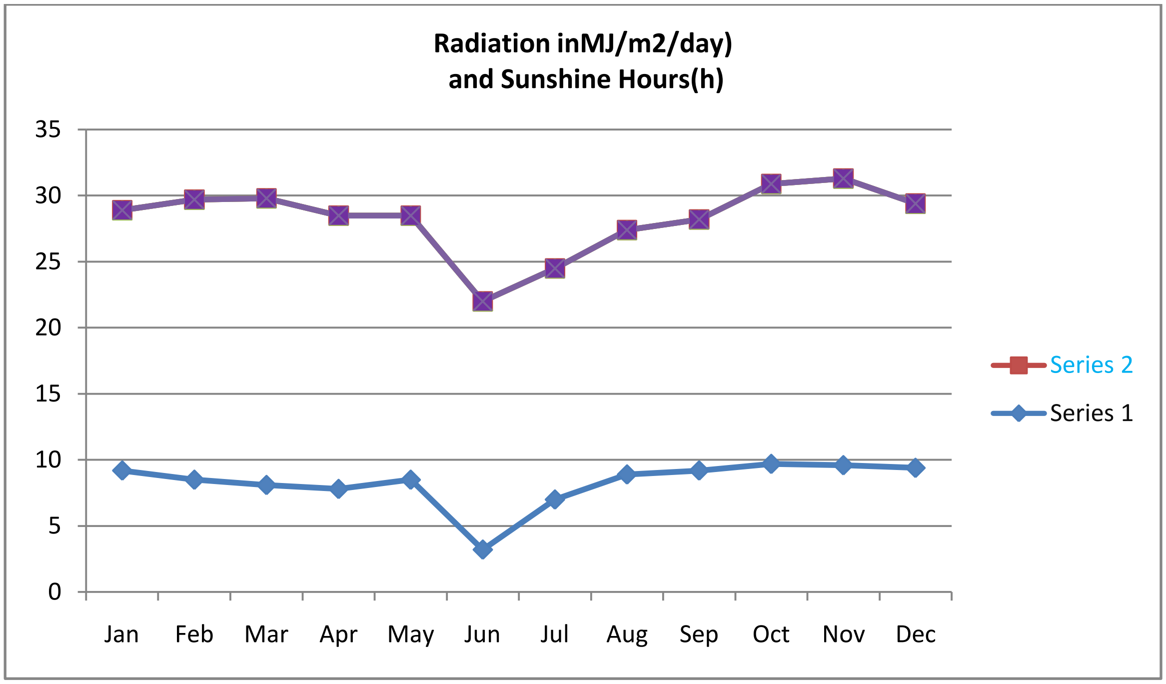


Figure 1.6: Radiation in MJ/m2/day and sun shine hour in (h)

Data source: National Meteorology Agency (2009).

1.7.10 Wind Speed

One of the factors of evaporation is wind speed. Any decrease in wind speed, resulting in the non removal of saturated vapor, affects the evaporation rate. The wind speed at the Addis Ababa metrological station reaches its peak in October and the wind is relatively calm in the month of July and August (see Fig. 1.5).

1.7.11 Evapo-transpiration

Evapo-transpiration is the combination of soil evaporation and vegetation transpiration and has a considerable impact on the water balance of the study area. The Piche evaporation (Ev) is shown together with the potential evapo-transpiration (EvT) in (Fig. 1.7).

The mean annual pan evaporation value obtained for data between 1979 and 2000 at Addis Ababa Observatory is about 1389 mm with mean monthly pan evaporation of about 116 mm and this value falls down to 58 mm in wet season (July).

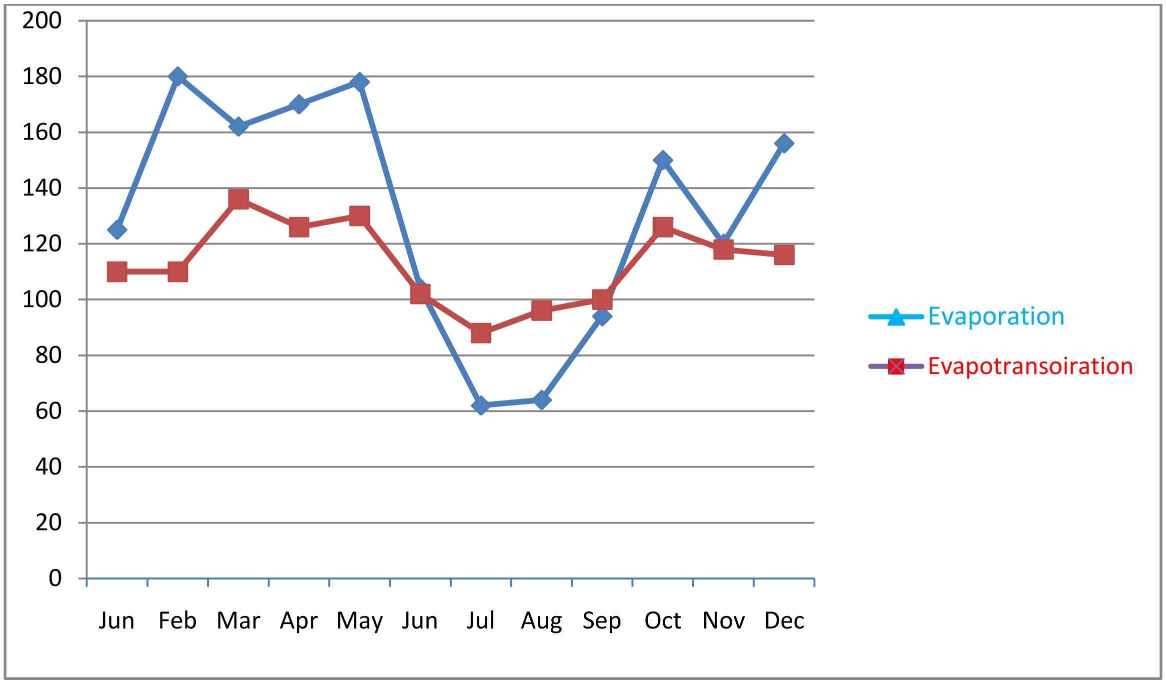


Figure 1.7: Evaporation and evapo-transpiration, Data source: National Meteorology Agency, (2009).

1.7.12 Geo-morphology/Landform

Dominantly, undulating mountain ranges in the North, North eastern and western part of the city are depicted. The central part encompasses mainly gentle slopes, and plateaus. The southern part is more or less plain.

The city is encircled by Cenozoic volcanic mountains of Entoto, Wochecha, Furi and Yerer. They have stretched North and North East, West, South west and East of the city respectively.

The volcanic mountains; Mt. Wechecha situated in the west, Mt. Furi, located to the north-west and Mt. Yerer, located southeast are the high massive volcanic centers rising to elevations of 3385, 2839, 3100 and 2989 m a.s.l, respectively. Seventy percent of the total land mass is mountains and uplands. Various researches have showed that the morphology of the region has been greatly influenced by magmatic process of the North western plateaus and the East African Rifting activities (e.g., I. D. Bastow et.al, 2008; Derek Keir, 2005). Those areas where high relief is more pronounced/mountain upland regions have been the major sources of water for the adjacent down slop areas. Basically, the upper plateau region is an initial point to most rivers and streams found in the study area. The morphology also plays an important role in the micro climatic conditions of the city. In general, five streams and rivers have been recognized in Addis Ababa city (JICA, 2008). The occurrence of ground water resource has been highly dependent on the existed morphology of the region. Accordingly, thirty percent of the water requirements coverage of the city has been supplied from ground water developments (AAWSA, 2007).

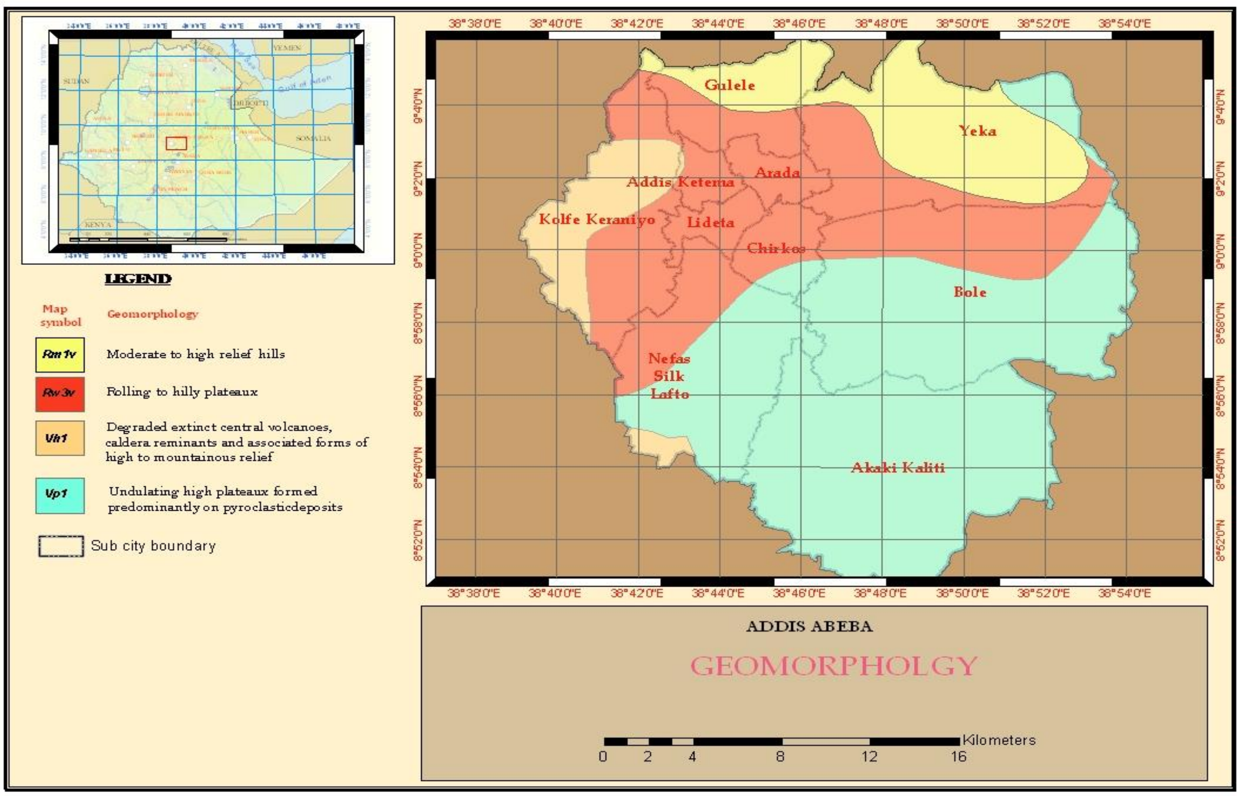


Figure 1.8: Geo-Morphology of the study areas, AA city (Temesgen Assefa, 2012).

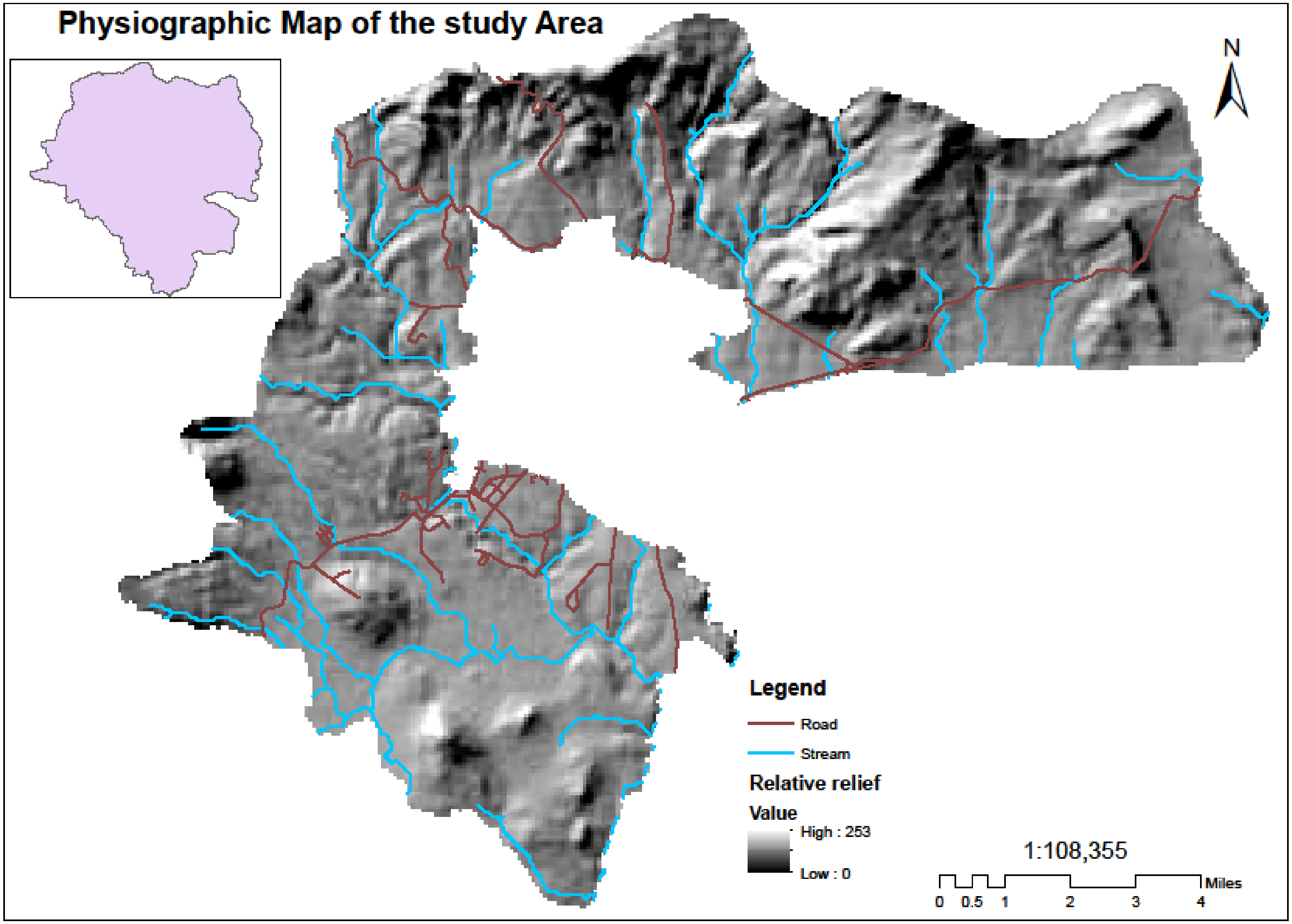


Figure 1. 9: Physiographic map of the study area; AA city (Temesgen Assefa, 2012).

1.7.13 The regional drainage pattern

Addis Ababa is found in adjacent with the highly dissected uppermost catchments area of the Awash River basin. Five Major rivers systems crossing the city have been originated from the mountain uplands of Entoto, Wochecha, and Furi, (Fig1.9). These are Bantyiketu, Kebena, Little Akaki, Big Akaki, and Hanku. The two main rivers importantly use full for urban agriculture, industrial, and domestic purposes to the large numbers of the city's dwellers, have been drained from North-East to East and from West to East are the big Akaki and the little Akaki rivers respectively. Various numbers of perennial and intermittent rivers join both big and little Akaki River and then lead to Awash River. The drainage pattern of the city is mainly dendritic and some streams are structurally controlled by the rifting system.

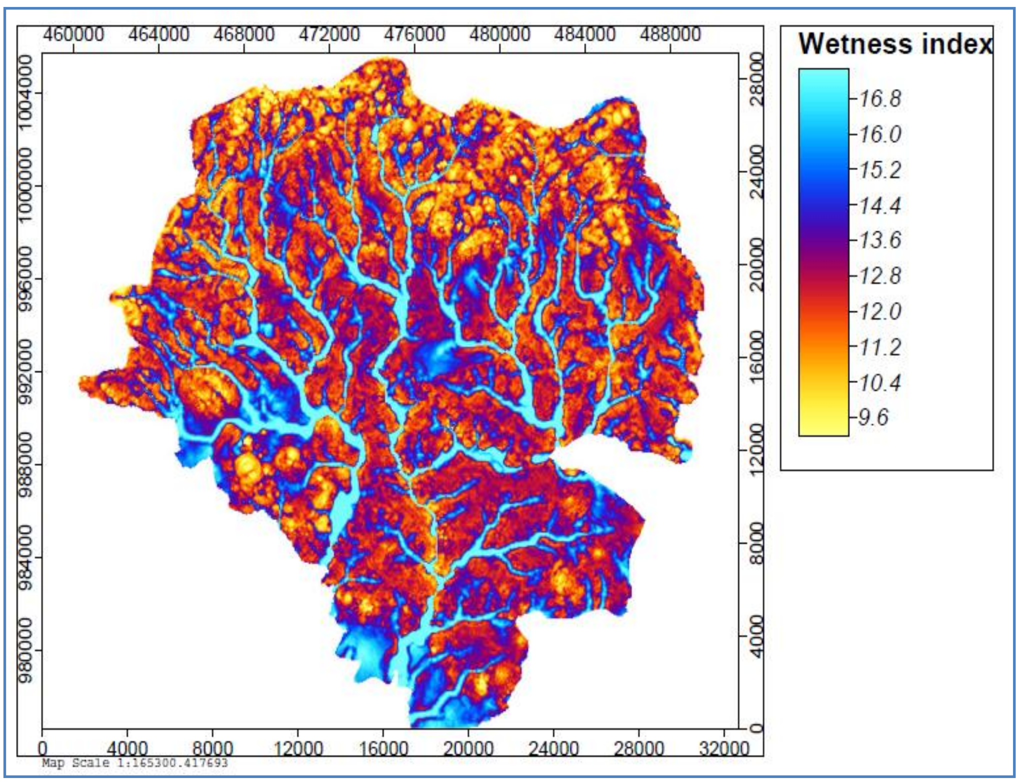


Figure 1.10: Drainage pattern and wetness index of the study area, AA city, Source: CLUVA

The wider expanse of the urban area is characterised by plains, rolling terrains and river gorges which are highly impacted by erosion and floods hence vulnerable to wider extent of environmental/ natural hazard occurrence. The inner city part has been mainly dominated by undulating and flat topography and gradually the flatness dominates farther to the southern part of the city (Fig. 1.8 and 1.9).

1.8 Regional and local geology

1.8.1 Regional Geology

The earliest Cenozoic volcanism in East Africa occurred in SW Ethiopia and the Turkana depression in northern most Kenya at 40–45 Ma [e.g., Ebinger et al., 1993; George et al., 1998; Furman et al., 2006]. Approximately 2 km of basalts and subordinate Rhyolites were then erupted rapidly across the Ethiopian Plateau at 29–31 Ma [Mohr, 1983; Hofmann et al., 1997] prior to or concomitant with the onset of rifting in the Red Sea and Gulf of Aden [e.g., Wolfenden et al., 2004]. Additional isolated shield volcanism in the interval 30–10 Ma occurred across the Ethiopian Plateau and added 2 km of additional local relief in areas such as the Simien, Choke, and Guguftu shield volcanoes [e.g., Kieffer et al. 2004, Tesfaye, 1988].

The geological setting of Addis Ababa region is contained in the initial edge of the north western plateau volcanic trap series and the margin of the Main Ethiopian Rift Valley as well. The margin is more recent, shows Mio-Pliocene volcanics and is characterized by normal faults down thrown towards the rift. The upper (outer) boundary of the margin is marked by the large fault running approximately east-west immediately north of the Addis Ababa-Ambo road. The lower boundary, according to Morbidelli et al., (1973) quoted in Zanettin et al. (1974), run northeast to southwest parallel to the principal systems of fissures of the rift-floor from Nazareth to Awash Station.

The tertiary Ethiopian volcanism occurred in three main stages separated by periods of quiescence. These are; the pre-Oligocene stage (Ashangi formation), the Oligocene-Miocene stage (Aiba, Alaji and Tarmaber formations) and the Miocene- Pliocene stage (Balchi and Bishoftu formations) (Zanettin et al, 1978)

1.8.2 Local Geology of Addis Ababa and the study area

Though, it has been based on the country level, the geological and stratygraphic sequences of Addis Ababa have been discussed by various researchers. Accordingly, the region has been characterized by wide range of volcanic rocks of different ages and types.

Based on stratygraphic disconformities, Blandford has divided the geological formation around Addis Ababa in two groups; the older Ashangi group and the younger Magdala group.

The older Ashangi group contains compact basalts with inter bedded trachytic flows in the upper part and frequent sedimentary intercalation.

Taken from different literatures and field works, and based on K/Ar absolute age determination, Haileselassie Girmay and Getaneh Assefa (1989) established the stratigraphy of Addis Ababa region. The suggested Miocene – Pleistocene volcanic succession from bottom to top are Alaji Basalts, Intoto Silicics, Addis Ababa Basalts, Nazareth Group and Bofa Basalts.

1.8.2.1 Alaji Basalts (end of Oligocene to Middle Miocene)

This unit is composed of basalts, which show variation in texture from highly porphyritic to aphanitic. The unit is intercalated with gray and glassy welded tuff. The outcrops of Alaji Basalts are situated in the North and Northeastern part of Addis Ababa. They form high topography and rhyolites have more areal extent than trachytes. Trachytes and rhyolites are contemporaneous in age. The Alaji basalt is underlain by tuffs and ignimbrites and is overlain by the Entoto trachyites (Mohr, 1967).

1.8.2.2 Entoto Silicics /Tarmaber basalts/ (Early Miocene)

The unit is unconformably overlain by Addis Ababa basalt on the foothills of Entoto hills and underlain by Alaji basalt. The Entoto silicics is composed of rhyolites and trachytes with minor amount of welded tuff and obsidian (Hailesellase Girmay and Getaneh Asefa, 1989). The rhyolitic lava flow outcrops on the top and the foothills of the Entoto ridge, predominantly in the western side. It also outcrops in the eastern part of the town around Kokebe-Tsebah secondary school (Kebena area). The thickness is quite variable as it frequently forms dome structure. In this rock unit, flow banding, folding and jointing are common.

These early Miocene Silicic volcanics may represent localized terminal episodes to massive Oligocene fissure-basalt activity in the Addis Ababa region (Morton et.al., 1979). The thickness becomes maximum on the top of Entoto ridge and thin both towards the plateau and the plain east of Addis Ababa. Regionally the Entoto basalts are classified as the Tarmaber basalt.

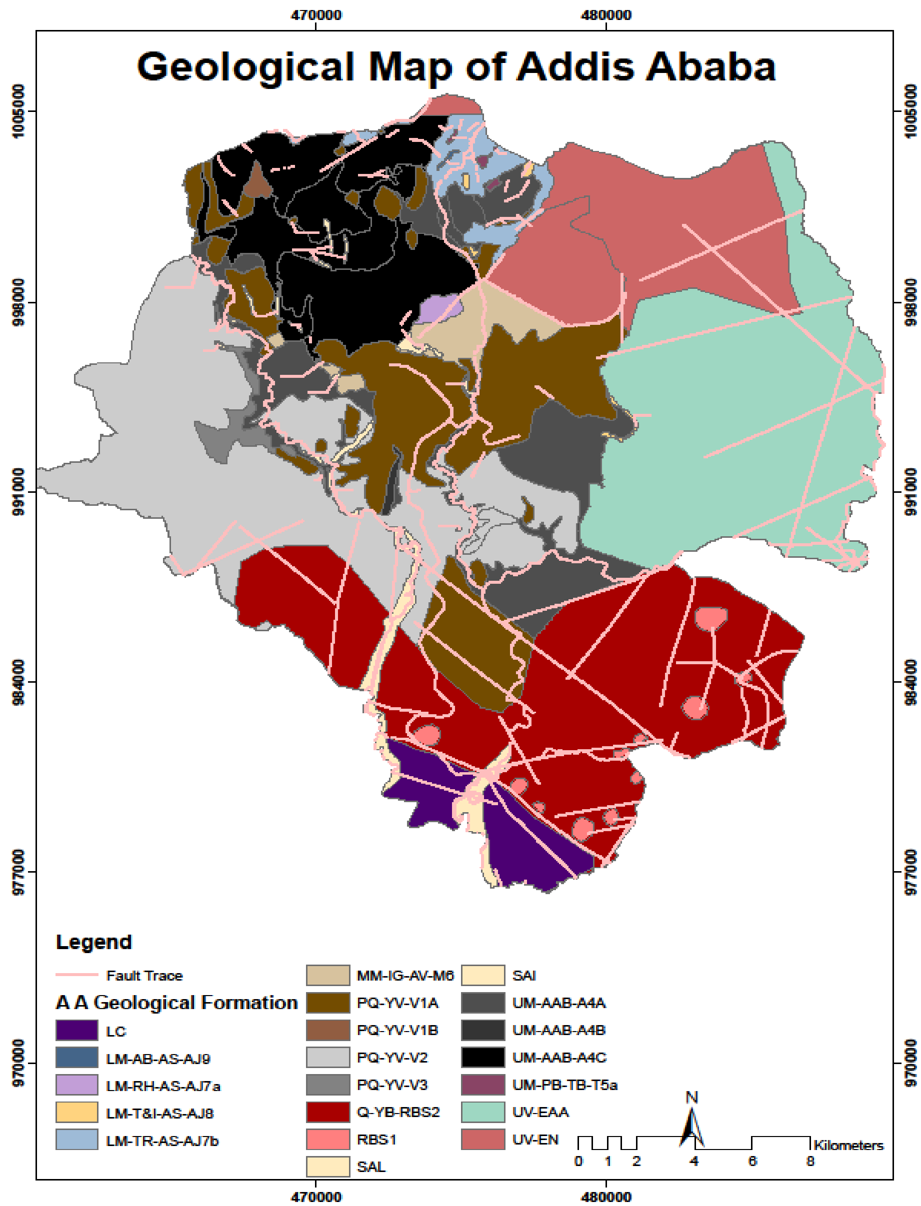


Figure 1.11: Geological map of Addis Ababa city, (Source: GSE, 2008).

Abbrivated words represent the following formation names: LC, clays and silts; LM-AB-AS-AJ7, Lower Miocene aphanitic basalts of Alaji series; LM-RH-AS-AJ7a, Lower Miocene rhyolites of Alaji series; LM-T&I-AS-AJ8, Lower Miocene Alaji Series Tuffs and Agglomerates; LM-TR-AS-AJ7b, Lower Miocene trchy basalts of Alaji series, MM-IG-AV-M6, Middle Miocene coarse grained ignimbrites of acid volcanic; PQ-YV-V1A, Pliocene to quaternary ignimbrites of young volcanic; PQ-YV-V1B, Tuffs of Pliocene to quaternary young volcanic; PQ-YV-V2, Trachytes of Pliocene to quaternary young volcanic; PQ-YV-V3, Trachy basalts of Pliocene to quaternary young volcanic; Q-YB-RBS2, Quaternary younger basaltic lavas, cinder cones and hydromagmatic deposits of pyroclastics ; RBS1, Scoria cones of quaternary younger basaltic lavas, cinder cones and hydromagmatics; SAL, SAI, Quaternary alluvial and elluvial soils; UM-AAB-A4A, Upper Miocene Addis Ababa aphanitic basalt; UM-AAB-A4B, Upper Miocene Addis Ababa porphyritic basalt; UM-AAB-A4C, Upper Miocene olivine basalt; UM-PB-TB-T5a, Upper Miocene Tarma ber porphyritic basalt; UV-EAA, Undifferentiated volcanics, ignimbrites, tuffs, rhyolites with subordinate trachytes; UV-EN, undifferentiated volcanic predominantly trachytes, trachy basalts and basalts with phenocrysts.

The rhyolites are overlain by porphyritic trachytes and underlain by a sequence of tuffs and Ignimbrites. Tuffs and Ignimbrites are welded and characterized by columnar jointing. The trachytic lava flow outcrops on the top of Entoto ridges and its foothills. The trachyte and the Alaji aphanitic basalts are separated by paleo soil indicating time gap.

1.8.2.3 Addis Ababa Basalts

Stratigraphically, this unit which is mainly present in the central part of the town are underlain by the Intoto silicics and overlain by lower welded tuff of the Nazareth group. It is porphyritic in texture, (Hailesellase Girmay and Getaneh Asefa, 1989). Olivine porphyritic basalt outcrop in the central part of the town that includes Merkato, Teklehaymanote and Sidest Kilo.

The Lower Welded tuff overlies both types of basalt nearby the building college, the kolfe Police School, the Kokebe-Tseba School and Yeka Lideta Le-Mariam church. On the other hand, only in the gorge of the Ketchene stream the olivine porphyritic basalt is overlain by the plagioclase porphyritic basalt.

1.8.2.4 Nazareth Group

The units identified in this group denoted as lower welded tuff, aphanitic basalt and upper welded tuff. Welded tuffs have been related to Wachecha and Yerer volcanisms. The group is underlain by Addis Ababa basalt and overlain by Bofa basalts. The rocks outcrop mainly south of Filwoha fault and extended towards Nazareth (Hailesellase Girmay and Getaneh Asefa, 1989). The descriptions of the units in this group are**:**

1.8.2.4.1 Lower Welded Tuff

This rock outcrops as small discontinuous body in Filwoha, western parts Addis Ababa and Sululta. Generally it is overlain by the aphanitic basalt and underlain by the olivine and plagioclase porphyritic basalt. The age of this unit overlaps with the period of the activity of Wechecha trachyte volcanoes.

1.8.2.4.2 Aphanitic Basalt

This basalt covers the southern part of the city, especially the area of Bole International Airport and Lideta Old Airfield. The rock body shows vertical curved columnar jointing together with sub-horizontal sheet jointing. Along the course of Akaki River large amygdales of calcite occur in this basalt. Kaolinite lenses are also present at the contact of this basalt with the younger ignimbrite.

1.8.2.4.3 Upper Welded Tuff

This rock outcrops all over the southern part of the city including Bole, Nefas Silk and Railway Station; nevertheless it is also present in the central and northern part of the city. It is gray colored, vertically and horizontally jointed and composed of sanidine, anortoclase, rebekite, quartz, pumice and unidentified volcanic fragments (Hailesellasie Girmay and Getaneh assefa, 1989)

The welded tuff is underlain by aphanitic basalt and overlain by young olivine basalts. Young trachytic flow outcrop in the southwestern part of the city from Dama Hotel towards Furi and Repi along the hills and foot hills of Hana Mariam and Tulu lyou.

1.8.2.5 Bofa Basalts

Bofa Basalts outcrop southward from Akaki River where they appear in the form of boulders reaching a thickness of ten meters. They are restricted and dominated in the southeastern part of the city. This rock is characterized by big vesicles that are filled by calcite. This basalt is underlain by the tuffs which cover the welded tuff.

1.8.2.6 Geological Structures: Fault trace and discontinuities

Globally, in extensional areas and whereby rifting activities predominates, voluminous magmatic eruptions poured out along the fissured segments of the crust which enabled to develop many faults, folds, and fault like structures. Accordingly, such structures have been found significantly in and around Addis Ababa city. Many of these structures follow the trend of principal structures in the main rift that is, North-East to South-West directions.

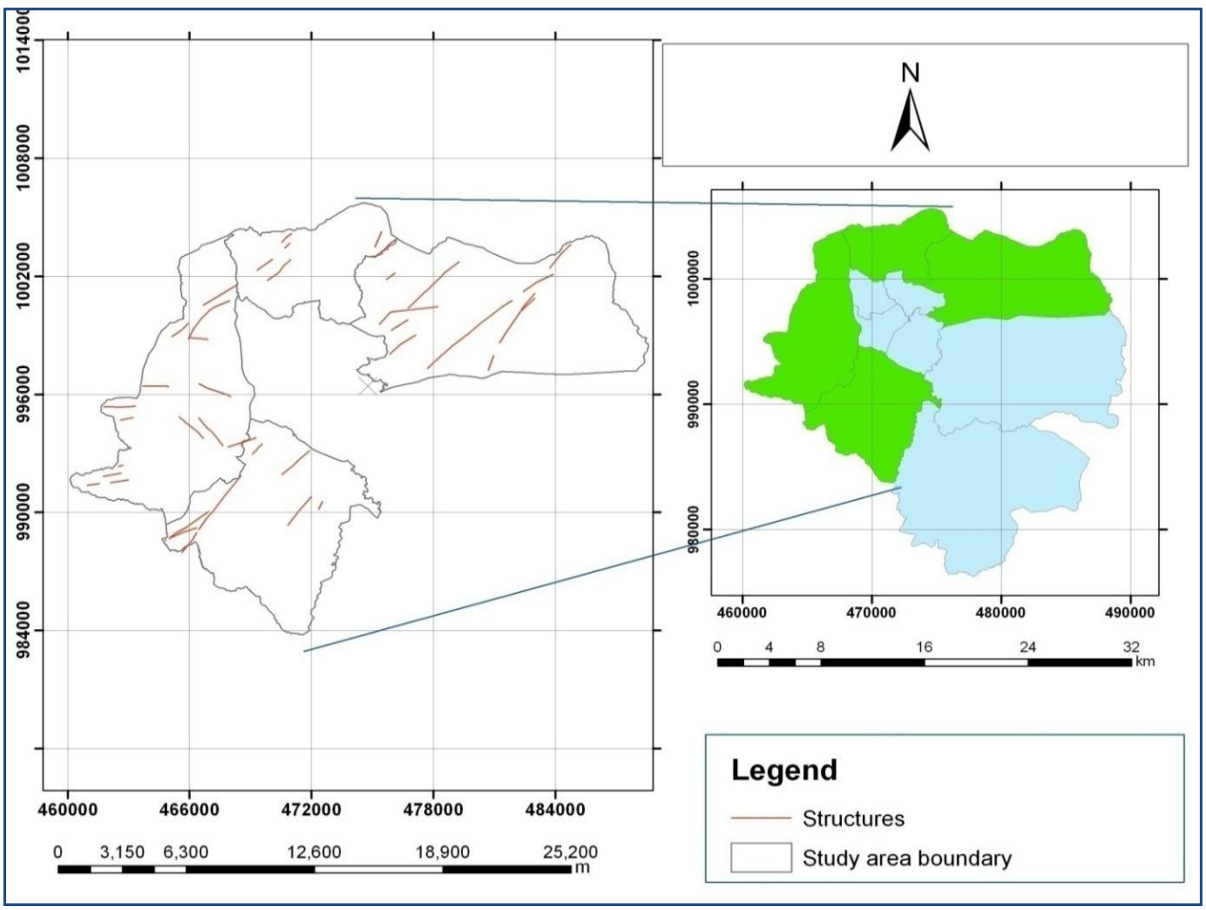


Figure 1.12: Major Fault traces found in the study area, Addis Ababa city, Tilahun Mamo, (2002).

Plate 1.3: Significant fault traces easily distinguished by displaced ground masses: characterized by sharp cliff; in the study area, a locality known as "Amora Gedel" Ankorcha, north east part of Entoto mountain (A), and Hana Mariyam, (B)Yeka sub city

Plate 1.4: NE-SW oriented discontinuities (sub-parallel to the regional structures), encountered on massive basaltic intrusions. It was exposed during excavations in a ring road construction project, Adissu Gebeya, AA.

Most of the fault traces recognized in the study area, having different lengths have sub-parallel direction with the principal fault structures i.e. NE-SE trending direction. Unlike most faults, the Ambo - Kesem fault running across the northern tip of the city and has an East-West direction (Tilahun M., 2005).

1.8.3 Geological formations found in the study area.

1.8.3.1 Soils

At the expanse of the city, including the study areas; soils found, varied in type and depth. The soils that have been developed in most parts of the city mostly depend on the tectonic activity, topography, parent materials and the degree of weathering (i.e. climatic factor) taking place. Although, on the slopes, the degree of weathering differs, soil type variation is possible. Significantly, in large parts, it is common to find highly dissected soil profiles. Mainly, where rugged morphology dominates erosion is highly experienced and as a result thin soil layers observed in most places. In some places where the geo-morphology is plain to gentle (central and southern part of Addis Ababa), thick soil profile have been encountered. As extracted data from water well logs (fig. 1.12), in some places, like Nefas silk lafto area, soil profiles as thick as forty five meters have been recognized (black cotton clay soils/Pellic vertisols).

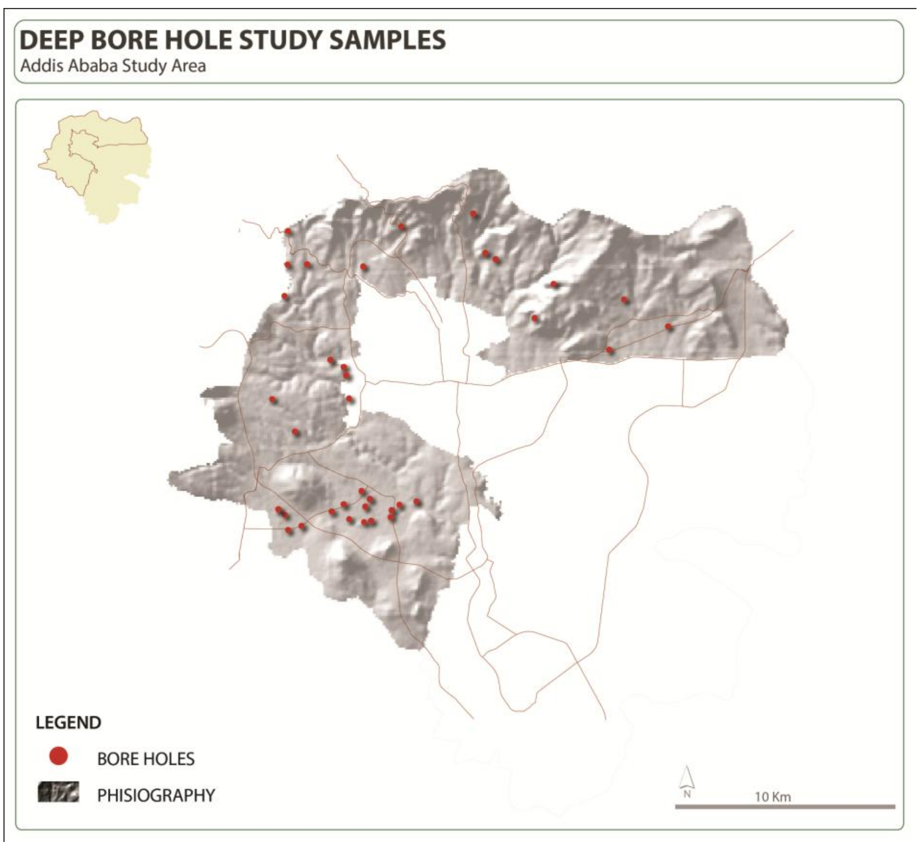


Figure 1.13 Sample deep groundwater wells (300m plus) in the research area; drilled for Addis Ababa drinking water supply project; (AAWSA, 2010) (see annex part for lithological description).

It is apparent that soil development and depth is highly governed by the region's tectonic activities, the type of parent material, and the morphology where by depositional processes takes place, and the length of time to which the parent material is subjected to weathering. Thus, old basic and acidic rocks that outcrop in the central, western and southwestern parts of Addis Ababa are weathered and form thick soil profile (plate 1.3). In places where young basalt and welded tuffs occur, soil cover is thin or absent.

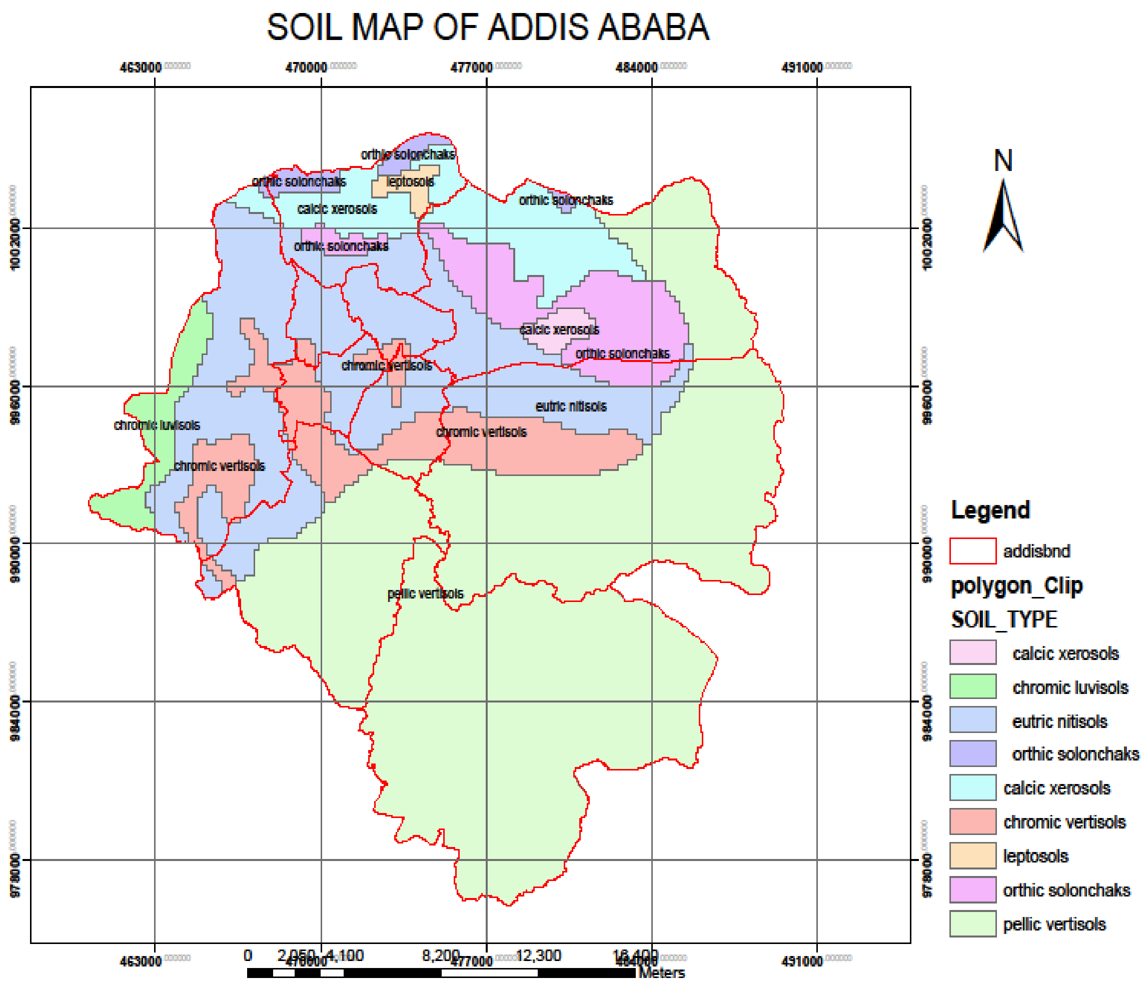


Figure 1.144. Soil map of AA city, Source: CLUVA, 2012.

**Soil classification is based on FAO.*

Plate 1.5. Residual soils: weathered brown to red silt clay soils(Eutric Nitisols) found in Gulele as thick as 12m; sections exposed during ring road construction (Gojam Ber, Gulele sub-city, AA), 2010

The detrital materials that are derived from elevated area of Entoto, Wechecha, and Furi are mainly transported and deposited in the piedmont and along the main stream courses of Addis Ababa. As a result, black cotton clays (Pelic vertisols) dominantly covered most parts of Mekanisa, Ayere Tena, Kaliti, Akaki, Lideta, and Bole (see figure 1.14).

1.8.3.2 Ground water resources

Ground water is an important natural resource formed geologically beneath the sub surface of the earth. Major world cities and urban centers widely relied on ground water resources to fulfill their water demands either for drinking, home use, agriculture and/or industries.

Accordingly, in the city including the study areas, potable water coverage (thirty three percent of the current city’s potable water production) has been significantly from groundwater abstractions (AAWSA, 2011).

Basically, the wider portion of most upper regions of Entoto which is mainly covered by weathered and highly fractured Tarma Ber basalts and the overlying Neogene acidic and basaltic volcanic rocks (highly pervious water bearing aquifer; Figure 1.11), are rich in hydrologic sources.

Apart from consumption, groundwater (the rise and fall of groundwater table) may enhance landslide hazards as a consequence of liquefaction.

Based on available data (drilled water wells), at various places (fig. 1.13) ground water table differs from one place to the other thus many areas tend to differ in landslide hazard exposures. And therefore, in this research work, to analyze landslide hazard, related to groundwater depth study areas have been categorized into three zones: < 25m, 25 -75m, and > 75m (see figure 1.15).

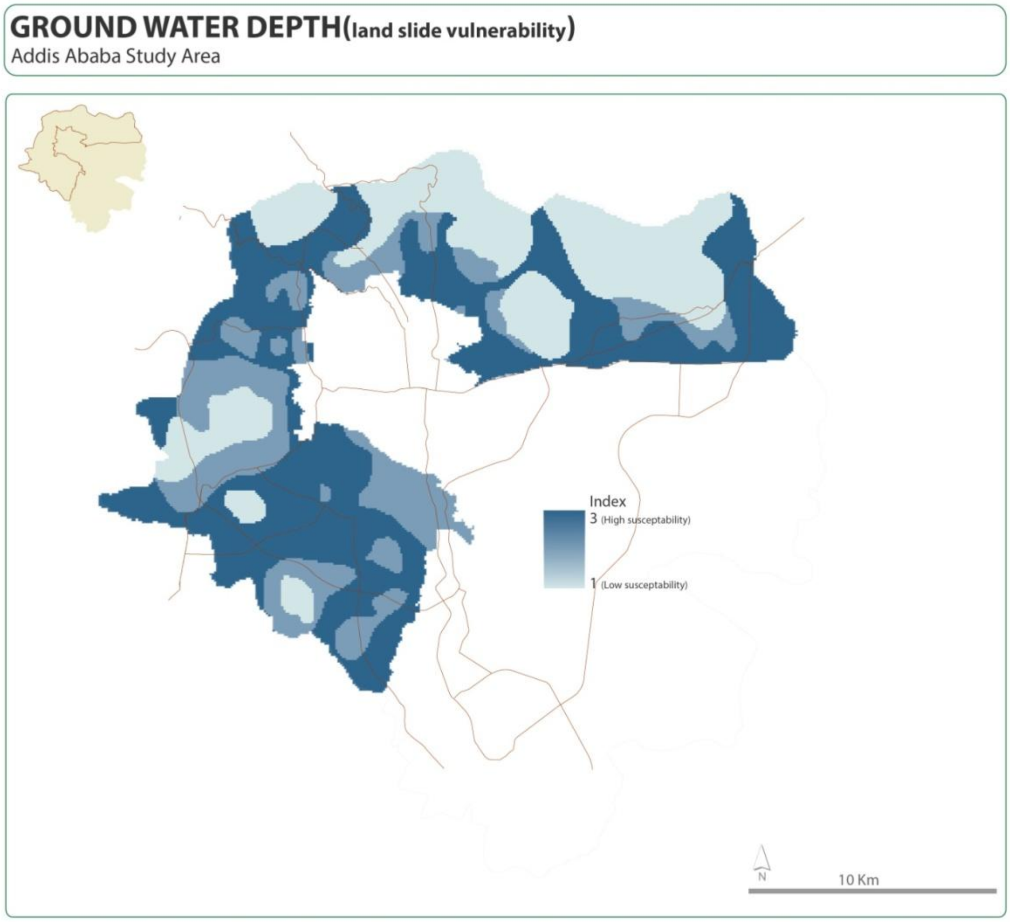


Figure 1.15. Depth of Ground water table in the study areas, Temesgen Assefa (2011)

1.9 Engineering geological description of rocks and soils in the study areas

In the attempt of prediction and mitigation of natural hazards, though it required a detail/site specific geotechnical investigations and examinations of geological formations i.e. soils and rocks; the engineering geological characteristics and behaviors of the rocks and soils found in the region was broadly studied by some researchers previously; for example, Kebede Tsehayu and Tadesse H/Mariam. On the study of Kebede Tsehayu and Tadesse H/ Mariam, 1990; the rocks and soils were classified in groups based on their engineering geological behaviors and characteristics (see Table 1.8 below).

Table 1.8: Types of Lithologies in the region and their rock mass strength

Source: Geological Survey of Ethiopia; study of Kebede Tsehayu and Tadesse H/ Mariam, 1990.

No	Type of Lithology	Rock mass strength (RMS) in mPa	Remarks
1	Aphanitic basalt	88 mPa	
2	Olivine basalt	78 mPa	
3	Feldspars	75 mPa	
4	Trachytes	68 mPa	
5	Rhyolites	60 mPa	
6	Ignimbrite	56 mPa	

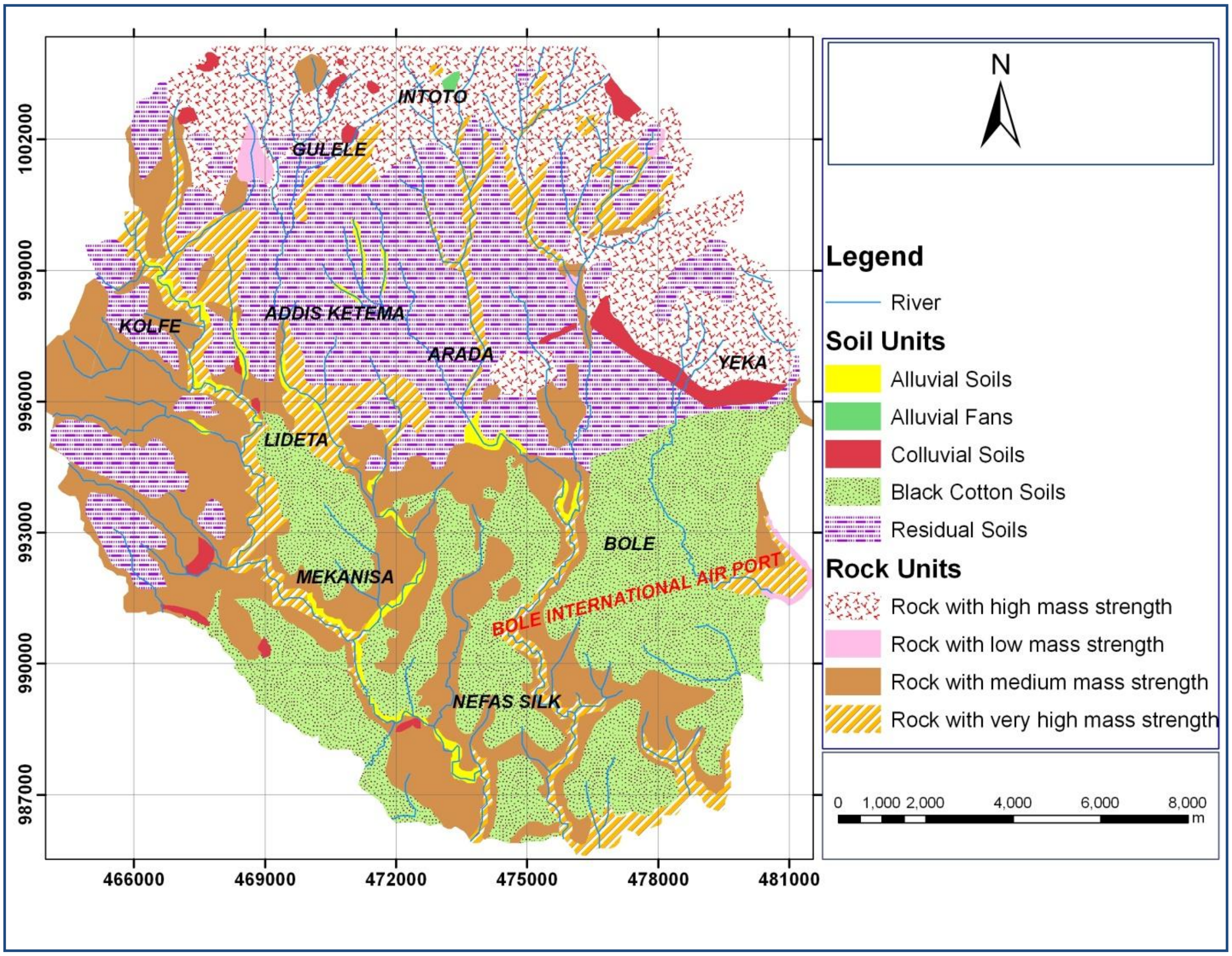


Figure 1.16: Engineering geological map of AA city, (adapted from Kebede Tsehayu et al, 1990).

Beyond earth material resources identification, knowledge of the engineering geological behaviors of rocks and soils has a vital importance in-order to categorize susceptible zones to various natural hazard extremes mainly those triggered by human actions.

Chapter II: Literature reviews on landslide and earthquake hazard occurrences and urbanization

2.1 **Natural hazards (landslide and earthquake) occurrences and urbanization at global and regional level**

Every year, many more million people crowed in to urban centers. Simultaneously, with an increase of urban population many more people's life inflicted to death by natural disasters particularly, by landslide, flood and earthquake (see figure 2.1 below).

Globally, based on statistical data, from 1991 to 2000, the Disaster Database of OFDA/CRED (1991-2000) record shows a total of 2557 hazards. These include landslides, droughts/famines, earthquakes, extreme temperature/heat waves, floods, forest/scrub fires, volcanic eruptions, windstorms and other natural hazards.

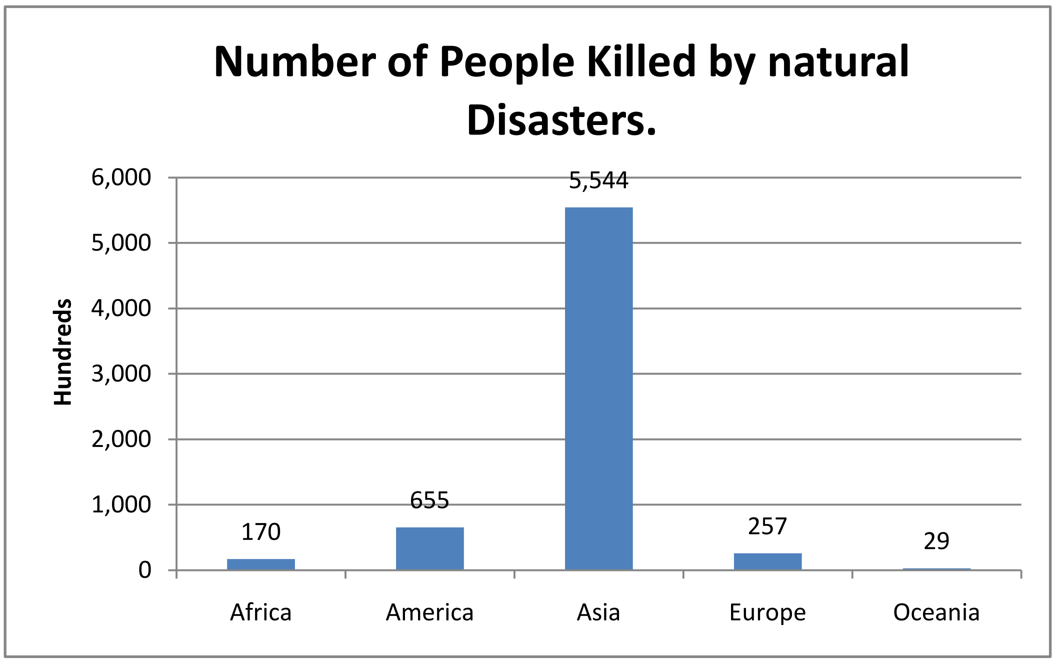


Figure 2.1: Total number of people reported killed by various natural disasters by continent

Data from Disaster Database of OFDA/CRED (1991-2000

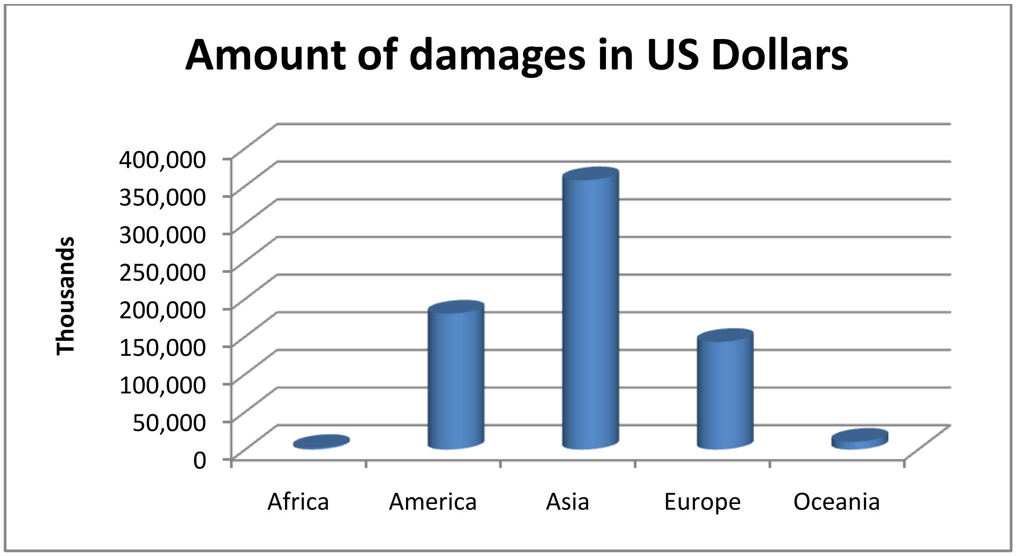


Figure 2.2: Total amount of estimated damage caused by various natural disasters by continent

Data from Disaster Database of OFDA/CRED (1991-2000)

Figures 2.1 and 2.2 clearly illustrate that Asia is more affected than the other four continents in terms of people killed and property damaged. The main reason rests on factors related to high relief, characterized by highly dissected mountain ranges; tectonic activity is intense, high precipitation rate and higher population density. All these factors make these regions susceptible to natural hazards development.

The regions of East African countries, including Ethiopia, Uganda, Kenya, and Mozambique, are basically found in a tectonically active zone where geological hazards like earthquake, floods, and landslides harm societies severely. In addition, due to climatic factors, these countries were also affected by recurrent floods and landslides, and many more thousands of people killed and huge properties were damaged. The more affected society, due to such natural extremes has been much of the urban poor. Because, data management is poor, in many of the countries, it over shadows the actual figurative representation of natural disaster records of the African continent (see fig. 2.1) and specifically, statistical data on disaster occurrences least present in Ethiopia. Even though statistical data is lacking, natural hazard occurrence was repeatedly observed.

For instance, the recent history of flood catastrophe in Dire Dawa, (2009), more than 300 hundred people were killed (ERCS, 2009 flood victims report).

2.2 Previous works on landslide and earthquake hazards related to the current research

2.2.1 Reviews on Landslide hazard

Even though, most researchers suffered much from appropriate data constraints, little has been done to reveal the existing situations of environmental/natural hazard occurrences in the region. An important research, done on this topic; the research works of for example, by Abebe,B., et al., 2009 will be used as best reference. This research work briefly discuss the causes and landslide hazards occurrences in high lands of Ethiopia and the rift zone margins (Abebe,B., et al., 2009, Landslides in the high lands of Ethiopia and the rift margins, 2009). According to this paper, in many areas, it has been geologically evident that clayey/marley formations present at various depths and it is overlain by hard rock which is basaltic, fractured aquifers; lime stone or sand stone, that may undergo water table fluctuations during heavy rain; are particularly prone to gravity driven deformation and failure (Ayalew,2000). Eventually, ground water pressure and seepage may trigger mass movements in colluvial deposits (depicted in vast areas of the country) covering the hydrological contact between a hard rock cliff and an underlying clayey/marley aquiclude (Ayalew, 2000, Nyssen et al., 2003).

In addition, research works of Ayalew, 1999, revealed damages due to landslides for the period 1993-1998. Accordingly, it have been reported that 300 people were killed, more than 200 houses demolished, and more than 500km road were interrupted.

The same research stated the causative agents for landslide problems. As stated by the paper, the over whelming population growth exhibited in most urban regions lead to overexploitation of the natural resources base and mainly forests were cleared. Besides, the spread of slums and squatter settlements along marginal lands of hilly mountainous areas, poor and intense construction of infrastructures such as high rising buildings, roads, sewer and irrigation canals, dams, were some major human activities heavily performed in upland urban regions which might have an adverse effect on the natural environment including hydrological disruptions and hence caused natural/ environmental hazards like floods and landslides. Along with human modifications made on most parts of the mountain hill slopes, the major triggering factors for landslides and flood occurrences are heavy and long-lasting rainstorms resulted from deforestations, earthquakes, and volcanic activities (Abebe, B., 2009).

Particularly, Addis Ababa city has been found on the very tip margin of the North-western high land plateau apex and tectonically active region as well where many swarms of seismic shocks observed thus made it quite vulnerable to frequent flood, and potential landslide hazards.

2.2.2 Reviews on Earthquake hazard

As Global history revealed, in most urban centers of the World, due to catastrophic earthquake hazards huge human death tolls were recorded. Earthquakes are restricted to certain geologically unique areas where tectonic activity and/or lithospheric movement predominate due to up-ward pressure of mainly shallow magmatic mantle plumes.

Accordingly, the study area selected for this research has been found in a seismically active region thus various faults and fractures dominantly recognized because of actions of magmatic up-wells in the region. For instance, the Filwoha fault, which extends from southern Sheraton hotel to Ayat Meri area (nearly about 25Km in length) and Ambo-Kesem fault which cuts Addis Ababa city almost east-west direction on the northern tip of city periphery, have been easily recognizable structures. Amazingly, seismic shocks proved to be amplified in areas of higher gradient zones and where fault traces exist (For e.g., Pierre Gouin, 1997; Laeke Mariam Asfaw, 1990, and Tilahun, 2005).

From various works of different researchers, seismic actions in the region has been strongly related to the magmatic activities of the East African Rifting system and especially the North western Ethiopian plateau magmatic processes [e.g. Chernet et al., 1998; Kieffer et al., 2004; Ferrandoet al., 2008].

Similarly, recent scientific studies which were conducted to understand the Ethiopian upper mantle seismic structures revealed that the existence of hot spot tectonism beneath the North-Western Ethiopian plateaus (e.g., Derek Kier et.al, 2009). This hot spot tectonic activity of the area has been also responsible for the seismicity conditions. While pressures developed due to the action of hot magma, sub surface rocks (even though they behave as elastic), can break if strained by excessive pressure, and energy released in the form of seismic waves thus ground shaking or earthquake hazards experienced.

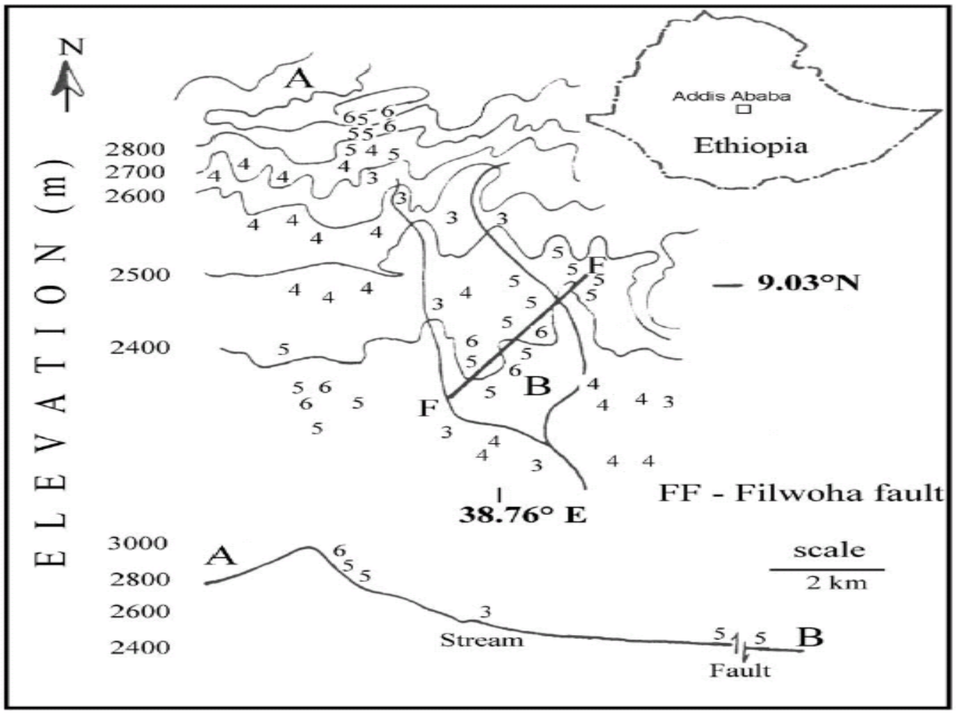


Figure 2.3. ***An earthquake intensity map prepared following the July 28, 1979 earth quakes of local magnitude 4.1 that occurred at a distance of about 22km south west of the city. Maximum intensities were observed at two localities A and B. the high intensity of locality A was due to topographic effect and that at B was due to the effect of the Filwoha fault /FF/.***

Accordingly, while the earth quake history of Ethiopia closely examined, in different time periods, many urban and rural towns were affected. Among others, the 1906 earth quake occurrence and the 1961 Kara Kore-Majete earth quake events were inflicted many deaths to humans and damages to properties (e.g. Table 2.12; Pierre Gouin, Earth quake History of Ethiopia and the Horn of Africa, Fekadu Kebede, 1996).

The 1979 earth quake with local magnitude of 4.1 occurred just 22km south west of the city and another in 1974 with magnitude 4.6 happened about 100km (Debre Berhan) northeast of Addis Ababa.

Table 2.1. ***Some major Earthquake events in Ethiopia: Data source, Fekadu Kebede, 1996***

Location	Year	Magnitude	Distance of Epicentre from A.A in Km	Damage
Langano	1906	6.8	110	Felt in Addis, damage were not quantified
Karakore	1961	6.7	150	Sever destructions on the town of Majete.
Central Afar area	1969	-		Total destruction of Serdo town.
Langano	1985		110	
Nazreth	1993	6.0	100	
Lake Shala	1999		250	

It is obvious that, in areas where tectono-seismic activities predominate and more population pressure encountered (like for example, in most towns found in the East African rift zone including the study region) sever catastrophic destructions will be experienced due to earthquake hazards.

Based on research results, it has been noted that strong correlations exist between faults and seismic wave propagations (e.g. Fred G. Bell, 2005).

Meanwhile, the faults, fractures, and fissures created serve as a conduit for mobile magmas thus volcanoes erupt along fissures consequently, earthquake hazards developed. The existing geo-morphology of the research area has been the result of such geologic actions.

The region mainly experienced high frequency of significant earthquake tremors (reports of Addis Ababa University geo-physical observatory station) and therefore will yield a probable earthquake hazard in the future, in and around the city.

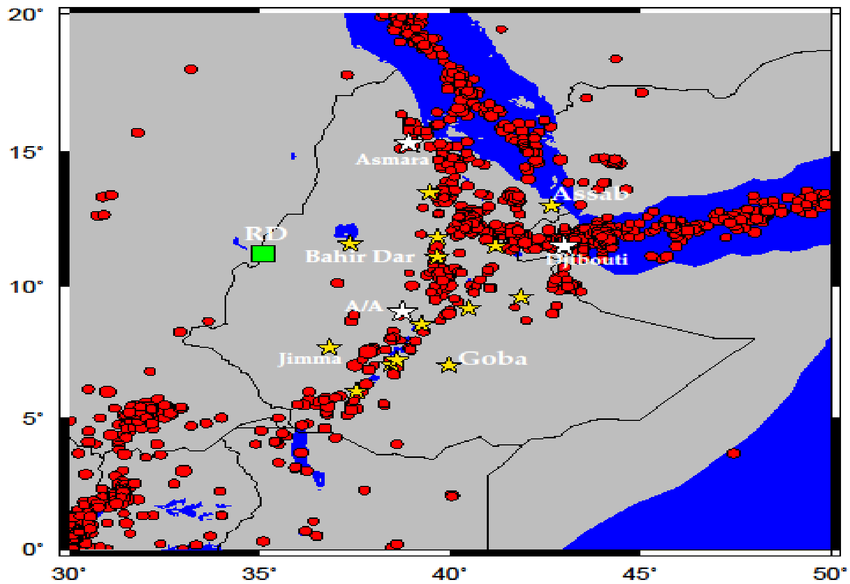


Figure 2.4 ***Country level Seismic events record: in Addis Ababa Geo-observatory, AAU; showing various epicenter*** **spots*****; national data. Source: Addis Ababa Geo-observatory, Addis Ababa.***

Figure 2.5 *The 1961 earthquake destruction: structures collapsed in Addis Ababa city.*

Chapter 3
3. Methods and materials used in the study

For the assessment and analysis of landslide and earthquake hazards in the selected region, qualitative and quantitative approaches were deployed. The qualitative approach rests on development of questionnaires, 200 in number. Interviews and focused group discussions were made possible. The quantitative method was entirely depended on the collection, acquisition, and interpretation of primary and secondary data.

Primarily, a through desk study was conducted about the study areas. Geological, engineering-geological, hydrogeological, seismic, and topographic maps were major data sources. Aerial photographs and satellite images were used further in the study to detect spatial and temporal changes. In addition, subsurface data collected and compiled from drilled deep bore holes. Thus made possible to characterize the stratigraphic columns of sub-surface soils and rocks; understanding their depth and/or thickness, and further identify any unconformities and weak zones which might cause potential failures of all kind.

Field observations and measurements of various geologic structures and slopes were also carried-out. Appropriate video and photographic data including voice recordings were captured.

Some physical and mineralogical behaviors of soils and rocks were acquired from previously done Lab tests (secondary data).

By using SPSS version-15 software, statistical data were analyzed. More importantly, the Analytical Hierarchy Processing (AHP) method (is a GIS-based semi-quantitative analytical method), has been used to analyze the whole GIS data layers which were considered as influencing factors/parameters. Finally, landslides and seismic hazard maps were generated. Geologist compass, clinometers, hand GPS, roller meter, geological hammer, video camera, hand lens, and field note books were instruments and materials used in the study.

Chapter 4 Discussions and results of Landslide and Earthquake hazards

4.1 Landslide hazard; its characteristics

Landslide hazard is defined as the probability of occurrence of a landslide within a specified period of time and within a given area (Varnes, 1984). According to Varnes (1984) landslide hazard zonation is defined as the subdivision of a land in classes with equal landslide hazard. Guzzetti et al. (1999) indicated that landslide hazard evaluation and mapping rely on knowledge of slope movements and on few basic assumptions which include the following:

The past and present are keys to the future (Varnes, 1984; Carrara et al., 1991; Hutchinson, 1995). This implies that slope failures in the future will be more likely to occur under the conditions which led to past and present instability. Hence, the understanding of past and present failures is essential in the assessment and prediction of landslide hazards (Guzzetti et al., 1999).

Slope failures have discernible morphological features; many of them can be recognized, classified and mapped both in the field or through remote sensing, mainly aerial photographs (Varnes, 1978; Hansen, 1984; Hutchinson, 1988; Dikau et al., 1996). Slope failures are controlled by mechanical laws that can be determined qualitatively or quantitatively. This means that conditions that cause landslides (factors directly or indirectly linked to slope failures) can be determined, rated (weighted) and used to build predictive models of landslide occurrences (Dietrich et al., 1995).

The probability of land sliding depends both on the factors that place the slope in a marginally stable state and on the triggering factors. If triggering variables are not taken into account in the instability predictions, the term “susceptibility” could be employed to define the likelihood of occurrence of a landslide event (Dai et al., 2002).

4.2 Types and mechanisms of slope failures

The mechanisms of slope failures range from creep type of slow movements (less than 0.15mm per year) to instantaneous and catastrophic slides (1.5m per second) (Cruden and Varnes, 1992). Distinguishing between the different types of movement requires considerations of several criteria (Selby, 1993): (a) velocity and mechanism of movements, (b) mode of deformation and geometry of the moving mass, and (c) water content. With so many materials and processes involved in mass movements, it is perhaps not surprising that there are many landslide classification methods in use, among which are Sharpe (1938), Nemcoke et al (1972), Varnes (1978), Hutchinson (1988) and Sassa (1989). In this research, however, the classification method of Varnes (1978) has been adopted and used for the description of landslides because of its simplicity, completeness and practicality.

The major types of slope failures include (Varnes, 1978): creep, slide, fall/topple, flow, and spread. Each of the different slope failures could have a number of common modes. According to several authors (Sharpe, 1938; Varnes, 1978; Bell, 1999): falling and toppling are features frequently associated with rock slopes; flowing and spreading are related to soil slopes; and creep and slides are related to both soil and rock slopes.

4.3 Causes of slope failures

Landslide, defined as the down slope movement of soil and rock under the influence of gravity without the primary assistance of a fluid transporting agent (Brunsden, 1979), is assumed to occur when the strength of the slope mass is somewhere exceeded by the stresses within it. A slope is considered stable if the safety factor clearly exceeds unity. From a physical point of view, slopes exist in one of the three stages (Crozier, 1986): (1) stable slopes where the margin of stability is sufficiently high to respond to the destabilizing forces, (2) marginally stable slopes in which the slope will fail at some time in response to destabilizing forces, and (3) actively unstable slopes whereby slopes are under continuous or intermittent movements. The three stability stages must be seen to be part of a continuum with the probability of failure being minimal at the stable end of the spectrum, but increasing through the marginally stable range to reach certainty in the actively unstable stage (Crozier, 1986).

Landslide influencing factors/controlling parameters are factors which make the slope susceptible to movements without actually initiating it and thereby tending to place the slope in a marginally stable state. The factor that initiates the movement of slope which was on the verge of failure is the triggering factor. According to several authors (e.g. Terzaghi, 1950; Varnes, 1978, 1984; Hutchinson, 1988; Selby, 1993; Abramson et al, 1996; Guzzetti et al, 1999), the processes and factors that influence slope stability are numerous and varied and they interact in complex ways. Abramson et al (1996) summarized that slope failures generally take place under the influence of various factors which include, among others, the following: (1) geological factors, (2) topographic variables, (3) hydrological factors, (4) Changes in slope geometry, (5) Changes in vegetation cover, (6) weathering processes, and (7) Earth quake induced.

4.3.1 Geological factors

According to various authors (e.g. Selby, 1993; Abramson et al, 1996) the basic geological features that could affect the stability of slopes include soil/rock material properties, geological anomalies, and discontinuities.

4.3.1.1 Soil and rock material properties

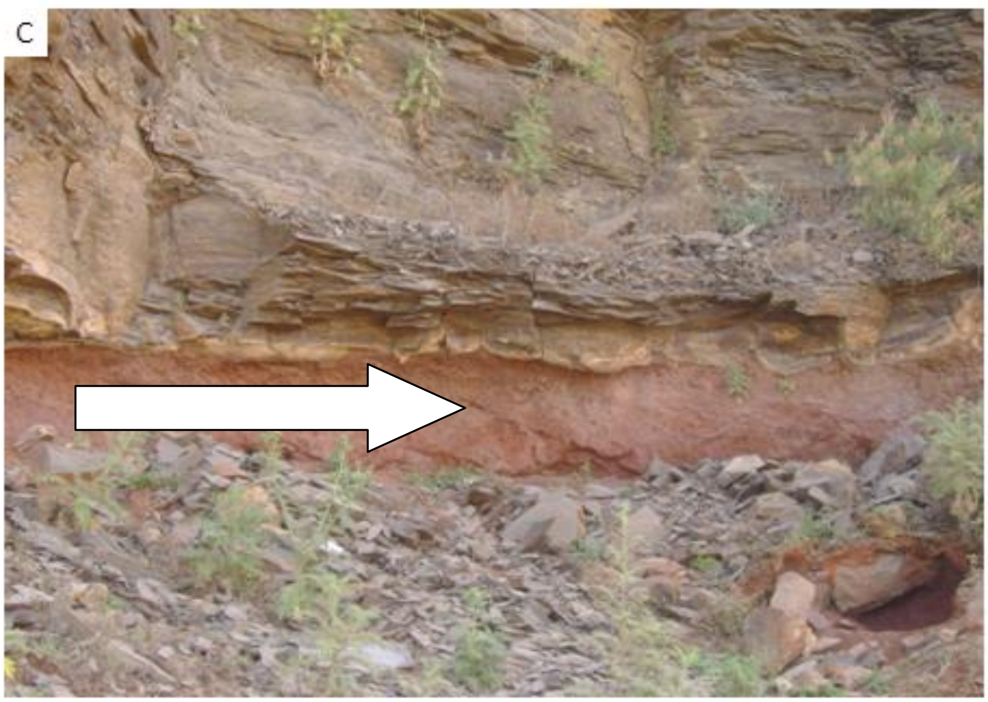
Factors inherent in the nature of the materials which include the types and orientations of minerals and their degree of interlocking may have an influence on engineering characteristics of slopes, as it causes a marked anisotropy in the strength and deformation characteristics of soil/rock masses (Selby, 1993; Abramson et al., 1996). As indicated by Selby (1993), an un-jointed rock could be stable against failure under compressive overburden load as long as the load does not exceed the strength of the rock material which then depends on the composition, degree of anisotropy and arrangement of the minerals in the slope materials.

4.3.1.2 Geological anomalies

In order to predict slope stability accurately it is important to recognize: (a) a sequence of weak and strong beds, (b) thin marker beds of soft materials, (c) old failure surfaces, (d) fault-related geologic features, and (e) hydro geological effects (zones showing permeability differences), because these different features have the following effects on the stability of slopes (Abramson et. al., 1996):

- Rocks with high intact strength overlying weaker units could be subjected to slope instability. The stronger rocks may be having higher shear strength, be resistant to weathering, and capable of maintaining steep slope faces. However, if they are underlain by soft, plastic, expandable, low strength, impermeable, easily weathered, crushed or highly fissured beds the upper rocks may be affected by instability, even when these have low slope angles.


B


C

D

E

Plate 4.1 Sub-surface weak zones encountered at various depths and places: *soft to stiff latterite soils (paleo soils); (A-E) intercalated with competent volcanic rocks. Arrows show red to brown stiff clay/Latterite soil over lain by moderately weathered and highly fractured columnar basalts. These geological formations have been exposed in varied depths at various locations in the city (see lithological log descriptions on the annex part). Many of them exposed during cuttings made for main road and bridge construction and quarrying activities; for instance in Nefas Silk Lafto(plate A), Bole air port(plate B,C & D), and Meshoalekia area, Cherkos sub city(plate E), A.A. Possible to find also at higher gradient zones: a triggering factor to landslides hazard occurrence.*

- Alternate strata, having lower and higher mass strength characteristics, are particularly prone to failure not only due to the higher susceptibility of the low strength masses to degradation processes (weathering and erosion) but also to the expected water pressure build-up on these low strength masses.
- Old failure surfaces are often susceptible to reactivation because the soil/rock masses along such old failure zones are often remolded, with shear strengths usually at residual value and take up high moisture.
- Fault-related geologic features could influence slope stability due to the presence of ground-up materials near fault zones which may result in less resistance to sliding because of loss of shear strength. Groundwater may be attracted to a fault zone due to the greater conductivity of the fractured and loosened rock along such zones. It should however be noted that case studies indicate that fault zones could be associated with low permeability due to ground-up materials along such zones. The formations of clay minerals along fault zones, due to weathering processes, could influence time-related slope stabilities (see figure 5.5, plate 5.2& 5.3).
- The presence of hydro geological features such as a water bearing stratum, underlying a much less permeable soil or highly weathered rock need serious consideration in slope stability assessment (Abramson et al., 1996; Terlien, 1996). The excess water in pervious stratum is expected to contribute to slope instability by creating pore-pressures within the masses forming the slopes, loading, washing out of fines present at the interface of the two layers of contrasting permeability, and softening the underlying materials that make up the lower slope (Abramson et al., 1996).

4.3.1.3 Discontinuities

Discontinuities generally influence slope stability because these are zones of weakness. The total strength available to resist shear is variable as the following factors are involved (Selby, 1993; Abramson et al., 1996): spacing of the discontinuities, orientation of the discontinuities with respect to the orientation of the slope, width (aperture) of the discontinuities, lateral or vertical continuity as well as interconnectivity of the discontinuities, infilling of material in the discontinuities, and waviness and unevenness of the discontinuities.

- Spacing of discontinuities could affect the behavior of rock masses, because cohesion is lost and frictional strength may be reduced as discontinuities open in rocks. The more closely spaced the discontinuities are, the weaker the rock mass is and the greater is the opportunity for water pressure and weathering processes to activate and weaken it further.

Plate 4.2 ***Major discontinuities seen on fissured fresh intrusive dome like basalt exposed in Gulele ring road construction project, and has been oriented similar to the main axis, i.e. N-E trending pattern, Gojam Ber area, Gulele sub city,A.A. See the compass needle directed towards N_S axis.***

- Orientation of the discontinuities with respect to the orientation of the slope affect the stability of rock slopes: for discontinuities dipping towards a slope face at angles greater than the friction angle of the discontinuity, the critical hill slope angle is equal to the angle of dip of the discontinuity plane. The orientation of the intersection of discontinuities with respect to the orientation of a slope face and the available shear strength along discontinuities control wedge failures in slopes.

Plate 4.3 ***very weak bedding planes dipping SSE direction, deeply cut by a stream (the inner side wall of a stream) located in the north eastern part of the city, Kotebe St,Gabriel church area, Yeka sub city, A.A.***

- Width (aperture) of the discontinuities affects the rock mass behavior as separation largely controls the frictional strength along the joint as well as the flow of water and the rate of weathering of the wall-rock. Widely open joints have resistance to shear which is generally dependent on the joint infill. Tightly closed joints may have high frictional and some cohesive strength, while those with widths between the two extremes have strengths dependent upon the joint roughness and contact between the wall-rocks.
- Lateral or vertical continuity as well as interconnectivity of discontinuities could affect the geotechnical behavior of rock masses in that the larger the bridges of intact rock between discontinuities and the lower the degree of interconnectivity, the greater is the effective cohesion. Continuous and interconnected discontinuities thus reduce cohesive strength, provide zones of shear, and permit the circulation of water.
- Infilling (type and thickness) of discontinuities affect the shear strength along the discontinuities (for example: by reducing the shear strength for clay type in fills

and increasing for silica type of infill materials, affecting the permeability and hence water pressure distribution).

- Waviness and unevenness of the discontinuities determines the shear strength along the discontinuities. In general the higher the surface roughness is, the higher is the shear strength along the discontinuities at low normal stress conditions but the importance of surface roughness for shear strength value reduces with increasing normal stress conditions (Selby, 1993; Abramson et al., 1996).
- State of weathering of the rock material and the discontinuities has an influence on the shear strength as the strength decreases with increasing degree of weathering.

Plate 4.4 ***Weak zones/laterite/paleo soils/ underlain by basaltic rocks; creates stability differences, triggering factors for landslides hazard occurrence. Lithological log data obtained from coring activity tests drilled for bridge construction at Meshoalekia, Cherkos sub-city, Addis Ababa.***

4.3.2 Topographic and climatic factors

Change in vegetation cover; change in precipitation, change in slope geometry, Slope orientation (angle and direction) and shape are important terrain variables which generally influence slope stability.

4.3.2.1 Changes in vegetation cover.

There are debates over the role of vegetation on slope stability. Greenway (1987) has summarized the influence of vegetation on slope stability, and indicated that vegetation influences slope stability by affecting the hydrology and/or mechanical properties of soil slope masses. As suggested by different authors (e.g. Prandini et al., 1977; Greenway, 1987), vegetation cover with deeper and wider roots have positive influence on shallow debris/earth slides, by improving the strength of soils through reinforcement of root networks and buttressing the slope masses by roots anchoring into the underlying bedrock. Prandini et al., (1977) made a review of the behavior of vegetation on slope stability and concluded that forest reduces the action of the climatic agents on the natural mass, in a manner favorable to slope stability.

Vegetation change could have a very important influence on slope stability in areas where forests are being removed from hill slopes (Selby, 1993).

The disadvantages of deforestation on slope stability include, among others (Prandini et al., 1977):

- Immediate cessation of the stabilizing effects of the forests, as a whole, on the climatic variations, with negative effects on the behavior of soils facing new stresses. This results in enhanced soil erosion, changes the micro-climate of the deforested areas which in turn affects the water cycle, exposes the soil/rock masses for more interaction with the atmospheric processes, facilitating surface weathering processes.
- Immediate cessation of interception, retention and evapo-transpiration which then causes an increase in the amount of water that reaches the ground and infiltrating water,
- The loss within a short time of the effects the superficial debris layer (retention, slow-down of runoff), with a consequent increase in erosion and infiltration,
- A rise in the groundwater table, as a consequence of the elimination of the evapo-transpiration, with possible effects on the saturation of the superficial soil, and increase in weight

- The loss, within a certain period of time, of the mechanical effects of the root systems, eventually reducing the induced apparent cohesion, and consequently, the shear strength of the natural slope mass.

It is obvious that, in urban centers especially, where unplanned urbanization dominates, in short period of time, vegetation cover diminished dramatically and, is strictly related to haphazard settlement expansions of squatter colonies.

- **Effect of the up-land settlement expansions/Urban sprawls specific to the study area**

Based on various data (WHO, PRB, 2010), Addis Ababa city is one of the major cities in the world where large numbers of squatter colonies reside in unsafe areas for human settlement. The alarming population growth; easily violated urban plan (inefficient as well) and land policy (strictly owned by government) considered as the main factor for the invasion of marginal lands by squatter colonies. (Refer the population statistics on Table 1.2).

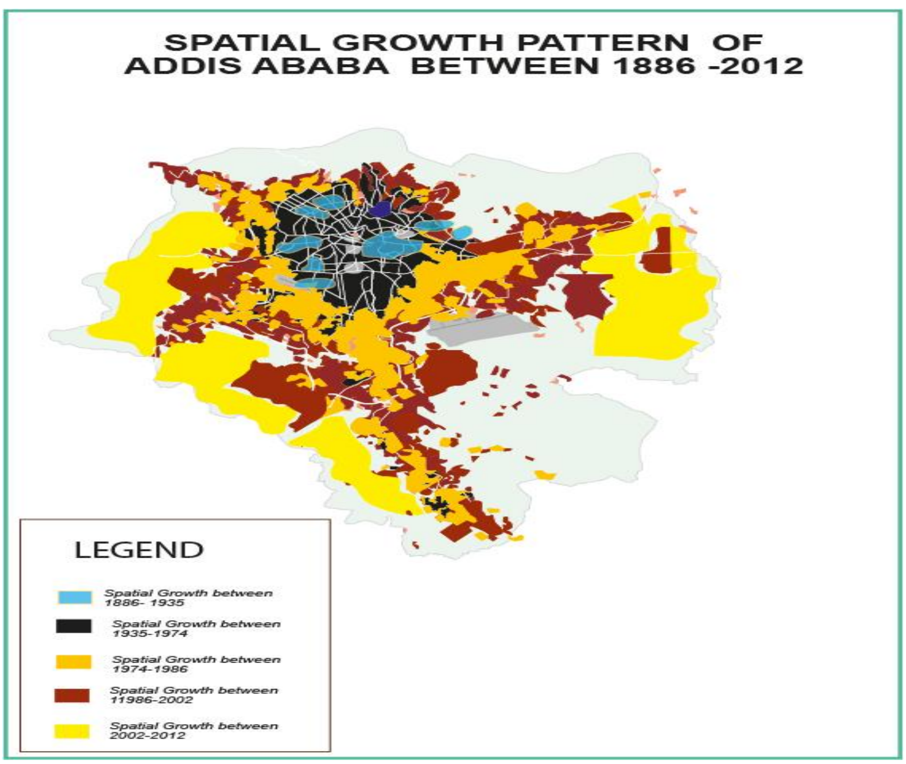


Figure 4.1 Spatial growth pattern of A.A city; from 1886-2012, Source: AA city planning Institute.

On the other hand, for the past decades, most areas experienced a huge construction boom thus, posed serious environmental challenges. Specially, in the target areas (Yeka, Gulele, Nefas silk, and Kolfe keraniyo) the unhealthy urban agglomeration create severe problems on the natural environment.

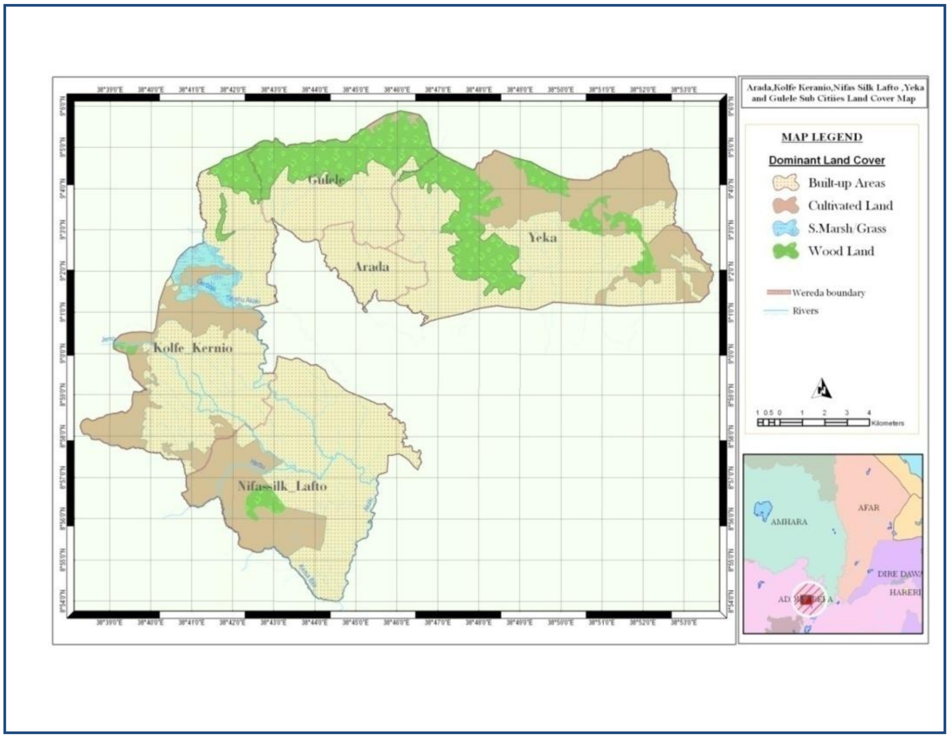


Figure 4.2 Former forest cover map of the study areas, Temesgen Assefa, (2011).

To full fill the energy needs (70% of the community is dependent on fuel wood for energy use) cutting of trees has been enormous. Farming, settlement expansions, and quarry activity on hill slope caused environmental degradation problems thus potential developing natural hazard.

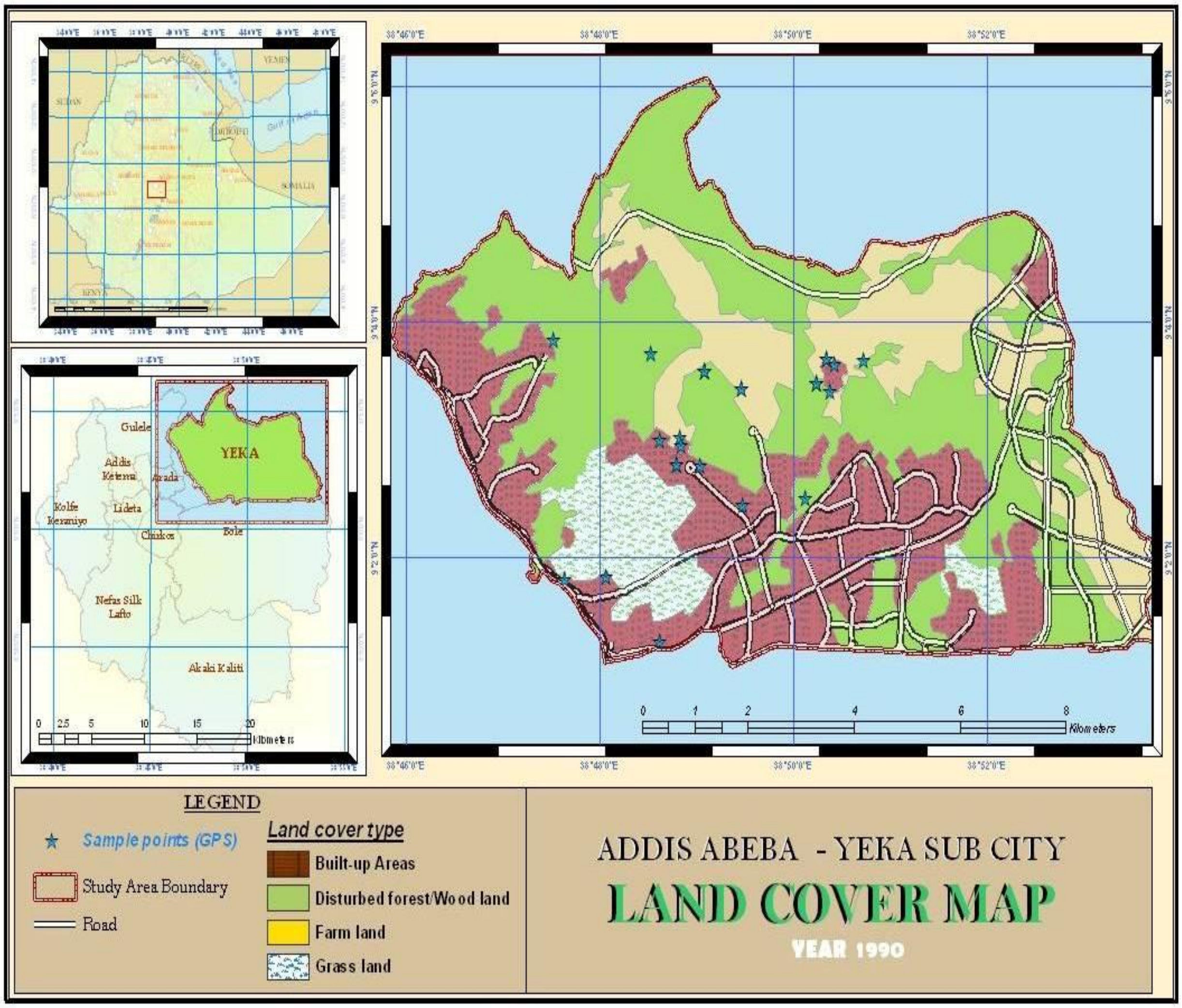


Figure 4.3 LU/LC map of Yeka in 1990 (Temesgen Assefa).

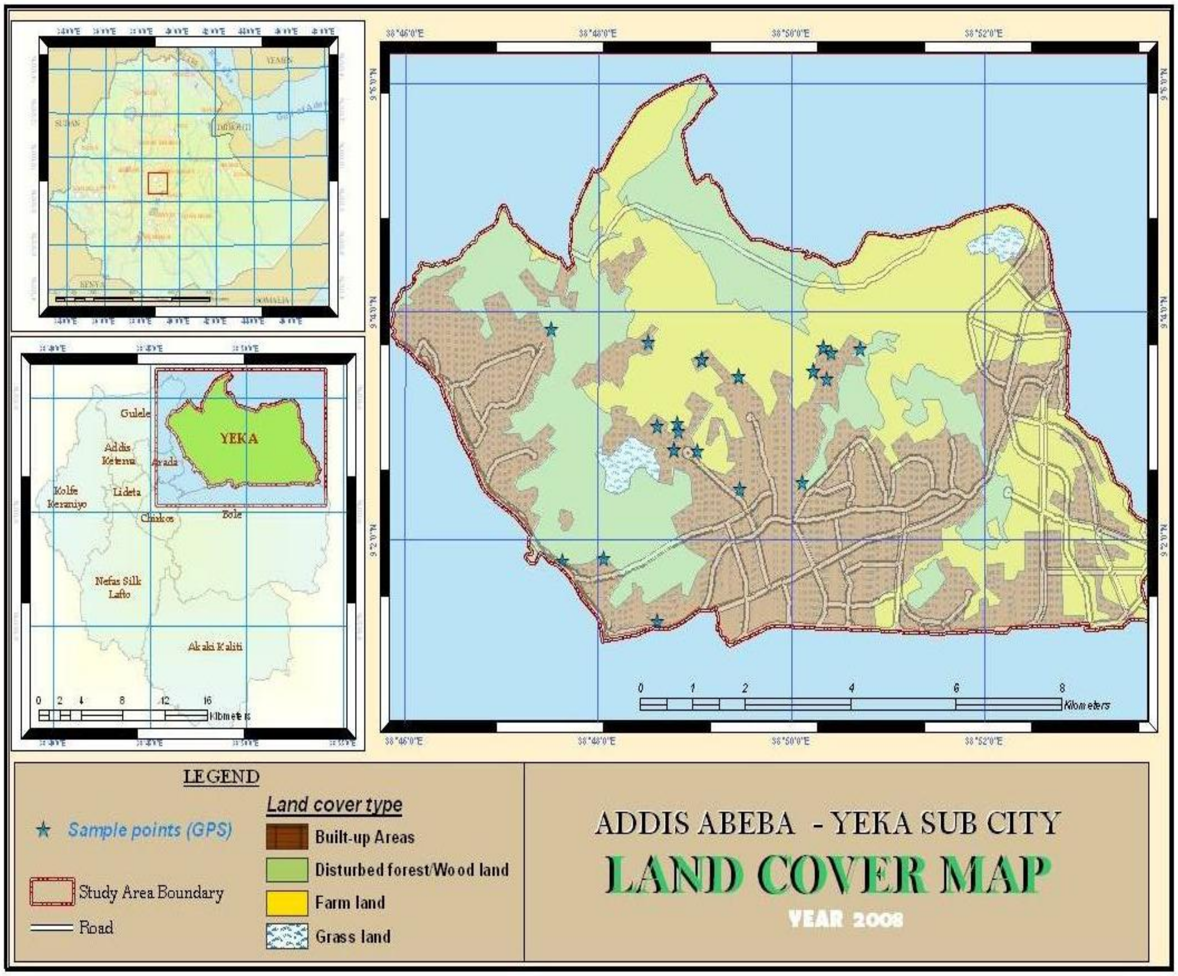


Figure 4.4 LU/LC map of Yeka, 2008, (Temesgen Assefa).

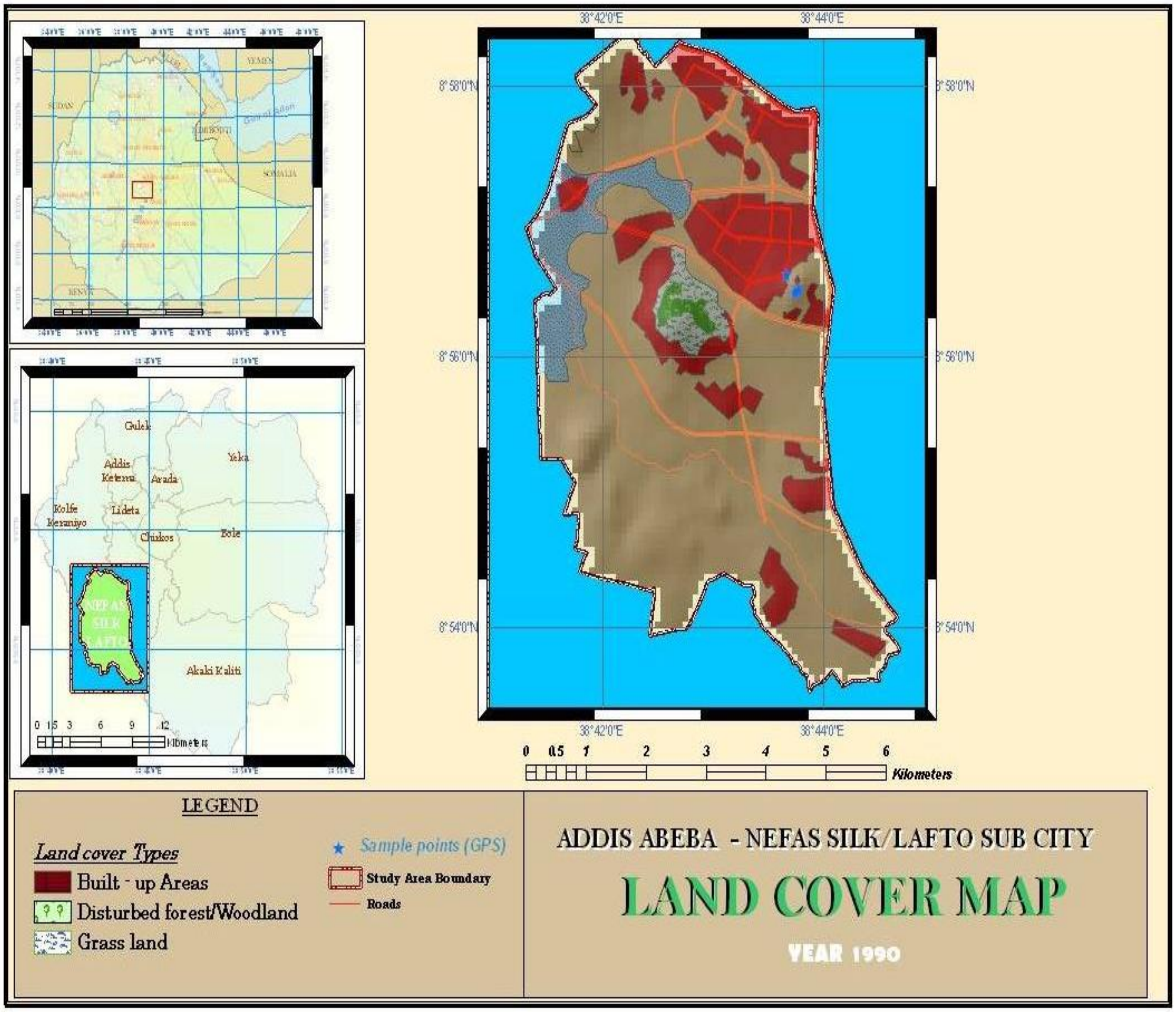


Figure 4.5 Land cover map of Nefas-Silk Lafto sub-city, 1990 (Temesgen Assefa).

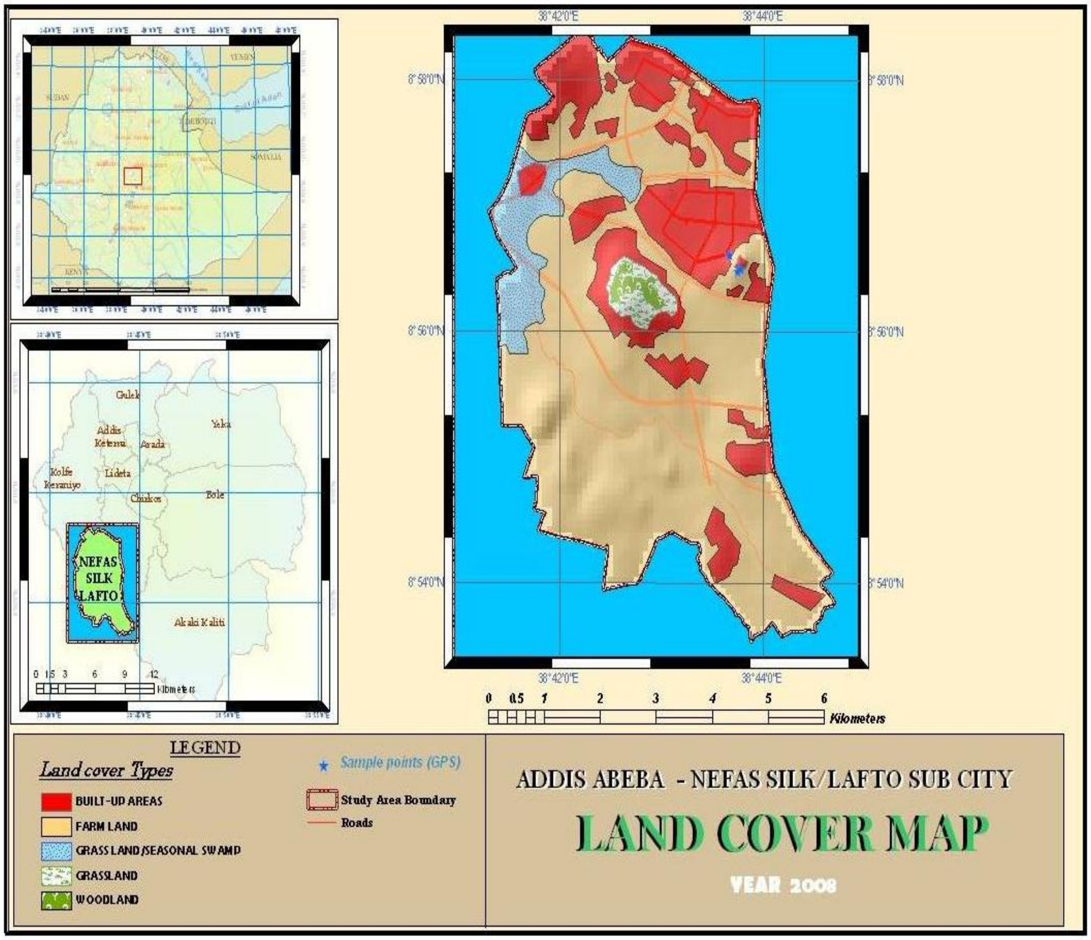


Figure 4.6 Land cover map of Nefas silk Lafto sub-city, 2008, (Temesgen Assefa).

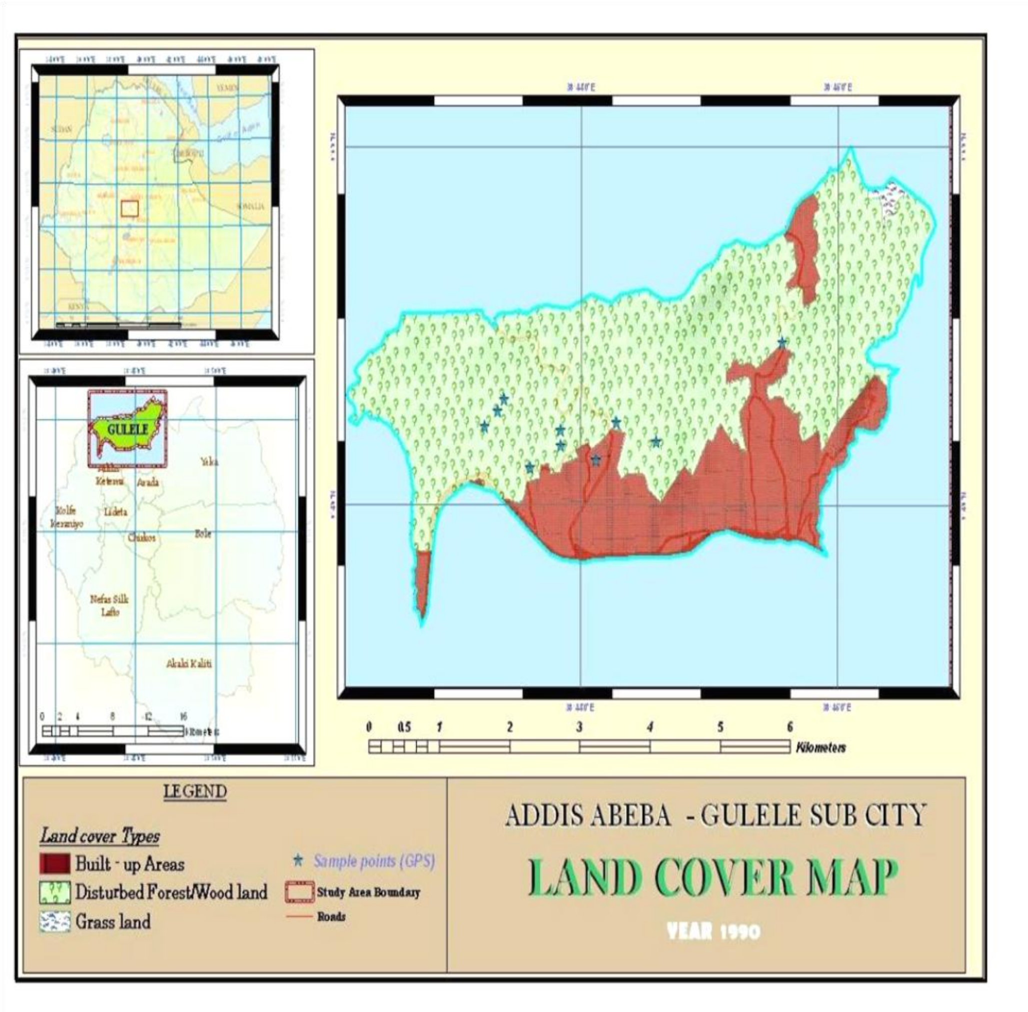


Fig. 4.7 Land cover map of Gulele sub-city; 1990 (Temesgen Assefa).

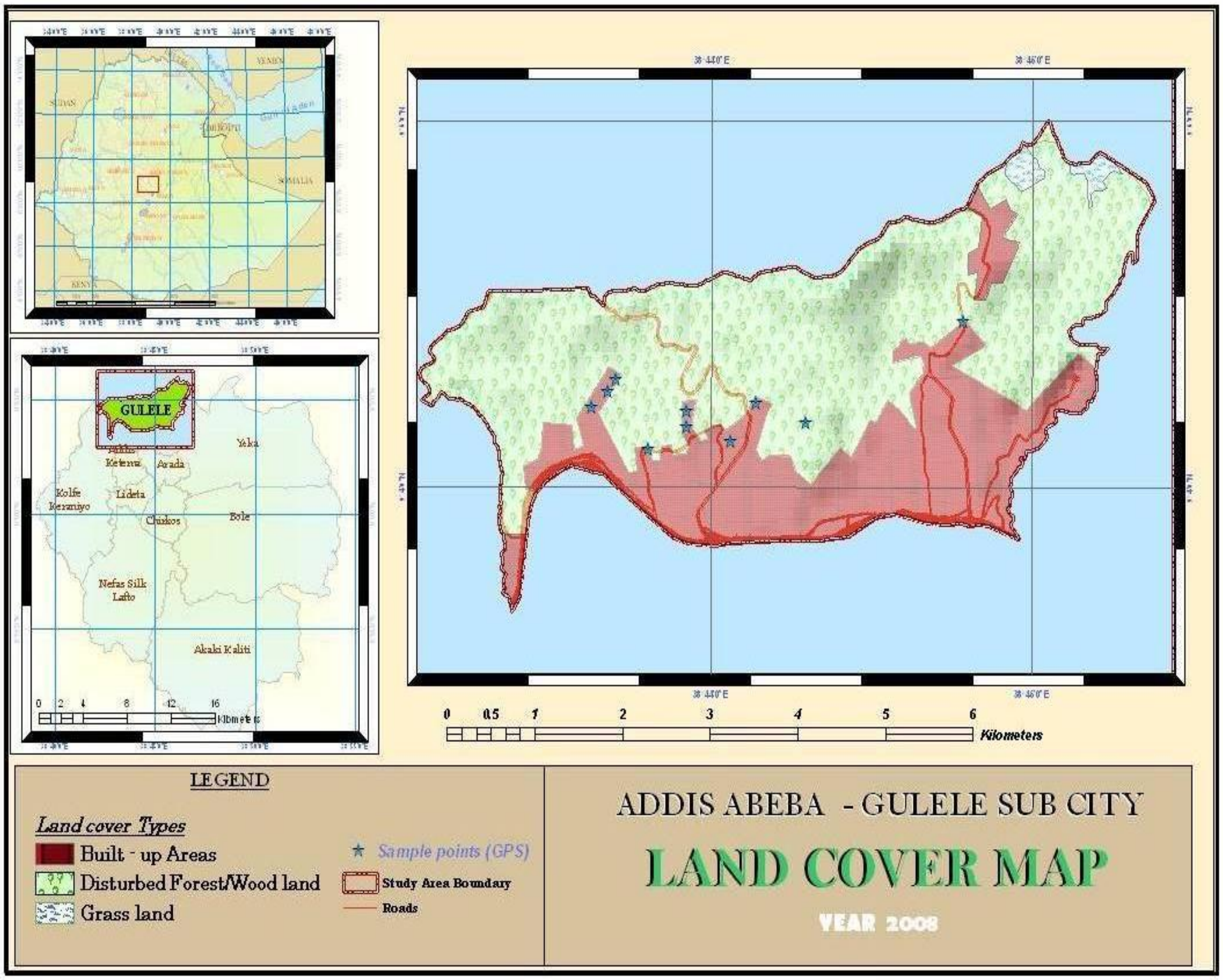


Figure 4.8 LU/Land cover map of Gulele sub-city; 2008 (Temesgen Assefa).

Table 4.1: Summary of LU/LC changes detected from image and aerial photo

Sub city		Year 1998	Year 2008	Area difference in ha
	Land Use/Land Cover type	Area in ha	**Area in ha**	
Gulele	Disturbed forest	1382	1275	-107
Gulele	Grassland	11	24	+13
Gulele	Built up area	563	657	-94
		1956		
Nefas silk/lafto	Wood land	27	27	0
Nefas Silk/Lafto	Grass land	75	55	20
Nefas Silk/Lafto	Grass land/seasonal	243	243	0
Nefas silk/lafto	Built-up areas	738	883	+145
Nefas silk/lafto	Farm land	2402	2277	-125
		3485		
Yeka	Built-up area	2397	3330*	+933
Yeka	Cultivated/farm* Farm lands	1505	2609**	+1104
Yeka	Disturbed forest / wood land	3502	1952	-1550
Yeka	Grass land	587	100	-487
		7991		

* Highest score, in settlement areas/built-up

** In the case of Yeka sub-city, farm lands increased because forest lands were cleared and changed to either human settlement (most are squatters) and /or to agricultural lands.

Analytically, it was possible to quantify the changes made on the physical environmental components; mainly land cover changes in the study area.

After analysis made, it was proved that 1650 ha of forest land were totally cleared and either changed to settlements, farming and/or quarry uses (see Table 4.1).

Figure 4.9 Squatter colonies/settlement expansions on the extreme high gradient zones of Entoto, Yeka sub-city, A.A: an area exposed for flood and landslide hazards, and hydro-geological regime disruption.

4.3.2.2 Landslides triggered by precipitation/rainfall

Slope failures can be triggered by rainfall if some threshold intensity is exceeded so that pore water pressures are increased by an amount which is required to initiate instability and the process is affected by several factors (Oliver et al., 1994): (a) duration of the rainfall, (b) slope angle, (c) distribution of shear strength and permeability (particularly within the soil mass), (d) the effect of subsurface erosion (pipes), (e) variations in soil thickness, and (f) antecedent weather and the pore water pressure conditions.

Plate 4.5 Human made i*nfrastructures/ utilities (abandoned water mains and gravity water tankers, with a capacity of 1.5million m^3) constructed on hilly areas; potential to develop subsurface pore water pressure due to seepages; considered as triggering factor for land instability; Yeka and Nefas Silk Lafto sub cities, A.A.*

Previous studies on the relationship between rainfall and landslides (e.g. Lumb, 1975; Wieczorek, 1987; Wilson and Wieczorek, 1995) have concluded that both antecedent rainfall and a critical intensity of rainfall are important factors in triggering landslides. Shimizu (1988) studied the relationship between rainfall and landslides, for an area in Japan, and found a good correlation between the moment of maximum rainfall intensity and the moment of slope failure, and explained the prevalence of shallow landslides by the development of positive pore water pressure in the topsoil due to reduction of the hydraulic conductivity with depth. Jahns (1978) also reported that larger, deeper slope failures were more likely to occur during long continuous wet periods, while shallow slides of slope failures were more characteristic of short-duration, high-intensity rainfall. Dai and Lee (2001) studied the relationship between rainfall and the number of landslides in Hong Kong, and found that with an increase in failure volume of landslides, the most important rainfall variable may vary from rainfall of short duration (12-h) to that of relatively long duration (24-h).

The occurrence of shallow landslides is frequently explained by the loss of capillary cohesion due to saturation of the topsoil during intense rainstorms (Anderson et al., 1987; De Campus et al., 1992; Tsutiya et al., 1992; Van Asch and Sukmantaya, 1993).

According to Anderson and Kemp (1991), a downward moving wetting front causes a difference in shear strength between the saturated topsoil and the stronger unsaturated subsoil, and when the wetting front reaches a critical depth landslides may be triggered. Generally, the location of a slip surface of landslides triggered directly by rainfall is not related to geotechnical or hydrological boundaries (Van Asch, 1992).

4.3.2.3 Change in slope geometry.

As described by several authors (Deere et al., 1971; Varnes, 1978; Greenway, 1987; Selby, 1993; Bell, 1999), modification of slope geometry through natural or artificial processes could influence the stability of slopes. These factors include, among others (Varnes, 1978):

- Removal of lateral support by erosion (streams and rivers, glaciers, action of waves or marine currents, successive wetting and drying), natural slope movements (slides, settlements), human activity (cuts and excavations, removal of retaining walls, draw-down of bodies of water).
- Removal of underlying materials that provided support by rivers or seas, weathering, underground erosion due to seepage (piping), dissolution of soluble agents, human activity (excavation or mining), loss of strength of the underlying materials due to various processes such as weathering.
- Human activities, such as construction of fill, buildings and other overloads at the crest of slopes.

4.3.2.4 Slope angle (gradient) and direction (aspect)

The common force tending to generate movements on slopes, of course, is gravity. In general, the steeper the slope, the greater is the likelihood that slope instability will occur. Obviously, there is no universal threshold value at which slope failures take place, since this must be related to the ground condition. Steep slopes on competent rock could be more stable than comparatively gentle slopes on weak materials. Nonetheless, numerous authors have reported critical angles below which failure does not occur in particular soil or rock types (Walker et. al., 1987).

Various authors (e.g. Carrara et al., 1977) have reported some relations of slope stability to slope aspect (direction in which a slope faces) because rainfall-pattern could be influenced by the direction in which a slope faces in relations to the wind directions.

On this particular aspect of the hydrological factor, reports were done by several authors (e.g. Hutchinson, 1988; Selby, 1993; Bell, 1999). Mainly, in many mountain areas where cliff faces are frozen for much of the winter and an increase in temperature results in melting of the snow. This causes freeze-thaw action on the slope face and it could generate seepage forces which could trigger slope failures (Bell, 1999).

4.3.2.5 Slope shape (curvature)

Slope shape is related to curvature of a slope in plan and profile. According to Parsons (1988):

- Plan curvature is curvature of corresponding normal section which is tangential to a contour. It is also called contour curvature and shows the bending of the surface perpendicular to the slope direction.
- Vertical or Profile curvature is curvature of corresponding normal section which is tangential to a flow-line.
- Plan curvature influences the susceptibility of a slope to landslides by governing the distribution of water (surface/subsurface) within a slope (e.g. Anderson and Burt, 1978; Reneau and Dietrich, 1987; Sitar et al., 1992). Positive plan curvature values (convex) indicate divergence and negative plan curvature values (concave) indicate concentration of flow. Concave plan terrains promote concentrated flow of water, while convex plan terrains cause divergence of flow (Anderson and Burt, 1978). Plan curvature therefore regulates converging/diverging flow and soil-water content.

- Profile curvature represents the rate of change of slope in the direction of dipping and it regulates flow acceleration and erosion/deposition rate of soils/debris on slopes (Crozier, 1986; Parsons, 1988). Positive profile curvature values (convex) indicate material depletion and negative profile curvature values (concave) indicate material accumulations. As indicated by numerous authors (Meis and Moura, 1984; Fernandes et al., 1994), topographic hollows usually show clear evidence of recurrent depositional and erosive events whereby materials of different ages and composition overlie one another and contribute to localized hydraulic discontinuities that promote the development of high pore pressures in concave portions of landscapes. Concentration of subsurface drainage within a concave slope, resulting in higher pore water pressures in the axial areas than flanks, is one possible mechanism for triggering landslides (Pierson, 1980).

Together with other factors, plan and profile curvatures control the distribution of water and soil masses in hill slopes and are therefore important in landslide susceptibility evaluations (Ayalew and Yamagishi, 2004). The same authors reported on landslides in the Blue Nile gorge (Ethiopia) and mentioned that debris and earth flows occurred when the lateral profile is concave and profile curvature governs the run-out distance of disturbed materials. According to Ayalew and Yamagishi (2004) the volume of material involved, the frequency of occurrences, the shape of rupture surfaces, etc are functions of both plan and profile curvatures in the northern highlands of Ethiopia.

4.3.3 Hydro-geological factors

Hydrological processes promote the occurrence of slope failures by governing the moisture and temperature conditions of an area (e.g. Lumb, 1975; Sangray et al., 1984; Selby, 1993). According to several authors (e.g. Selby, 1993; Abramson et al., 1996), water is the most dominant hydrological factor which affects slope stability because it:

- Reduces the shear strength of soil/rock masses by changing the effective stresses and thus the resistance to shear stress and generates seepage forces from subsurface water flows towards the slope face which augment those forces tending to destabilize a slope;
- Changes the mineral constituents through chemical alteration and solution of materials forming the slopes (such as dissolution in soluble materials, and swelling in expansive clays);
- Changes the bulk density of the material forming the slope;

- Causes both internal erosion (dislodge mineral grains from poorly cemented materials such as silts) and external erosion;
- Increase in lateral pressure by water in cracks and fissures, freezing of water in cracks and expansion of clay.

Many researchers (e.g. Sangrey et al., 1984; Okimura and Kawatani, 1987; Anderson and Kemp, 1991; Van Asch, 1992; Terlien, 1996) have stressed the importance of detail hydrogeological investigations of landslide prone areas in order to find out whether slope instability hazards are triggered directly by rainfall, by perched water table or by ground water pressure.

4.3.3.1 Landslides triggered by a perched water table/aquifer.

Rulon and Freeze (1985) gave a short literature review of landslides that may have been triggered by a perched water table and indicated that shallow failures of slopes are sometimes associated with the rise of perched water table over an impermeable layer. According to Abramson (1996), perched water table may be transient, rapidly developing in response to heavy rainfall and dissipating quickly, or permanent, in response to seasonal variations in rainfall levels.

4.3.3.2 Landslides triggered by groundwater

Landslides may be triggered by a combination of shear strength reduction due to saturation in the upper part of the soil profile and the build-up of positive pore water pressures in the lower parts of the slope profile. As indicated by several authors (e.g. Okunishi and Okimura, 1987; Okimura and Kawatani, 1987; Montgomery and Dietrich, 1989; Benda and Zhang, 1990; Terlien, 1994), rainfall can also trigger landslides by convergence of saturated subsurface flow and groundwater flow in terrain concavities and hollows. In all these previous studies, the main controlling factors in the concentration of saturated subsurface flow in concave terrain depressions (hollows) are the topography of the bedrock, the hydraulic conductivity of soil and bedrock, and geological structures (such as faults and major joint systems).

4.3.4 Weathering Factors

According to different authors (e.g. Terzaghi, 1950; Varnes, 1978; Abramson et al, 1996), in some cases the decay of the material fabric, as a result of weathering, could result in loss of strength. In early stages of weathering it appears that there is a general increase of fracture per unit volume and in later stages of weathering there is a rapid increase in chemical decay (Selby, 1982; Zhao et al., 1994). According to these authors, the state of weathering of a rock mass has a major influence upon its strength, porosity and permeability, and deformation characteristics.

4.3.5 Earth quake/shock induced landslides

External mechanisms which include earthquakes and other shocks/vibrations (natural ground displacements or artificial blasts) are important triggering factors of landslides (Abramson et al., 1996).

4.4 Landslide hazard analysis: the Qualitative method, use of questionnaires and interviews

The qualitative method relayed on developing questionnaire and conducting interviews with sample groups in the target area. Respondents were selected at random basis; 271 in number but not statistically selected. The basic criteria for selection was living longer period (35 years and above) in their respective locality and thorough knowledge about their surroundings, able to memorize past events including natural hazard occurrences.

Among the participants 186 were men and 85 were women. Around half of the participants were farmers (49.8%). Among others, the two main significant participants were pensioners 19.9% and fire wood collectors 12.5%. Most participants (58.9 percent) had lived in their communities for more than 30 years; 39.1 percent of the participant had lived 45-75 years in their locality.

Table 4.2 Background characteristics of participants by sub city, occupation, and percentage distribution

Occupation		Sub city / woreda				Total
		Gullele	N. Lafto	Kolfe Keranyo	Yeka	
Daily laborer	Count	4	0	0	0	4
	%	6.3	0		0	1,5
Driver	Count	0	1	0	0	1
	%	0	1.6		0	0.4
Employee	Count	1	0	0	0	1
	%	1.6	0		0	0.4
Farmer	Count	5	57	32	41	135
	%	7.9	91.9	45.7	53.9	49.8
Fire Wood collector	Count	10	0	18	6	34
	%	15.9	0	25.7	7.9	12.5
Guard	Count	3	0	2	1	6
	%	4.8	0	2.9	1.3	2.2
Housewife	Count	3	0	0	2	5
	%	4.7	0	0	2.6	1.8
No work	Count	1	2	4	3	10
	%	1.6	3.2	9.8	4.7	3.7
Pensioner	Count	29	0	6	19	54
	%	46	0	8.6	25	19.9
Petty Trader	Count	0	0	2	1	3
	%	0	0	2.9	1.3	1.1
Petty trader and farmer	Count	0	0	4	1	5
	%	0	0	9.8	1.3	1.8
Priest	Count	1	0	0	1	2
	%	1.6	0	0	1.3	0.73
Service	Count	4	1	0	1	6
	%	6.3	1.6	0	1.3	2.2
Teacher	Count	0	1	0	0	1
	%	0	1.6	0	0	0.4
Weaver	Count	2	0	2	0	4
	%	3.2	0	2.9	0	1.5
Total	Count	63	62	70	76	271
	%	100	100	100	100	100

The analysis made from the findings of the sample groups were based on an in-depth interview of the following six core issues:

- knowledge and experience of the agricultural productivity status
- knowledge and experience on volumes of the river water
- Knowledge and experience on the precipitation status.

- Knowledge and experience of soil erosion status.
- knowledge and experience of natural hazard occurrences
- Knowledge and experience of climate change.

After discussions held, most of the respondents were able to cite major environmental problems and its main causes on the existing urban environment: anthropogenic effects; construction of buildings, roads on mountain up-lands; deforestations and natural calamities. Further, as a solution, they also shared their views and some indigenous knowledge based coping strategies that could bring climate change more resilient. Accordingly, the collected raw data has been statistically arranged and analyzed by using SPSS version 15.

- ***Knowledge and experience of the current agricultural status***

Almost all participants know about the agriculture status from 98 percent of the total count 62.2 percent of the respondent confirms the non- productivity of agriculture. Rain fall pattern fluctuation, sever soil erosion by water, decreased farm lands due to population pressure were most attributes to the declining of agricultural products.

Table 4.3 Percentage and frequency distribution of respondents on agricultural productivity status

	Current status of agricultural productivity		**Yes**	**no**	**Total**
1	Productive	Count	6	0	6
		%	6.2	0	6.1
2	Moderate	Count	31	0	3.1
		%	32	0	31.6
3	Non-productive	Count	60	1	61
		%	7.9	100	62.2
Total	**Count**		**97**	**1**	**98**
	%		**100**	**100**	**100**

- **knowledge and experience on volume of river water**

Almost all the respondent noted that lack of rain fall and temperature rise is associated with deforestation and huge population settlement (low carrying capacity) caused to decrease the river water volume. They observed the link between climate change and the decline of the volume of the rivers (recurrent droughts were occurred) in their locality. This situation is clearly shown in Table 4.4

Table 4.4 Respondent observation of river water volume change with respect to climate change

Observation of river water volume change		Yes	No	Total
Declined	count	175	1	176
	%	91.1	100	91.2
No-change	Count	16	0	16
	%	8.3	0	8.3
Increased	Count	1	0	1
	%	0.5	0	0.5
Total	Count	192	1	193
	%	100	100	100

- ***Knowledge and experience of precipitation with respect to climate change***

Most respondent noted that deforestation was caused by large human settlements (encroachments) occurred on marginal lands/forest areas. Besides, most of the population has been dependant on natural resource, the existing forest resources have been used as energy and construction materials. Thus desertification is widely experienced in the wider area. Rainfall, if not completely ceased but diminished, and the pattern fluctuates. In addition, forest lands have been transformed to agricultural farms and quarry sites.

Almost all respondents knew the link between the fall of precipitation and climate change.

Table 4.5 *Respondent's observation on precipitation status and climate change*

Status of precipitation		Do you observe any climate change		Total
		Yes	**No**	
Increased	Count	3	0	3
	%	1.5	0	1.5
No change	Count	3	0	3
	%	1.5	0	1.5
Declined	Count	192	1	193
	%	97	1	97
Total	**Count**	**198**	**1**	**199**
	%	**100**	**100**	**100**

- **Knowledge and experience of soil erosion**

Most of the respondents noted that intensive soil erosion was repeatedly observed in the hilly areas of Yeka and Gulele.

The vast population pressure, deforestation, poor agricultural practices, farming grass lands and quarrying activities were the major attributes to soil erosion manifested in their locality.

Table 4.6: *Respondent's observation on soil erosion*

Is there any soil erosion in your locality?			Individuals		Total
			Yes	**No**	
	Yes	count	164	1	165
		%	82.8	100	82.9
	No	Count	34	0	34
		%	17.2	0	17.1
Total		**Count**	**198**	**1**	**199**
		%	**100**	**100**	**100**

- ***Knowledge and experience of natural hazard occurrence***

All most all respondents knew what natural hazard is and noted that they were experienced an earth quake hazard at least twice in their life time. The society was also faced recurrent drought and stricken by several severe floods.

Table 4.7 ***Respondent's observation on natural hazard occurrences***

Do you observe any natural hazard occurrence			**Yes**	**No**	**Total**
	yes	Count %	190 96.4	1 100	191 96.5
	No	Count %	7 3.6	0 0	7 3.5
Total	**Count**		**197** **100**	**1** **100**	**198** **100**

4.5 Semi-quantitative Landslide hazard analysis, using GIS based (AHP) method.

Several authors (e.g. Brabb, 1984; Carrara et al., 1991; van Westen, 1993; Soeters and van Westen, 1996; Terlien, 1996; Guzzetti et al., 1999) have suggested different methods for landslide hazard assessment using GIS. At present, there are no agreements among scientists either on the methods for or on the scope of producing hazard maps (Brabb, 1984; Carrara, 1989). The reported methods, however, share a common approach:

- Inventory/mapping of landslides and evaluating the characteristics of failures,
- Defining a set of parameters which are supposed to be directly or indirectly related to slope instability,
- Ranking and assigning weights to the different parameters based on their relative degree of influence on landslide evolutions, and
- Classifying an area into domains of different landslides probability or susceptibility degree.

Approaches for landslide hazard assessment using GIS could be categorized into qualitative, quantitative, and semi-quantitative methods.

❖ Qualitative methods

Qualitative methods are subjective which rely on the ability of the investigator to estimate actual and potential slope failures and present the hazard zoning in descriptive (qualitative) terms (Hansen et al., 1995). According to Soeters and van Westen (1996) and Aleotti and Chowdhury (1999) these include direct methods (hazard mapping) and indirect (heuristic or index based) models.

❖ Quantitative methods

Quantitative methods are based on observed relationships between controlling factors and landslides (Guzzetti et al., 1999) and produce numerical estimates (probabilities) of the occurrence of landslides in an area. Quantitative methods, according to numerous authors (e.g. Carrara et al., 1992; van Westen, 1993; Carrara et al., 1995; Hutchinson, 1995), include statistically based models, deterministic/ geo-technically or physically based models, and frequency analysis.

- **Semi-quantitative methods**

Some approaches, however, incorporate a priori knowledge of an expert into mathematical models and arrive at ranking and weighting the different landslide-influencing factors. Such approaches are semi-quantitative in nature. Being partly objective, results of semi-quantitative methods are often useful for regional studies (Soeters and van Westen, 1996; Guzzetti et al., 1999).

In this research work, the Analytical Hierarchy Process (AHP) (Saaty, 1980) which is a semi-quantitative type GIS-based method, applied for landslide and earthquake hazard analysis of the selected areas of Yeka, Gulele, Kolfe-Keranyo, and Nefas Silk sub-cities of Addis Ababa.

Prior to analysis of landslide and earthquake hazards the major influencing/controlling factors which led to the occurrences of landslides and earthquake hazards were selected (table 2.8). The deformability characteristics of lithologies; shear strength of soils; changes in land use land cover (LU/LC) types; change in slope and altitude differences; depth to ground water table, proximity to major fault traces; and population density per square kilometer were principal factors considered for current analysis purpose. Apparently, parameters assumed to be similar in characteristics grouped under similar category and were given a class value. According to their relative importance with respect to occurrence of landslide and earthquake hazards, weights were assigned for each parameter and finally analyzed hierarchically (AHP method) by using GIS software; Arcmap-10.

Further descriptions about selected parameters used in the analysis were given in the following table (4.8).

Table 4.8 Influencing Factors for Landslide and/or earthquake hazard analysis in the study area

Influential factors/parameters	Principal influencing criteria and descriptions in response to hazard occurrence	Categories	Assigned Class	Weight factor (Relative contribution to natural hazard occurrence)
I. Ground water depth	**Depth**: Depth to ground surface is inherently related to development of pore water pressure at final stage, slopes tend to fail due to liquefaction	<10m in depth	5	Dependant on specific hazard to be analyzed
		10-25m	4	
		25-40m	3	
		40-55	2	
		>55	1	
II. Faults, Fissures and fracture related structures	**Fault length and proximity**: Fault traces distance, fracture frequency, their length and aperture, orientation and angle of dip govern landslides occurrences. With respect to earthquake actions faults do play role of amplification	<500mt	5	Dependant on specific hazard to be analyzed
		0.500-1.5km	4	
		1.5-4km	3	
		4-5km	2	
		>5km	1	
III. Lithologies/Rocks	**Rock mass strength (RMS):** Rocks having different rock mass strength have various responses to landslide occurrence. Rocks with High rock mass strength have less susceptibility to mass wasting, and vice-versa. In case of seismic action different rocks respond seismic actions differently. Even though, rocks behave like elastic, while maximum pressure exerted, rocks can break thus energy dissipate in the form of seismic wave.	Fresh and un weathered massive volcanic rocks (e.g Plieocene-Quaternary Yerer Volcanics-2 and 3)	1	Dependant on specific hazard to be analyzed
		Moderately weathered and Slightly Fractured Volcanic rocks (e.g Upper Miocene-Addis Ababa Basalt Aphanitic,rocks)	2	
		Highly Weathered and Highly Fractured volcanic rocks (e.g Lower Miocene Alajie series and Lower Miocene Tarma Ber aphanitic basalts, and undifferentiated volcanic)	3	
		Ignimbrites, Strongly welded Tuffs and very stiff paleo soils (e.g Pliestocene-Quaternary Yerer volcanic ashes, Upper Miocene perforated basalt highly weathered Tarmaber basalt, Middle Miocene Ignimbrites)	4	
		Loose depositional materials of undifferentiated volcanic, Pliestocene Yerer Volcanic ashes, conglomerates; Highly decomposed Lower Miocene Tarmaber and alaji series basalts; Alluvial soils; agglomerates	5	

Influential factors/parameters	Principal influencing criteria and description in response to hazard occurrence	Categories	Assigned Class	Weight factor (Relative contribution to natural hazard occurrence)
IV. Soils	**Shear strength and thickness:** Soil type and their properties/shear strength and thickness have a strong relation to landslide occurrence. Soft/unconsolidated soils more suffer from slope instability than firm/stiff soils and vice-versa. In case of earthquake events unconsolidated materials/soils show amplification effects.	Eutric nitisols	1	Dependant on specific hazard to be analyzed
		Chromic liptosols and luvisols	2	
		Calsic xerosolos	3	
		Pellentic and chromic vertisols	4	
		Orthic solonchacks	5	
V. Land use/Land cover	**Land use land cover change (LU/LC):** Land use system followed in a region has major impacts on the existing ground condition; any changes made on land forms can trigger or hamper natural hazard occurrences. Taking in to account the role of vegetation to control land slide. Land use functions left for physical establishments, type degree of concentration, linearly correlated to seismic actions vulnerability. The more they are concentrated the more they will be affected by seismic actions.	Mixed residential Residential Manufacturing and storage Education Health Transport Terminal	5	Depend on the hazard to be analyzed
		Administration Commercial Recreation Religious institutions	4	
		Special use Under construction Infrastructures and utilities Road network Open space	3	
		Social and cultural welfare Municipal services	2	
		Plantation Mixed forest River Vegetable farm Riverine Field crops	1	
VI. Population density	**Population density in a given area:** Human settlement/human induced actions cause slope instability. Building	V. High dense population.	5	Dependant on specific hazard to be analyzed
		High	4	
		Moderate	3	
		Less	2	
		v. less /rare	1	

	construction and road cuts trigger land sliding. In case of earthquake events densely populated areas suffer more than dispersed population numbers.			
VII. Relative relief	**Height:** Relative relief has a strong correlation with mass wasting/slope instability. Objects at higher level tend to fall rapidly than objects found at lower level. In the case of seismic wave actions objects at higher altitude more suffer than lower ones by the effect of earthquake actions.	>2700 a.s.l	5	Dependant on specific hazard to be analyzed
		2400-2700	4	
		2100-2400	3	
		1800-2100	2	
		<1800 a.s.l	1	
VIII. **Slope gradient**	**Gradient:** Slope angle is directly related to slope instability. As slope angle increases, slope mass sliding increases as well; and vice-versa. Slopes, in case of seismic actions, when the angle of repose large, they tend to fail and vice-versa.	>20% gradient	5	Dependant on specific hazard to be analyzed
		12-20%	4	
		7-12%	3	
		2-7%	2	
		<2%	1	

Class values assigned in each parameter signifies a level that corresponds to its degree of susceptibility to a specific hazard considered, and given a value of one to a least susceptibility condition, and five to a higher one. It is optional to use vice-versa conditions. In table 4.9 to the assigned numbers/values, corresponding meanings were described.

Table 4.9 ***Description of class values/scores assigned for the parameters considered in accordance to susceptibility.***

Class value	**1**	**2**	**3**	**4**	**5**
Description	Very low	Low	Moderate	High	Very High

Similarly, in the respective hazard analysis, based on their degree of influence, each parameter considered was given a relative weight. Clarifications of the qualitative descriptions on relative weight factor assignment were presented on table 4.10.

Table 4.10 W*eight factor assigned values to the various influencing parameters considered*

Weight factor	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Description	Insignificant	V.less Significant	Less Significant	Significant	Moderately significant	Highly significant	Very highly significant	Extremely high significant

In this analysis, according to the weights/values given to all considered parameters, ratings were made possible (based on the discussion made in section 2.3.6.3).

4.5.1 Ratings of lithologies related to landslide hazard.

In this rating, relative ages of the various lithological formations and degree of exposure to weathering have been the basic issues considered (observations was made from collected deep water well lithological logs; see annex part).

Lithological type	**Category in RMS**	**Class value**	**Weighted value**
PQ-YV-V2, Trachyte of Pliocene to quaternary young volcanics	5	1	
PQ-YV-V3, Trachyte of Pliocene to quaternary young volcanics	5	1	
UM-AAB-A4A, upper Miocene Addis Ababa aphanitic basalt	4	2	
UM-AAB-A4B, upper Miocene Addis Ababa aphanitic basalt	4	2	
UM-AAB-A4C, upper Miocene Addis Ababa aphanitic basalt	4	2	**9**
LM-AB-AS-AJ7a, Lower Miocene Alaji series rhyolite	3	3	
LM-TR-AS-AJ7b, Lower Miocene Alaji series trachyte	3	3	
LM-AB-AS-AJ9, Lower Miocene Alaji series aphanitic basalt	3	3	
UV-EN, undifferentiated volcanic predominantly trachyte, trachy basalt,	3	3	

and basalt with			
PQ-YV-V1A, Ignimbrites of pliocene to quaternary young volcanics	2	4	
UM-PB-TB-T5a, upper Miocene porphyry basalts of Tarmaber basalts and trachytes	2	4	
MM-IG-AV-M6, middle Miocene acidic volcanic of coarse grained Ignimbrite	2	4	
UV-EAA, undifferentiated volcanic	1	5	
Q-TB-RBS2, quaternary younger basaltic lavas, cinder cones and hydromagmatic pyroclastic deposits	1	5	
LM-T&I-AS-AJ8, lower Miocene Alaji series tuffs and agglomerates	1	5	
PQ-YV-V1B, Tuffs of pliocene to quaternary young volcanics	1	5	
SAL, quaternary alluvial soils	1	5	
SAI, quaternary alluvial soils	1	5	

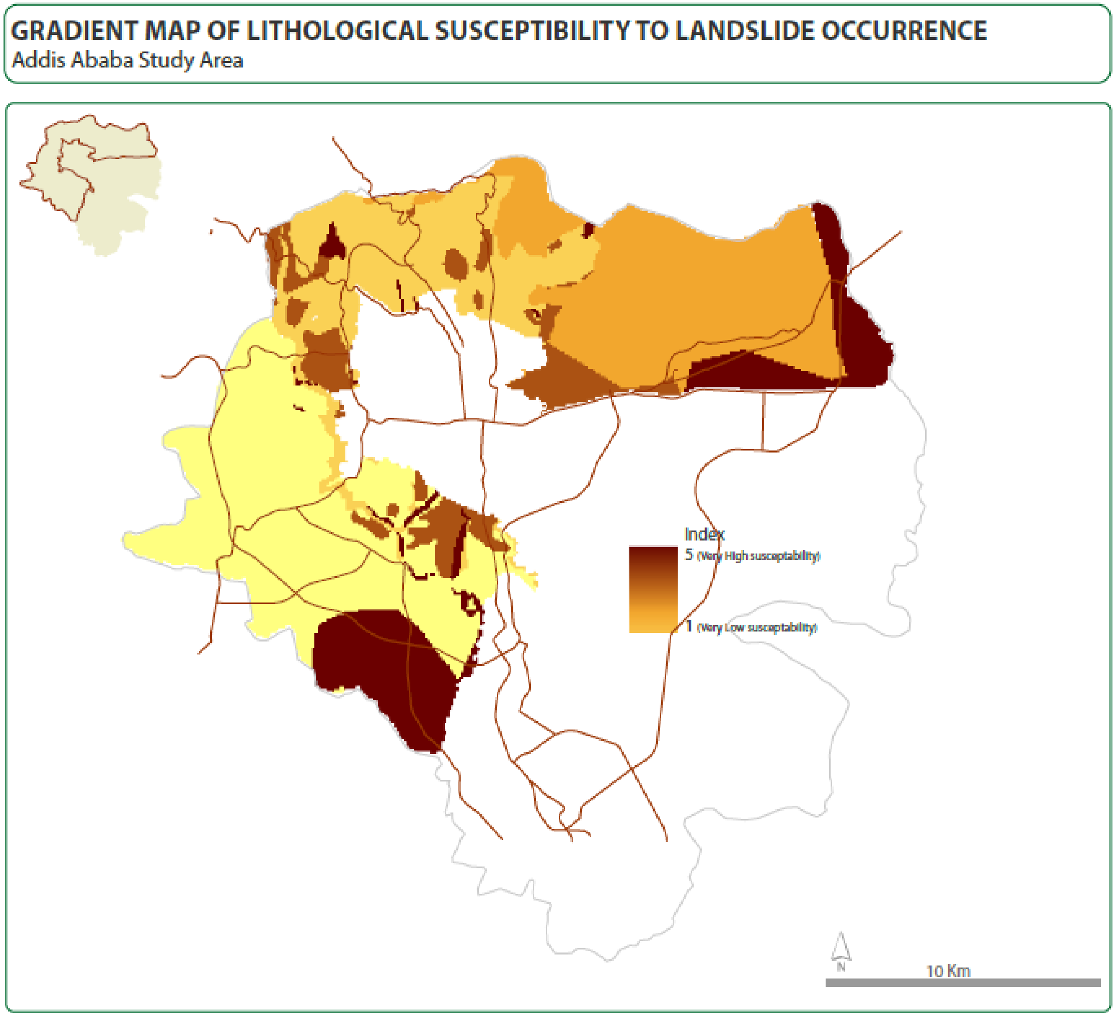


Figure 4.10 ***Gradient map of lithological susceptibility to landslide occurrence***

4.5.2 Ratings of soils types related to landslide hazard

Soil type	Category	Class value	Weighted value
Orthic solonchacks	1	5	
Pellintic and chromic vertisols	2	4	
Calcic xerosols	3	3	**8**
Chromic leptosols and luvisols	4	2	
Eutric nitisols	5	1	

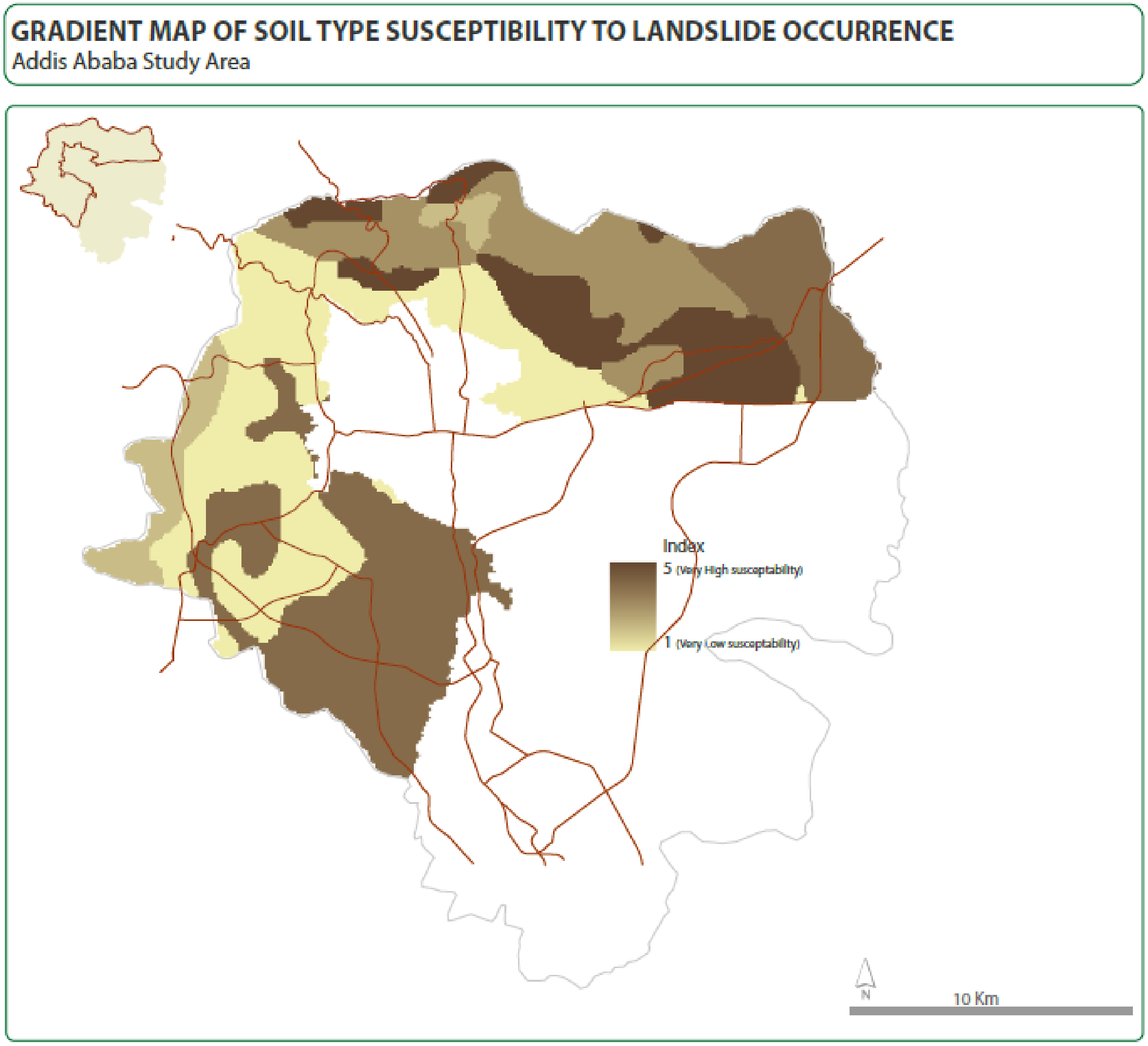


Figure 4.11 ***Gradient maps of soils shear strength to landslide vulnerability.***

4.5.3 Ratings of LU/LC verses landslide hazard

Land use/Land cover type	Category	Class value	Weighted value
Vegetable farm	1	5	7
Plantation	1	5	
Riverine	1	5	
Mixed forest	1	5	
Field crops	1	5	
Rivers	1	5	
Mixed residential	1	5	
Residential	1	5	
Under construction	2	4	
Road	2	4	
Infrastructures and utilities	2	4	
Open space	3	3	
Municipal services	3	3	
Manufacturing and storage	3	3	
Special use	4	2	
Religious institutions	4	2	
Recreation	4	2	
Commercial	4	2	
Health	5	1	
Education	5	1	
Social and cultural welfare	5	1	
Transportation	5	1	
Administration	5	1	

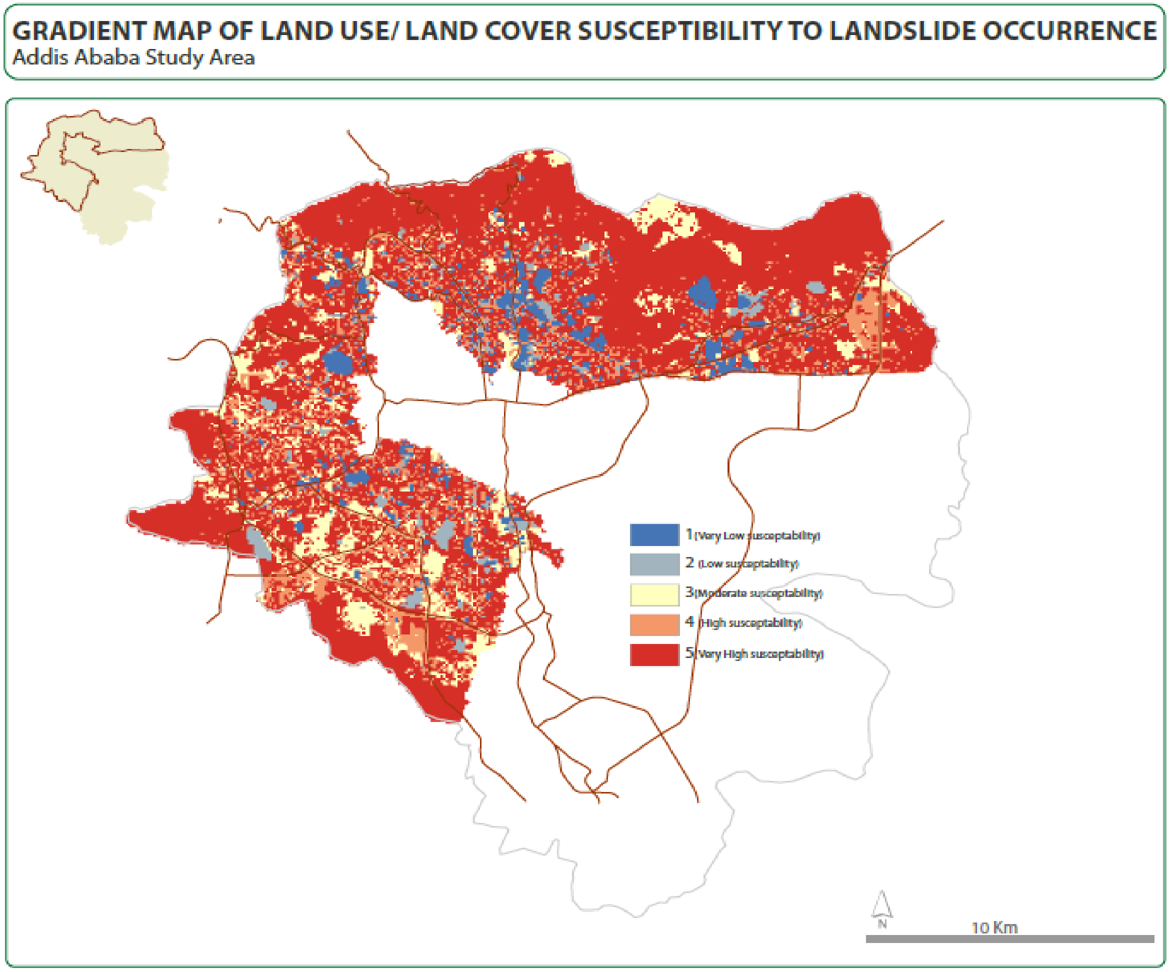


Figure 4.12 ***Gradient maps of LU/LC system to landslide vulnerability.***

4.5.4 Ratings of slope angle related to landslide hazard occurrence.

Slope in percent	Category	Class value	Weighted value
<2	1	1	
2-7	2	2	
7-12	3	3	**6**
12-20	4	4	
>20	5	5	

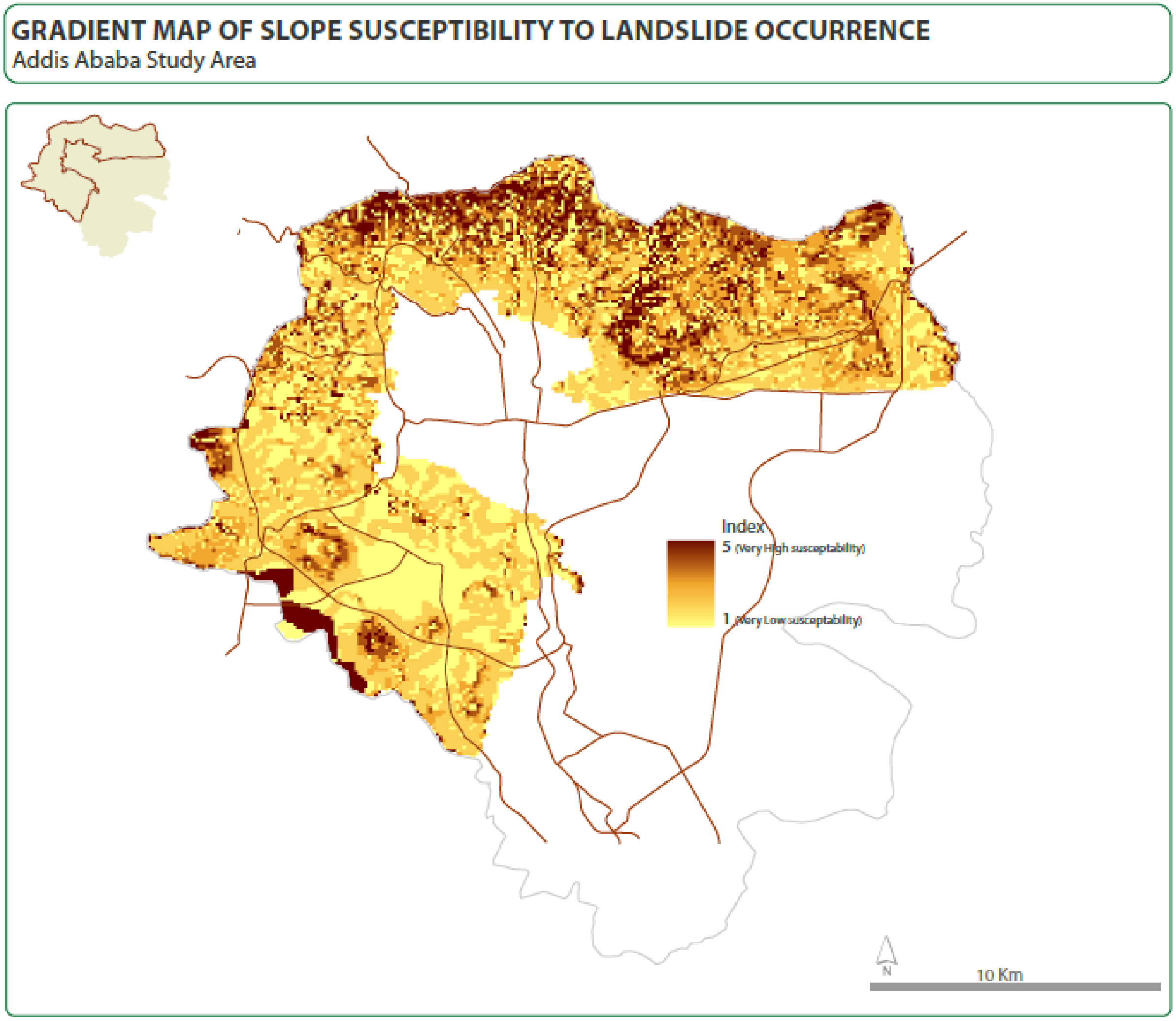


Figure 4.13 ***Gradient maps of slope related to landslide occurrence.***

4.5.5 Ratings of altitude related to landslide hazard occurrence.

Altitude in meters	category	Class value	Weighted value
<2400	1	1	**5**
2400-2500	2	2	
2500-2600	3	3	
2600-2700	4	4	
>2700	5	5	

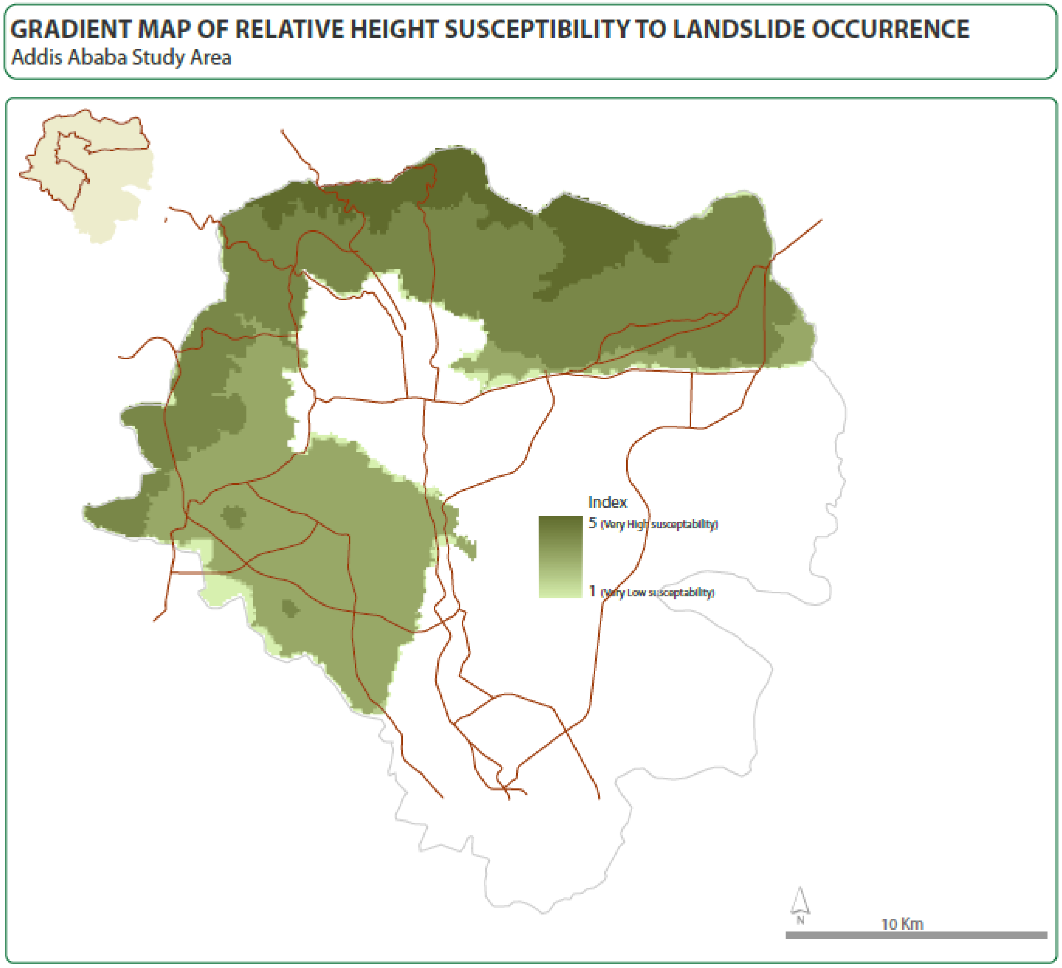


Figure 4.14 ***Gradient maps of altitude.***

4.5.6 Ratings of fault trace proximity related to landslides hazard occurrence.

Area proximity to fault trace, in meters	category	Class value	Weighted value
<500	1	5	**4**
500-1000	2	4	
1000-1500	3	3	
1500-2500	4	2	
2500-4000	5	1	

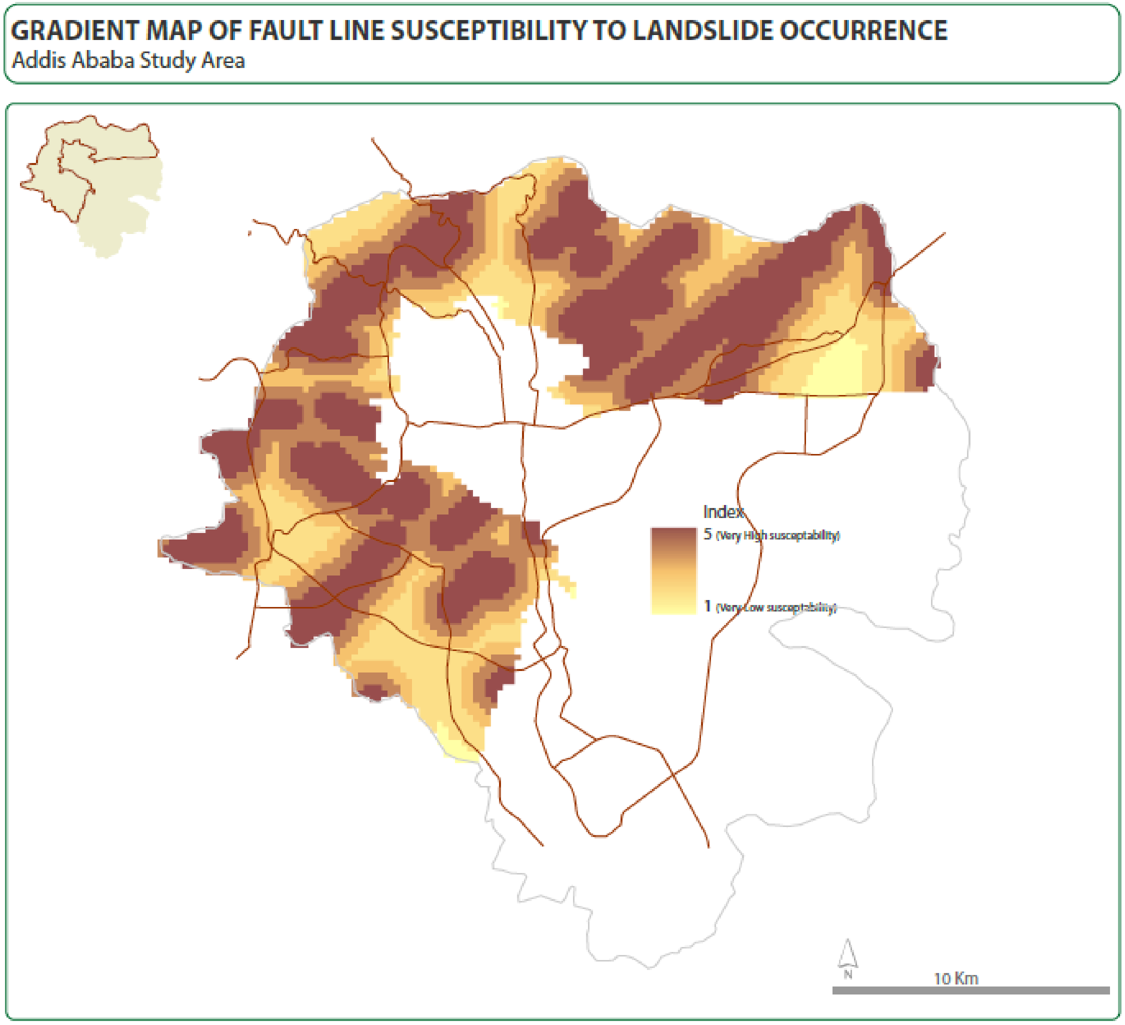


Figure4.15 *Gradient maps of fault traces susceptibility related to landslide occurrence*

4.5.7 Ratings of population density related to landslide hazard.

Population density per hectare	category	Class value	Weighted value
<100	1	1	3
100-200	2	2	
200-300	3	3	
300-400	4	4	
>400	5	5	

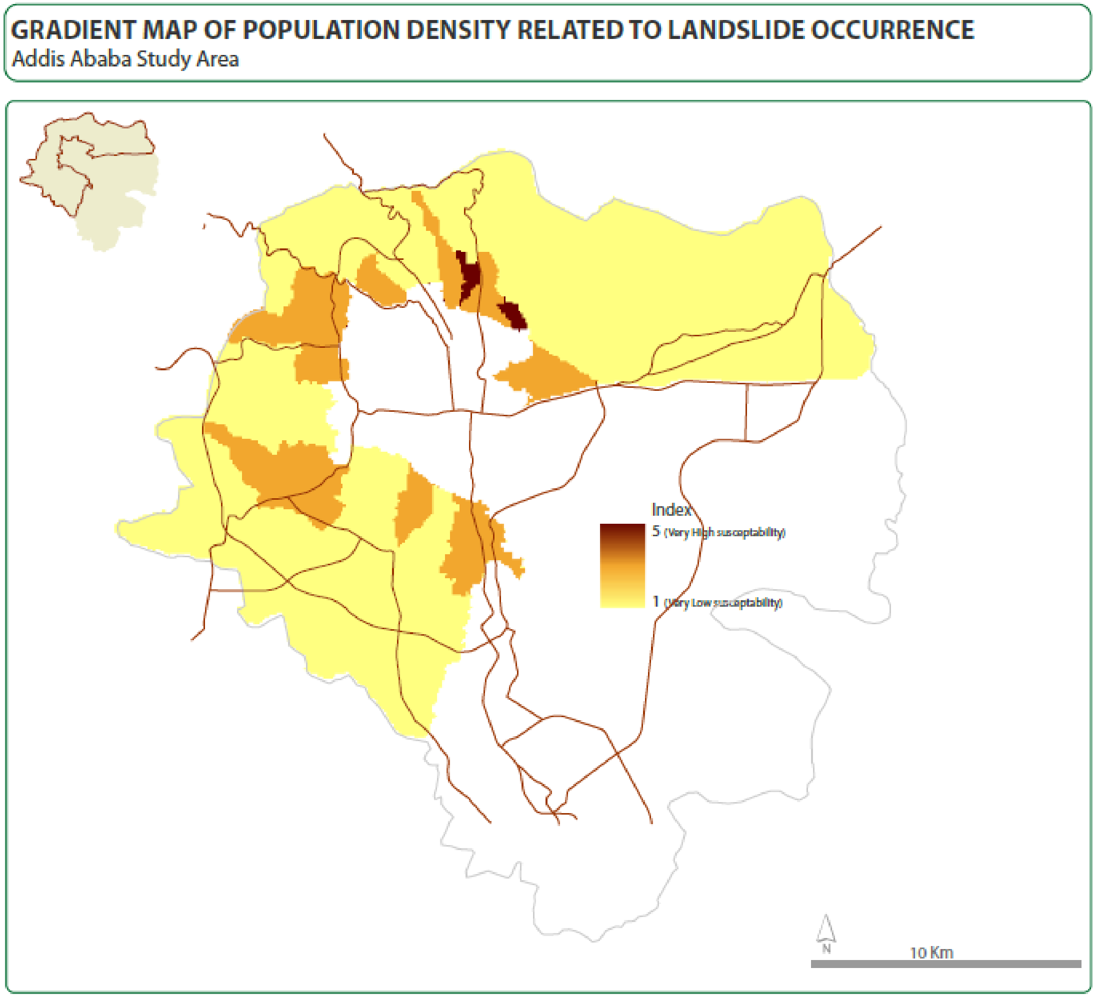


Figure 4.16 ***Gradient maps of population density.***

4.5.8 Ratings of ground water depth related to landslide hazard.

Ground water depth in meters	category	Class value	Weighted value
<75	1	3	**2**
75-1500	2	2	
>1500	3	1	

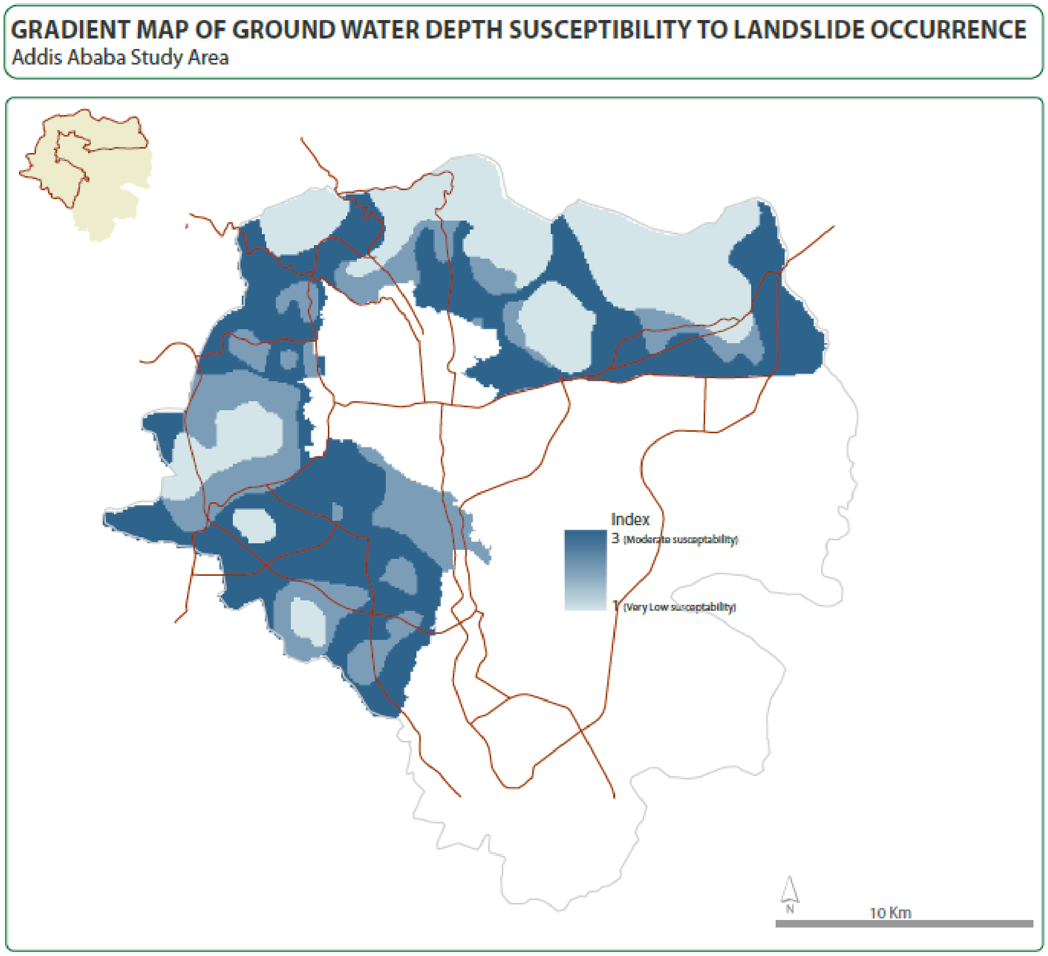


Figure 4.17 ***Gradient maps of ground water depth.***

4.6 Results of the analysis on Landslide hazard

In this study, the various parameters i.e. rocks, soils, land use/land cover, fault traces, altitude, slope, population density, and ground water depth have been prepared as GIS data layers, using the preferred method of analysis, i.e., analytical hierarchy process (AHP) and weighted according to their relative importance to hazard development, i.e., landslide and earthquake. The final out-put, in both cases, a hazard map was generated.

In understanding how the basics of the algorithm done in GIS, ranked values given for the influencing parameters; according to priorities of their relative importance to hazard development, each GIS data layer having a similar pixel value were added altogether and therefore, the total weighted sum value represented by graphical images generated at the end. For example, in this specific research, selected number of parameters considered (eight in number), the maximum pixel value attained will not exceed more than 8 x 45= 360. On the other hand, the minimum value attained will not be less than 2x8=16. Further, all those pixels having similar values will be added and the total weighted sum value will be represented by a hazard map, as a final out-put. Higher values describe higher degree of hazardousness and vice-versa.

Table 4.11 Figurative description showing how the total weighted sum values were calculated

Relative weight	Class values				
	5	4	3	2	1
9	45	36	12	18	9
8	40	32	24	16	8
7	35	28	21	14	7
6	30	24	18	12	6
5	25	20	15	10	5
4	20	16	12	8	4
3	15	12	9	6	3
2	10	8	6	4	2

The graphical representation of the added layers which led to the final out-put map has been shown on figure 4.12.

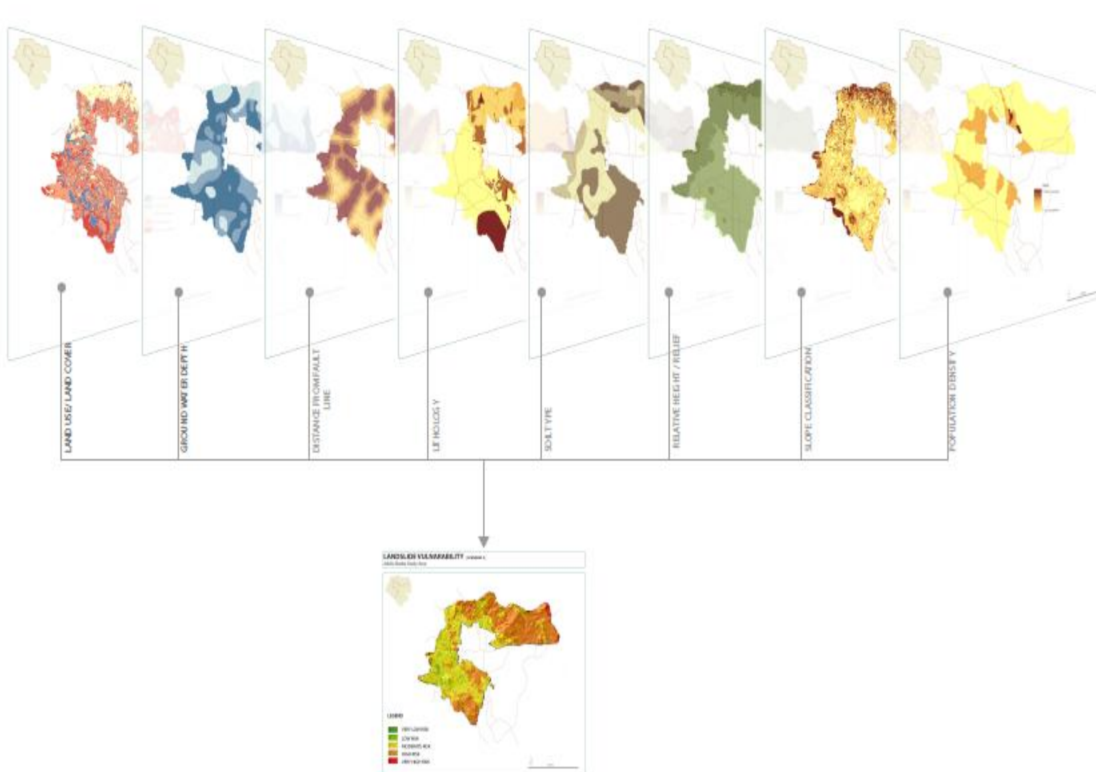


Figure 4.18 ***Graphical representation of GIS data layers constructed for total weighed sum value analysis***

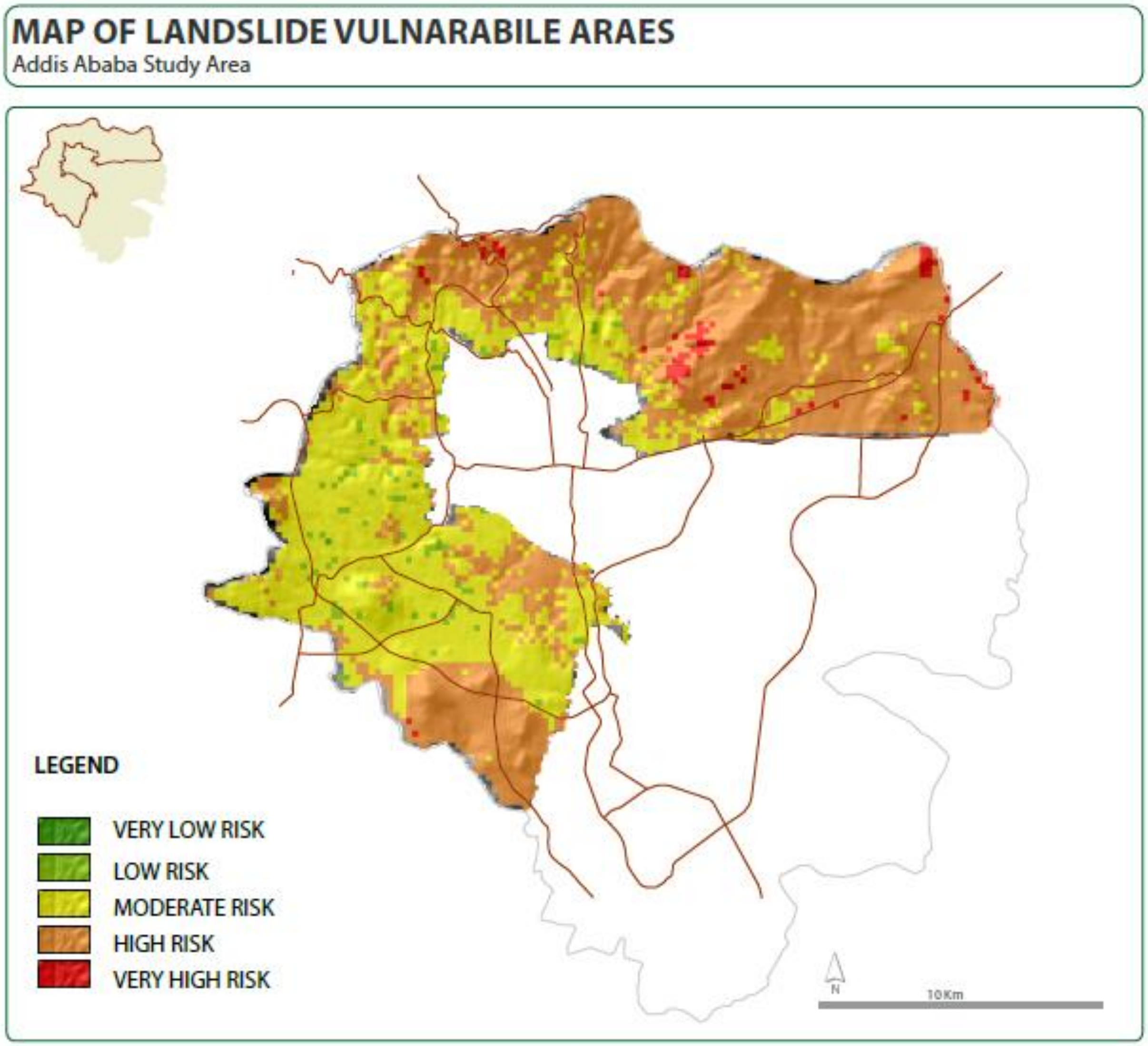


Figure 4.19 ***Landslide hazard map for the study area.***

This research out-come confirmed that major areas in Yeka and Gullele; and some places in Neffs-silk Lafto sub-city fall under high values of landslide hazard. While ground verification was made, values obtained after analysis (representing on the hazard map) have been significantly correspond to existing problems on the ground (see Plate 4.6- 4.9 A-K).

4.7 Practical evidences on Landslide hazards specific to study areas

In major parts of the study areas, landslides problems have been observed at various places. Such problems occurred under the influence of geologic, topographic, and /or human induced factors. In the hilly areas for example, around Megenagna, Eggeziabhere-Abe, and Shegole (Atari Sefer) areas which have been encroached with many numbers of concrete buildings (used as commercial and residence), huge gullies were formed. Intensive quarrying and farming have been common practices observed in Yeka, Gullele, Kolfe Keraniyo, and Nifas Silk Lafto area. Amazingly, slope gradients greater than thirty percent have been affected by such human induced actions. As a result, landslide problems have been critical challenges.

Furthermore, in a typical area known as Yeka Michael, slope failure (a dip-seated geological activity) has been recognized (might be a fault driven? but it needs further detailed research work). In this study, a deep well drilled for water production in the premise of Yeka park was investigated. As data revealed from the litho logical log description, significant weak geological formation/strata has been confirmed in the sub-surface thus, potential to develop land sliding effects in the area.

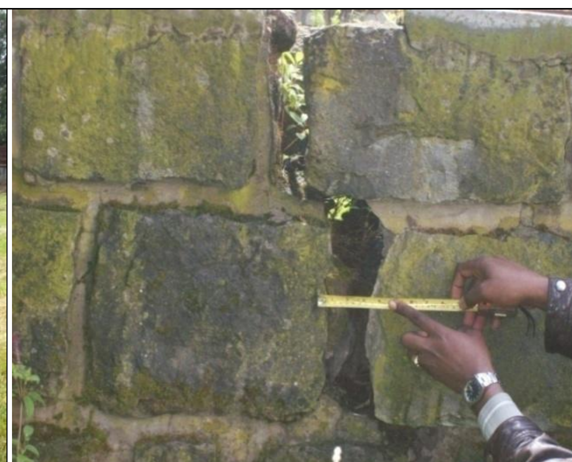



Plate 4.6 ***Displaced infrastructures due to landslide problem: a ground tennis court in Yeka Park, Addis Ababa has been found displaced east wards. As measured by measuring tape, the retaining wall has moved apart a distance of about 20cm.***

More evidences (plate 4.6 above and plate4.7 and 4.8 below) have been found in the premises of Yeka Park. Leaning trees in a similar direction (towards a North-East) were observed and this is quite clear evidence to the presence of landslide problem in the area. Surprisingly, all trees leaned were the older ones; more than forty years since planted. This situation confirms that the earth flow is inherently an active geological process taking place in the area.

Further evidence could be built structure used as a seat for fans, which was built in 1989 in the premise of the park; have been displaced significantly: 20cm cracks were developed on the segment of the structure. The displacement/crack formed (rate of movement) has been calculated as 2cm per year hence the slope movement is classified as creep.

Plate 4.7: ***Leaning trees: an example of landslide occurrence. Majority of the old trees for example, Accacia Decurence (shown on the plate) which have been found in the Park were lean significantly in a similar fashion to that of structures due to earth flow/deep seated land slide. Yeka park, Addis Ababa, 2010***

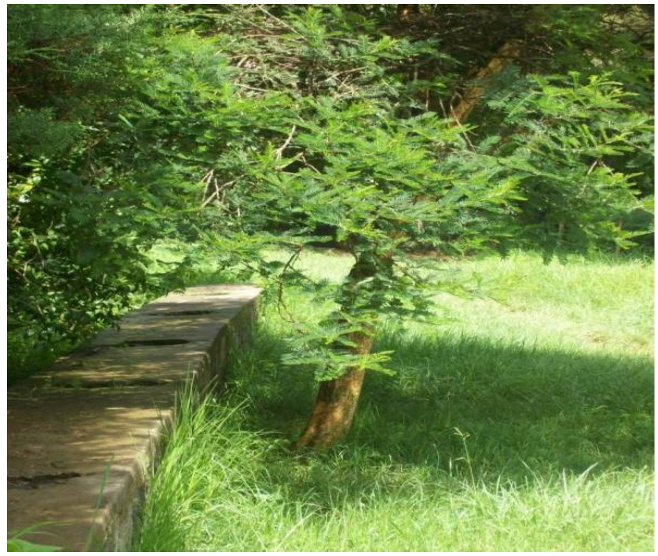


Plate 4.8 ***Object displacements: structures along with plants moved in a similar direction: clear evidence to landslide occurrence. Both objects (structure and vegetation) flow to the east direction; Yeka park, Yeka sub-city, Addis Ababa.***

Some additional threats have been developed from seepage driven problems. In mountain top areas (it is a tectonically active zone), gravity water tankers that can contain more than 1.5 million cubic litters were placed in many places. Detailed geological/or engineering geological investigations were absent. Seepages created (see Plate 4.5 a, b) thus favors potential landslide hazard to develop in the upper gradient zone. Obviously, hill slopes that might remain stable under static load can fall under a dynamic load or due to the stress from ground motion developed. Similarly, pore-water pressure/liquefaction: if slopes composed of rock containing many open fractures and discontinuities, are especially prone to land slide during ground motions (e.g., Fred G.Bell, 1999; Graham A.Tobin and Burrell E.Montz; Martin Beniesten, 2000). On this respect, many basaltic and rhyolitc rocks found in the north and north east areas are characterized by weathered and fractured materials thus can create slope failures. Apparently, the steepness of the slope, the cumulative effect of the constructions under taken (dynamic load development combined with poor construction methods); trigger slope to fail.

Plate 4.9 The plates ***A to K (from bottom to top) shows series of events of landslide hazards occurred since 2010 in a locality known as Egziabhere-Ab; significant numbers of people abandoned their home due to the landslide problem, Gullele sub-city, Addis Ababa.***

K

J


I


H


G


F


E


D


C


B

Areas, adjacent to any corners of the near-by legal urban settlements in higher gradient zones, were affected significantly by huge constructions like for instance, high rise buildings used for residential and commerce, and various infrastructures like roads; thus landslide hazard anticipated in the future. For example, in most mountain up-land areas of Megenagna and Egziabher-Ab (as shown on the above plates 4.9 A-K), it is apparent that landslide problems have been significantly a threatening hazard to most urban communities residing there. It has been clearly observed that in Egziabher-Ab localities (plate 4.9 J and K) some people have abandoned their homes because of the threatening landslide hazard situations (currently more than four kilo meters long displaced area of land have been formed).

Eventually, large portions of the higher gradient zones which have been characteristically predominated by weathered and fractured volcanic materials and simultaneously impacted by urban sprawls, attained higher degree of vulnerabilities to landslide hazard occurrences though huge losses of human lives and property damages anticipated in the future if not properly addressed.

4.8 Analysis on Earthquake hazard risks in the study areas.

It is quite understandable that in a particular region, while assessment of earthquake hazard is performed, three fundamental conditions must be thoroughly investigated: effects of Earthquake sources, their path, and the site conditions (physical entities and geological elements). Fault directivity effects and different ground motion models are additional relevant data to consider.

The aim in this research has been to map-out Earthquake prone areas. Provided that, source and path effects are negligible, the evaluation was made on more importantly by considering the site effects/geological factors and the physical elements encountered in the selected area.

Therefore, identifying the controlling factors and/or parameters with respect to earthquake hazard has been an initial step. In a deterministic way, with prior knowledge of the researcher parameters were selected and understanding the characteristics of the relevant parameters considered including rocks and soils, LU/LC, altitude, slope gradient/ geo-morphology, population density, fault traces, and ground water depth have been mainly analyzed. Descriptions were given bellow on how the selected influencing parameters would be associated with natural hazard effects including like earthquake.

Rocks: in case of seismic action different rocks respond seismic actions differently. In general, while maximum pressure exerted (due to magmatic actions), though rocks behave like elastic, breakage can occur. Due course of action, energy can be released as form of seismic waves in the surrounding area and ground shaking resulted.

Soils: soft/unconsolidated soils more suffer from ground shaking than firm/stiff ones; and vice-versa. Further, when earthquake events occur, unconsolidated materials including soils amplify seismic waves. Thus, smaller magnitude shocks will result sever destructions.

Fault: with respect to earthquake actions, similar to that of soils, faults do play role of amplification effects.

Land use functions: those lands mainly left for physical establishments, either for roads, commercial and or residential buildings, and other constructions, (degree of concentration in a given area also matters), linearly correlated to seismic actions vulnerability. The more they are concentrated in a given area, the more the destruction will be.

Depth of water table to ground surface is inherently related to development of pore water pressure. When water table rise up void spaces can be filled with excessive moisture thus, slope tends to fail due to liquefaction.

Densely populated areas: highly vulnerable to earthquake events and severely destructed more than dispersed numbers of population.

Altitude: in the case of ground shaking, objects at higher altitude more suffer than lower places.

Slopes: in case of seismic actions, when the angle of repose becomes large, slopes tend to fail and vice-versa.

Accordingly, parameters considered as influencing factors and that have been described above were analyzed using the preferred method; AHP method. Primarily, based on the knowledge of the researcher, according to their responsiveness to specific hazard each and every each of the selected influencing parameters has been assigned class values. Further, rated (given a weighted value) according to their relative importance/degree of contribution in relation to the anticipated significant magnitude of seismic action; and finally summed to give the total weighted sum value (as an out-put) thus, an earthquake risk map was generated.

4.8.1 Ratings of lithological types related to seismic hazards

Various rock types have various deformability characteristics thus exhibit differences in response to seismic action stress while an earthquake event occurred. Due to this fact, for similar magnitude of earthquake shocks, various rock types can show quite different accommodation characteristics.

For various lithologies encountered in the study region, ratings were made on the basis of similarities in stress accommodations.

Lithology type	Category in RMS	Class value	Weighted value
PQ-YV-V2 (Pliestocene-quaternary Yerer volcanic)	5	1	**8**
PQ-YV-V3 (Pliestocene-quaternary Yerer volcanic)	5	1	
UM-AAB-A4A (Upper Miocene Addis Ababa basalt, aphanitic)	4	2	
UM-AAB-A4B (Upper Miocene Addis Ababa basalt, aphanitic)	4	2	
UM-AAB-A4C (Upper Miocene Addis Ababa basalt, aphanitic)	4	2	
LM-AB-AS-AJ7a (Lower Miocene Alaje series basalts)	3	3	
LM-TR-AS-AJ7b (Lower Miocene Alaje series Tarma Ber basalts)	3	3	
LM-AB-AS-AJ9 (Lower Miocene Alaje series basalts)	3	3	
UV-EN (Undifferentiated volcanic)	3	3	
PQ-YV-V1A (Pliestocene-quaternary Yerer volcanic)	2	4	
UM-PB-TB-T5a (Upper Miocene Addis Ababa basalt, aphanitic)	2	4	
MM-IG-AV-M6 (Middle Miocene Ignimbrites)	2	4	
UV-EAA (Undifferentiated volcanic)	1	5	
Q-TB-RBS2 (Quaternary Tarmaber basalts)	1	5	
LM-T&I-AS-AJ8 (Lower Miocene Tuffs and Ignimbrites Alaje)	1	5	
PQ-YV-V1B(Pliestocene-quaternary Yerer volcanic)	1	5	
SAL (soils residual)	1	5	
SAI (deposited soils)	1	5	

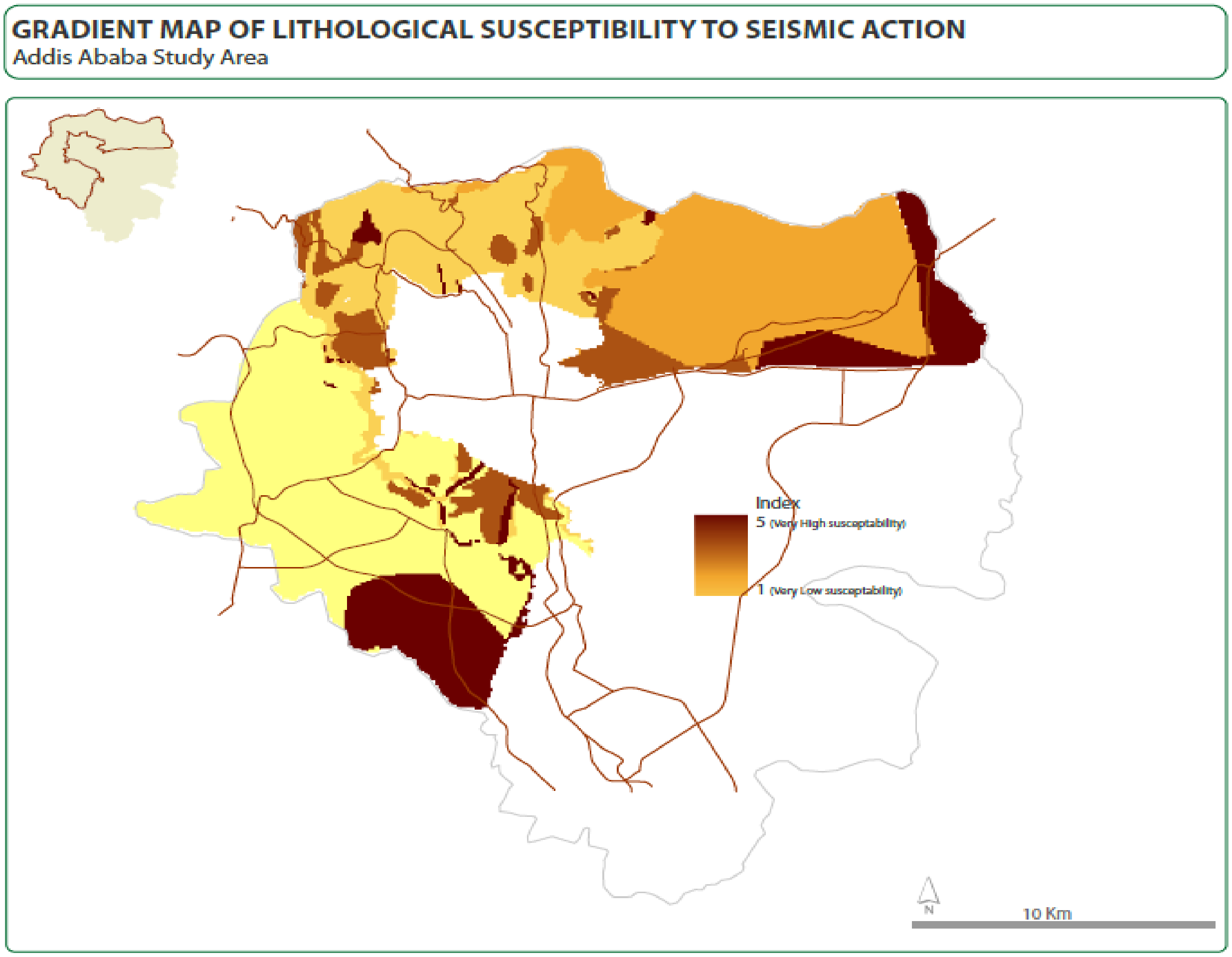


Figure 4.20 ***Gradient maps of lithological susceptibility to earthquake hazard***

4.8.2 Ratings of soil types related to seismic hazard

At time of earthquake events, based on their shear strength and depth or thickness, soils will show varied responses/ characteristics to seismic wave propagations.

Therefore these characteristics have been considered while the ratings were made.

Soil type	Category	Class value	Weighted value
Orthic solonchacks	1	5	**9**
Pellintic and chromic vertisols	2	4	
Calcic xerosols	3	3	
Chromic leptosols and luvisols	4	2	
Eutric nitisols	5	1	

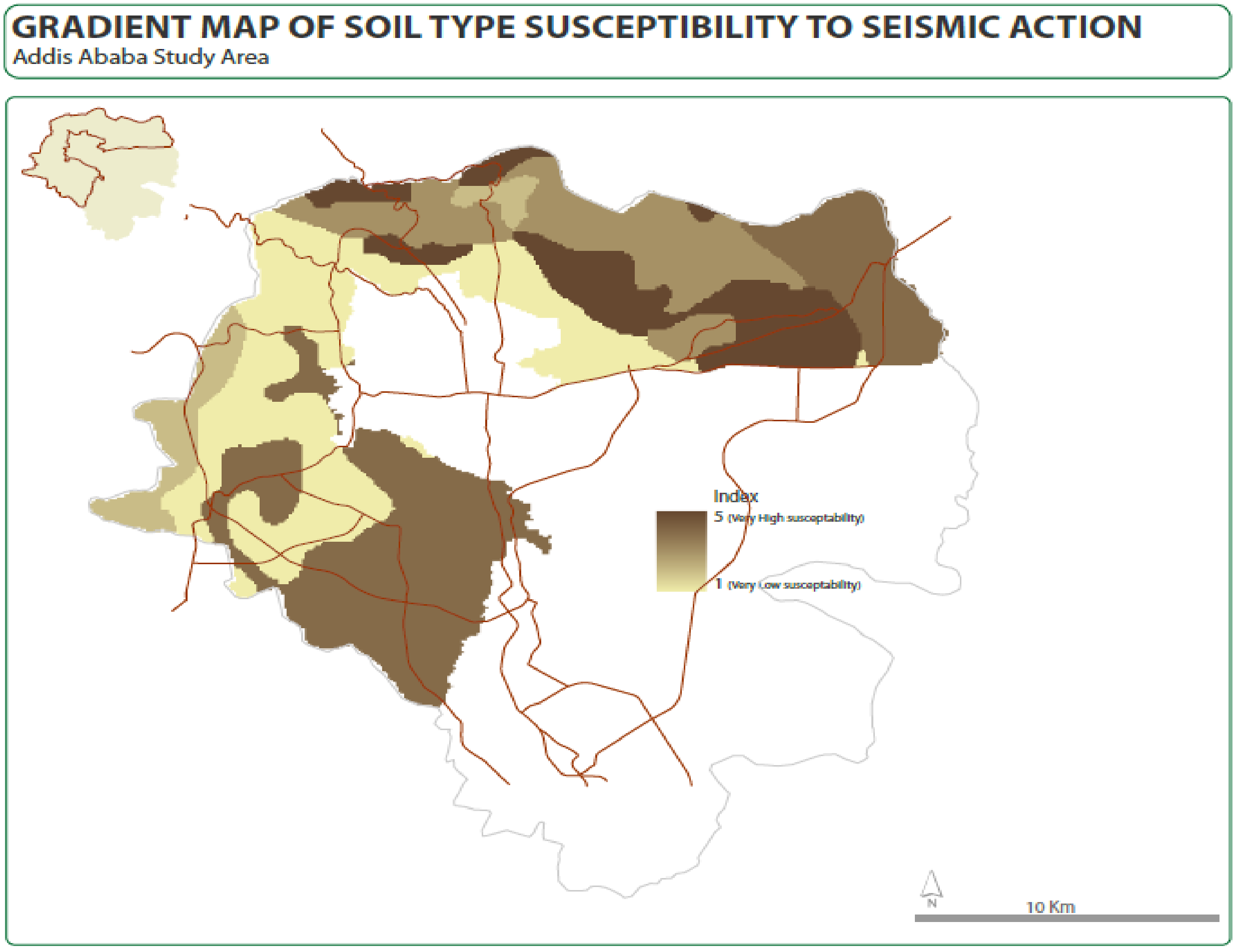


Figure 4.21 ***Gradient maps of soil susceptibility to seismic actions.***

4.8.3 Ratings of fault axis proximity related to seismic hazard.

Formation of fault structures, their length and aperture believed to have a strong correlation to an earthquake hazard. As observed in many earthquake incidents, their effect (amplification characteristics) will cause greater losses even in a smaller magnitude earthquake hazards. Structures also proximate to active faults might suffer huge destructions.

Area proximity to fault axis, in meters	category	Class value	Weighted value
<500	1	5	**7**
500-1000	2	4	
1000-1500	3	3	
1500-2500	4	2	
2500-4000	5	1	

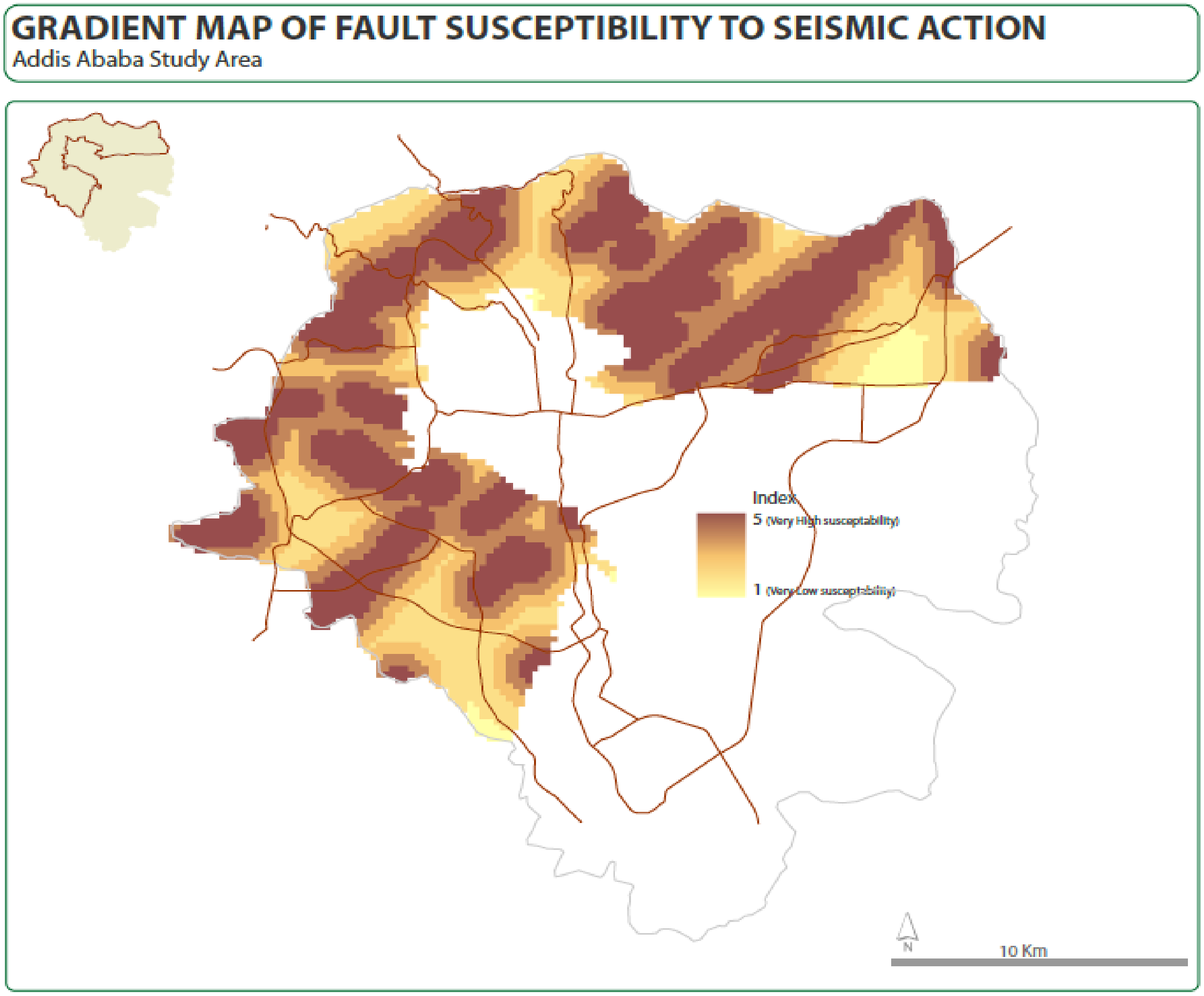


Figure 4.22 ***Gradient maps of fault trace susceptibility to seismic action.***

4.8.4 Ratings of LU/LC types related to seismic hazard.

Land use /land cover system adopted in a given region will have a determining factor to any natural hazard incidents. Because some land use functions will enhance natural hazard occurrences, at time of planned processes of land preparation, primary consideration given will mainly be the avoidance of hazard prone areas. While ratings were made for this section, land use function responses to seismic actions were accounted.

Land use type	Category	Class value	Weighted value
Commercial	5	5	**6**
Education	5	5	
Health	5	5	
Infrastructures and utilities	5	5	
Manufacture and storage	5	5	
Mixed residential	5	5	
Recreation	5	5	
Religious institutions	5	5	
Residential	5	5	
Road network	5	5	
Special use	5	5	
Cultural and social welfare	4	4	
Municipal services	4	4	
Transport terminal	4	4	
Under construction	4	4	
River	3	3	
Administration	3	3	
Field crops	2	2	
Plantation	2	2	
Riverine	2	2	
Vegetable farm	2	2	
Mixed forest	2	2	
Open space	1	1	

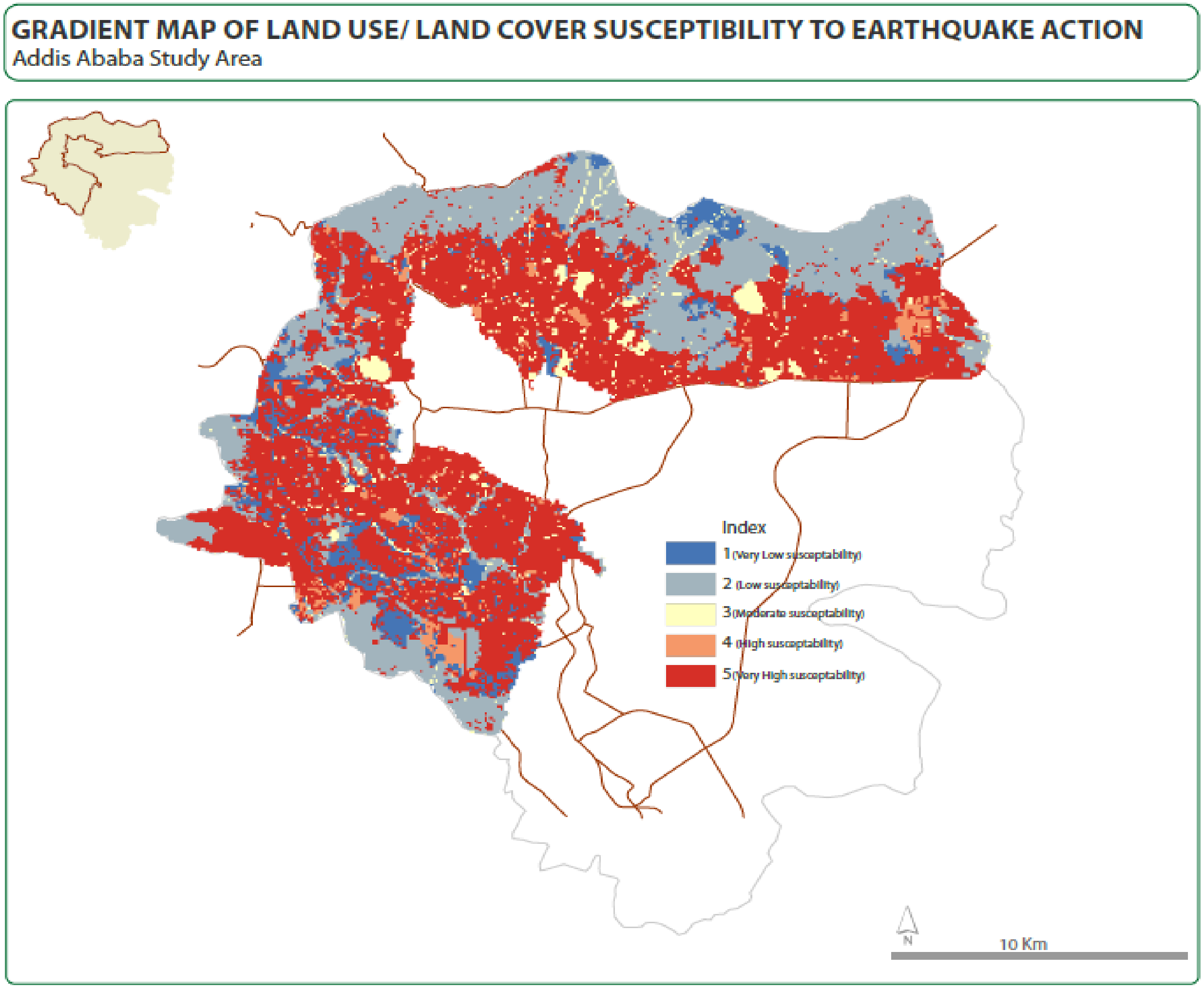


Figure 4.23 G*radient maps of LU/LC change vulnerability* to seismic actions.

4.8.5 Ratings of altitude

Altitude has major contribution while an earthquake incident occurred. Objects found at higher relief zones more suffer due to seismic actions than objects found at lower relief areas.

Relief relative In meters	category	Class value	Weighted value
<2400	1	1	**5**
2400-2500	2	2	
2500-2600	3	3	
2600-2700	4	4	
>2700	5	5	

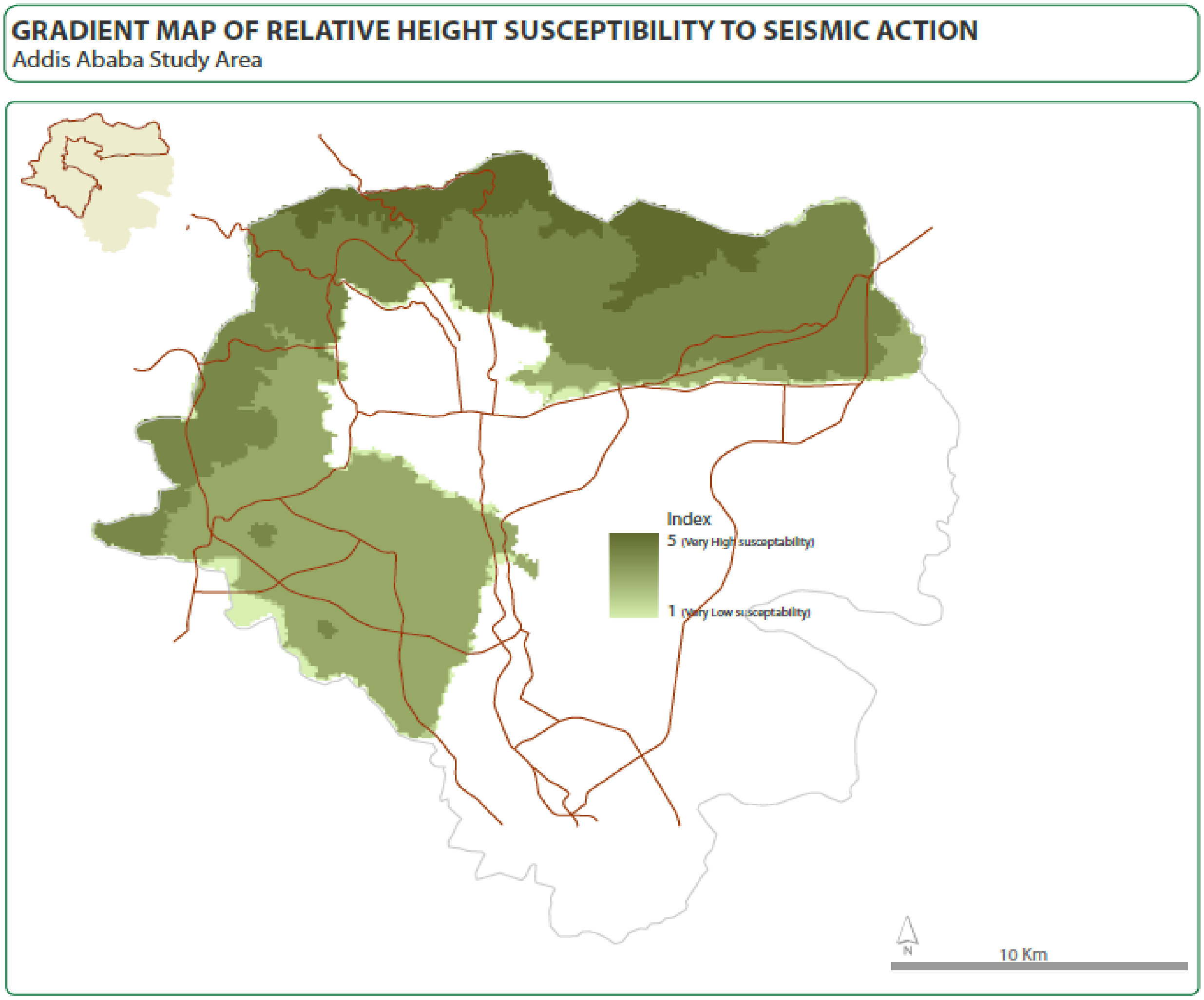


Figure 4.24 ***Gradient maps of altitude vulnerability*** **to seismic actions**.

4.8.6 Ratings of slope angle

Slope in percent	Category	Class value	Weighted value
<2	1	1	**4**
2-7	2	2	
7-12	3	3	
12-20	4	4	
>20	5	5	

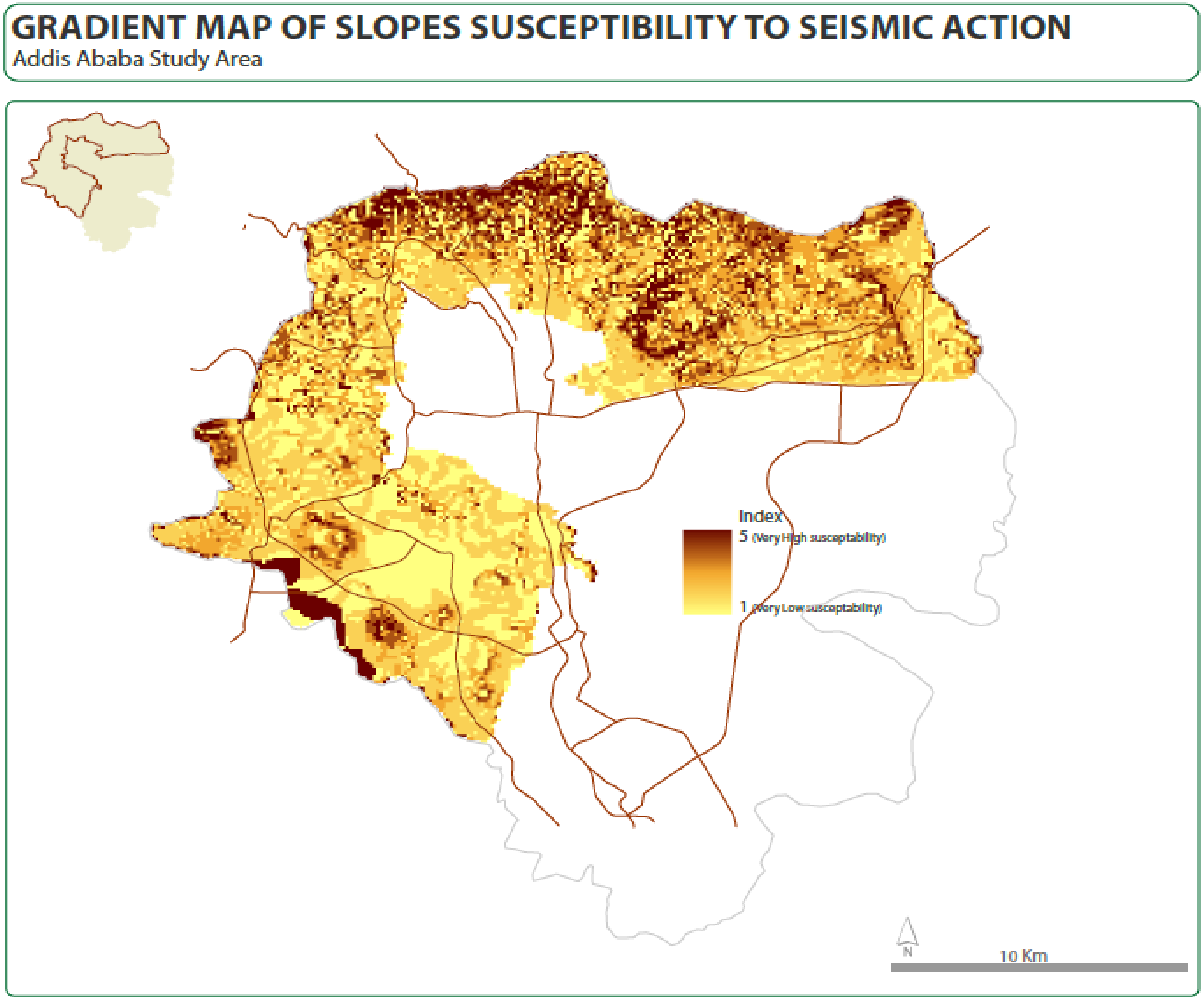


Figure 4.25 G*radient map* of slope *susceptibility* to seismic actions.

4.8.7 Ratings of population density

Population density per hectare	category	Class value	Weighted value
<100	1	1	**3**
100-200	2	2	
200-300	3	3	
300-400	4	4	
>400	5	5	

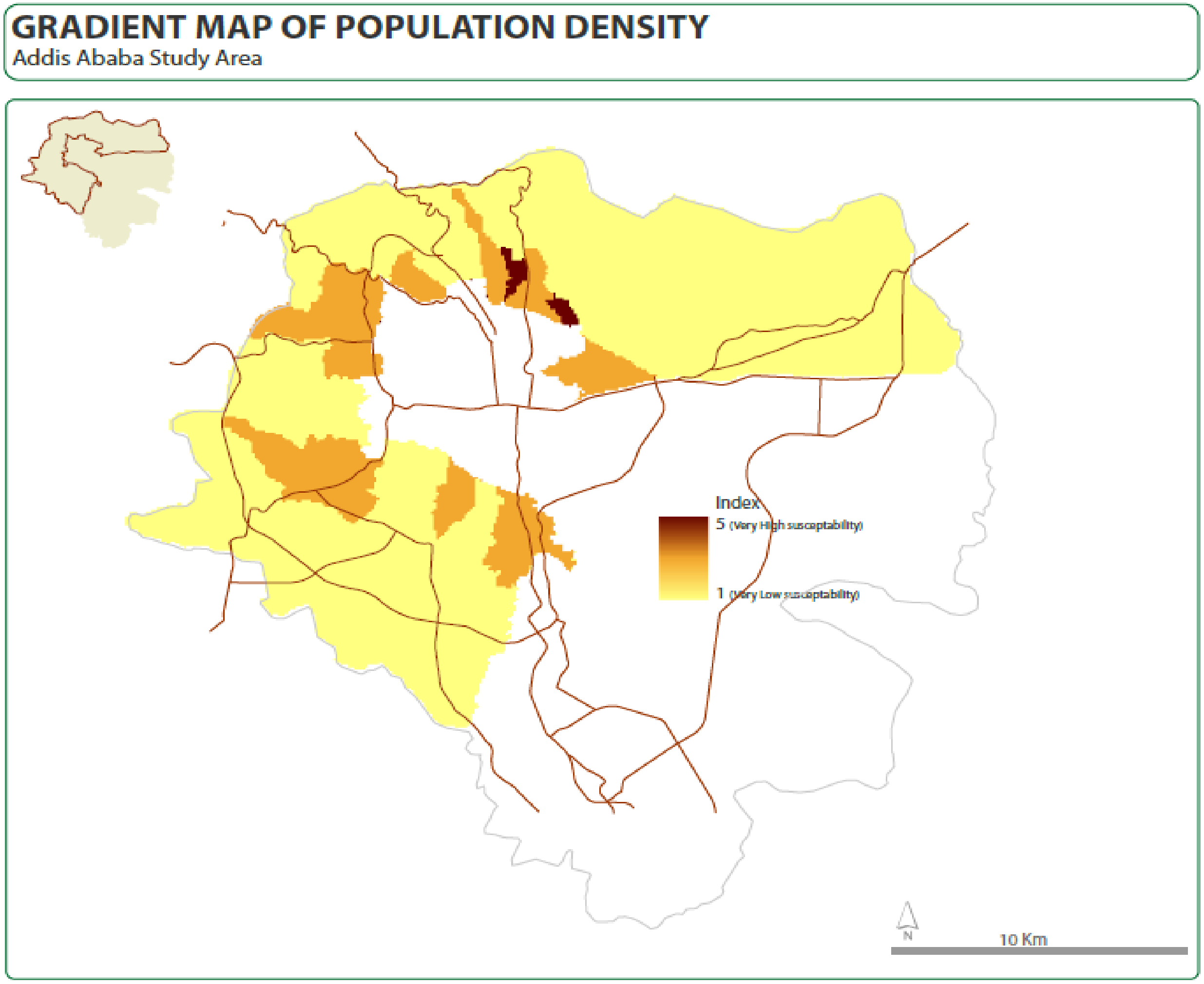


Figure 4.26 ***Gradient map of susceptibility with respect to population density*** **to seismic actions.**

4.8.8 Ratings of ground water depth

Ground water depth in meters	category	Class value	Weighted value
<75	1	3	**2**
75-1500	2	2	
>1500	3	1	

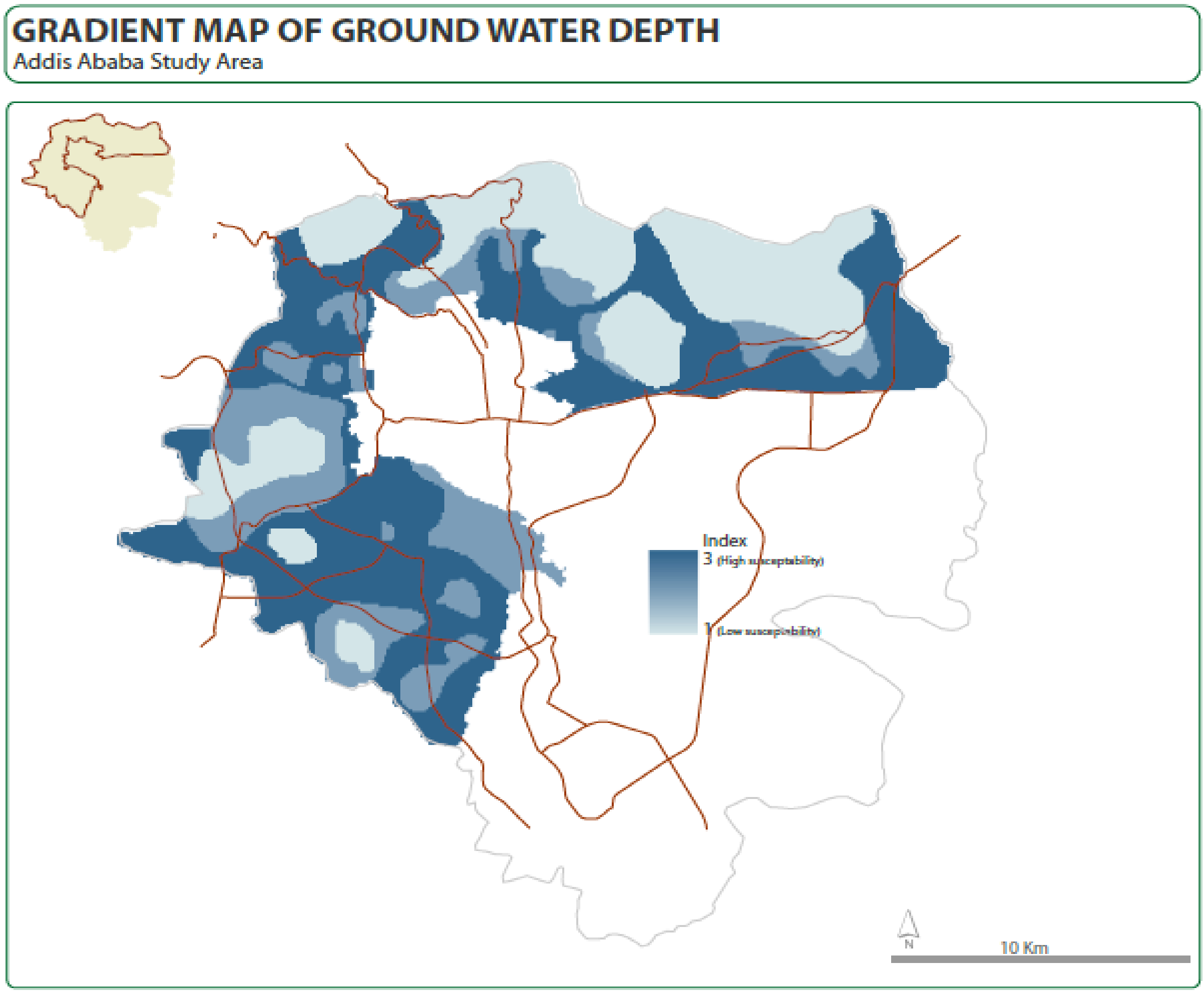


Figure 4.27 *Gradient map* of ground water depth

4.9 Results of Earthquake hazard analysis: the Earthquake hazard map.

According to their degree of importance, the factors accounted for significant ground shaking events were evaluated and their result (sum weighted value) has been generated.

As has been done on the hazard analysis of landslide, the algorithm took place in a similar manner. Fundamentally, in the method of analytical hierarchy process (AHP) a GIS method, ranked values given for the influencing parameters; according to priorities of their relative importance to hazard development. Each GIS data layer having a similar pixel value were added altogether and therefore, the total weighted sum value represented by graphical images generated at the end. For example, in this specific research, selected number of parameters considered (eight in number), the maximum pixel value attained will not exceed more than 8 x 45= 360. On the other hand, the minimum value attained will not be less than 2x8=16. Further, all those pixels having similar values will be added and the total weighted sum value will be represented by a hazard map, as a final out-put. Higher values describe higher degree of hazardousness and vice-versa.

Table 4.12 Way of arithmetical algorithms done by the tool (GIS) to calculate the total weighted sum.

Relative weight	Class values				
	5	4	3	2	1
9	45	36	12	18	9
8	40	32	24	16	8
7	35	28	21	14	7
6	30	24	18	12	6
5	25	20	15	10	5
4	20	16	12	8	4
3	15	12	9	6	3
2	10	8	6	4	2

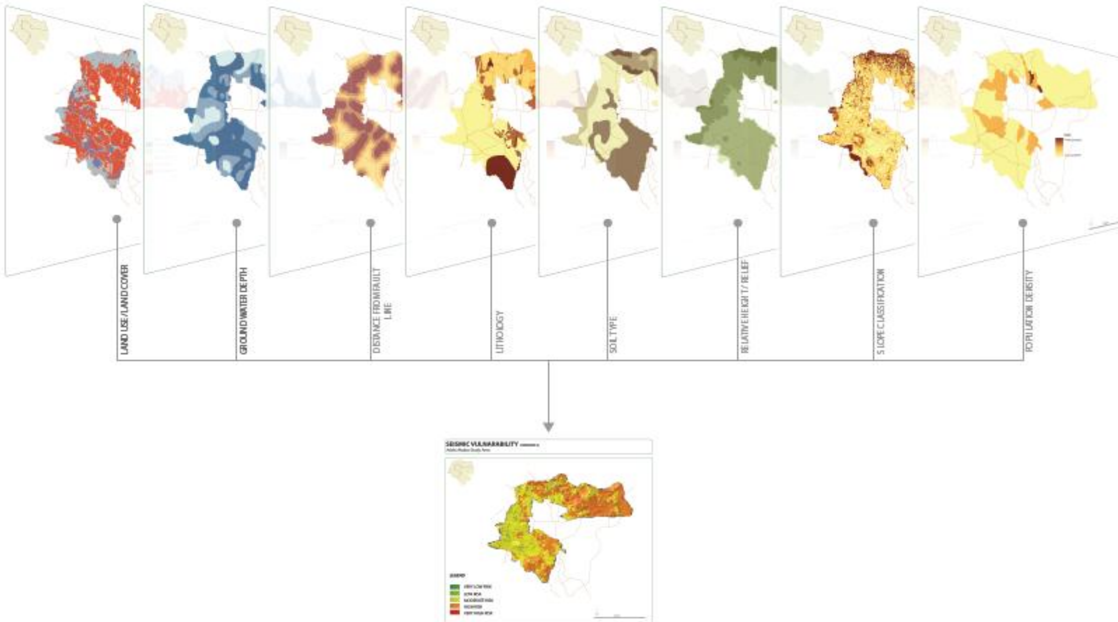


Figure 4.28 ***Graphical representations of GIS data layers used in calculating total weighed sum value.***

Accordingly, in this earthquake hazard analysis, the influencing factors that were constructed as a GIS data layer were added to give the total weighted sum value and made possible to generate the final out-put map i.e. the earthquake hazard map (fig 4.28).

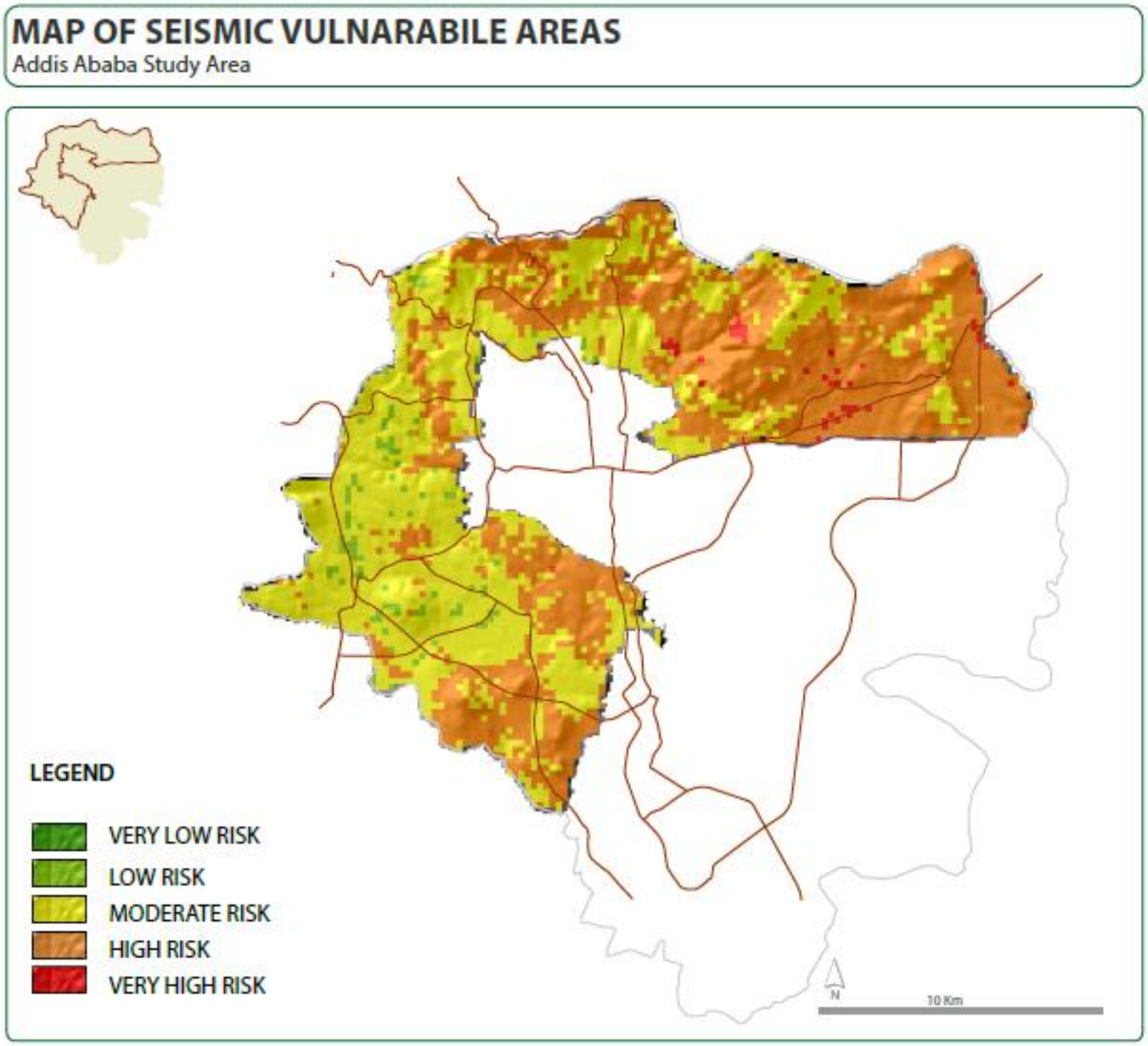


Figure 4.29 ***Earthquake hazard map of the Study Area.***

According to this research result; major portions in the north east and south western part of the city, very high to high risk values to earthquake actions have been recorded. Besides, areas covered by thick residual soils (black cotton/Vertisols) as thick as 36m along many regions; and at the same time, grounds displaced by faults and fractures; and weathered volcanic formations became dominant, seismic waves greatly amplified thus possible to create severe destructions especially at the rugged higher gradient zones and the lower depositional areas due to potential earthquake incidents, in the future.

Chapter 5
5. National and regional Policy: its response on natural hazards

Earthquakes and landslide risk have been an urban public safety issue that requires proper attention by governments. To address such problems appropriate measures must be taken in-order to safeguard citizen's life. Irrespective of other related tasks to perform, formulating appropriate policies and arranging rules and regulations have been the major issue considered by Governments in-order to minimize the critical challenges of urban communities due to natural hazard occurrences.

Concerning the national policy of Ethiopia towards natural and/or environmental hazard protection programs, it has been entirely focused on the emergency response programs, (ERCS, 2010; National Policy and Strategy on Disaster Risk Management; a draft document, version 10).

The Federal government of Ethiopia; renamed the former RRC, which works on disaster relief prevention programs in the past regime to DPPC; and the later DPPC was undertaking similar tasks and responsibilities since 1993; where the ratification of NPDPM is possible.

In 1993, at country level, disaster management strategy revised and adopted the National Policy on Disaster Prevention and management thus the policy making and oversight responsibilities was vested on a committee called the National Disaster Prevention and Preparedness Committee (NDPPC), since 1993. The major objective of this committee was to save lives, integrate relief assistance with development effort in-order to mitigate the impacts of disaster, and enhance the coping capacities of the affected people through creation of assets in the affected areas (ERCS, 2010; National Policy and Strategy on Disaster Risk Management; a draft document, version 10).

Even though the government of Ethiopia has showed strong desire to tackle disaster problems, related to the tasks and responsibilities of the NDPPC, there have been some basic limitations: the NDPPM guided relief management policies, institutions, and processes where by drought disasters were identified and resources especially food aids were mobilized and prioritized for the affected areas. So, the policy directions were and still focused on drought disasters. Secondly, the policy implementation was not supported by legal enforcement. Furthermore, the NPDPM did not give due emphasis to research applications on natural disaster issues where by the country has been at risk to some natural hazard events because it is found on the tectonically active zone; and identifying and mapping of disaster prone areas prior to the occurrence of natural hazard events were not accounted for by the committee. More importantly, it does not have any attention to urban communities, where more crowed of people reside in smaller areas comparatively to rural areas: where by a single incident of natural hazard events, catastrophe may occur.

In recent years, international preoccupation with disasters and their impacts has got more emphasis and put it in a higher level closer to the top of the development agenda.

As similar to the current Ethiopian practice; for many years, the international practices in response to disasters were largely confined to emergency relief and short-term life-saving actions. But over the last two decades, the critical importance of disaster preparedness, mitigation, and prevention, has been widely recognized.

It has become increasingly apparent that a relatively small investment in disaster preparedness can save lives, reduce the number of people requiring emergency assistance and preserve vital economic assets, as well as reduce the cost of overall relief assistance to disaster-stricken countries. Appreciation of this idea would largely contribute to the systematic decrease the number of people hurt at time of disaster events and also significantly reduces property damages.

Therefore, the country's policy direction should have to concentrate towards the development of rules and regulations which might have strong implementation capabilities of natural hazards and disaster preparedness programs.

Chapter 6

6 Conclusions and Recommendations

6.1 Conclusions

Based on various existing geological facts, the area selected for this research has been dictated by the Afar rifting possesses and the north western Ethiopian hot spot magmatic activities (Derek Kiere et al., 2008) hence the degree of natural hazard incidents to occur is very likely.

Based on quantitative and qualitative data analysis, areas prone to landslide and earthquake events were identified in fig.4.19 and 4.29 respectively.

Accordingly, in both cases(landslide and earthquake vulnerability situations) most parts of the selected region for this research work i.e., Yeka, Gullele, Kolfe Keraniyo, and Nefas Silk Lafto sub cities of Addis Ababa, and those having a rugged morphology and dissected mountain up-lands were considered to be hazard prone zones. Due to relatively high precipitation conditions, the piles of volcanic rocks which were erupted at different time series/gaps and found extendedly in most parts of the north, north-west and north-east regions have been reactivated by intense weathering processes thus weathered and fractured units can be easily susceptible to landslide and earthquake actions.

Evidently, in sub-surface conditions, it is quite common to observe competent rocks overlain by incompetent ones (Plate 4.1 A-E) thus because of stability differences, if dipping strata exposed to stresses, sliding can easily occur.

Apparently, in-situ or residual soils with a thickness of up to 40mt mostly found in the study region (fig.1.14 and plate 1.5), they are characteristically less cohesive thus susceptible to mass wasting. Accordingly, various soil columns found deep sub-surface in wider areas have different shear strength characteristics, if exposed to potential stress, it made them susceptible to any slope failures particularly, at higher gradient zones.

More importantly, it is tectonically an active region where the Afar magmatic rifting and the western Ethiopian plateau magmatic up-wells dictate, anticipated natural hazards (geological and/or anthropogenic) like earthquake, earthquake /human induced landslides have high probability to occur in the future thus the hazard experienced will be severe.

6.2 Recommendations

Reasons for natural hazards occurrence might be due to geological or anthropogenic (human induced actions) or both. In addition, topography and climatic conditions play a great roll towards natural hazard occurrences (e.g., Graham A.Tobin and Burrell E.Montz).

In most urban areas, drastic disasters have been commonly reported every year due to incidents of flood, landslides and earth quakes. It is typical where landslides and other types of mass movements accompany earth quake incidents and fatality increased.

Based on various existing geological facts, the area selected for this research has been dictated by the Afar rifting system and the north western Ethiopian hot spot magmatic activities (Derek Kiere et al., 2008) hence the degree of natural hazard incidents to occur is very likely.

To address the analyzed problem properly, soft solutions and hard solutions have been recommended.

❖ **Soft solutions**: **devise policy frame works towards natural hazard preparedness programs.**

Currently, governments put hazard preparedness programs at their for front development agenda. It has been statistically noted that hazard preparedness programs have triple less costs than emergency programs.

In addition;

- Implement proper rules and regulations and enforcements related to challenges of natural hazards
- Set-up and/or strength appropriate authorities and institutions

- Conduct a detailed study on the region’s geology and generate geological and engineering geological map at regional level and /or at urban planning scale
- assess and identify natural hazard prone areas and prepare hazard zoning maps at urban planning scale
- establish and implement safe building construction codes or made amendments every specified year
- increase public awareness on natural disaster prevention methods
- based on geological and geo-technical understandings, adopt land-use planning strategy
- adopt less and/no insurance policy on natural hazard prone areas
    - ❖ **Hard solutions: engineering geological and hazard specific management and follow-up solutions.**

This includes;

- Based on geological understanding, put-in place appropriate life lines (water mains, sewer lines, and fire brigades); need to be efficient prior and after natural hazard events.
- Avoid faulty design structures; insure the placement of proper structural designs that can with-stand anticipated natural hazards.
- Arrange and implement appropriate supervision practices (working in ethically calibrated manner) to maintain designed structures un-lawfully unchanged.
- Managing hazard prone areas with engineering structures designed to maintain soil and rocks stability (like retaining walls), in tandem with less expensive land conservation practices, like good agro-forestry practices, conducting a forestation programs, managing river side’s with vegetation, and avoidance of un-wise slope or ground modifications.

Glossary

Definitions

Risk: The probability of disaster occurrence or the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damage) due to a particular hazard for a given area and reference period. It is often expressed as the product of hazard and vulnerability. (CRED, UNDP, UN-ISDR)

Hazard: The potential for a natural or man-made event or phenomenon to occur, which potentially will result in physical damage and severe life-threatening disruption (CARE, CRED, NEMO).

Disaster preparedness: All measures and policies taken before an event occurs that allow for prevention, mitigation, and readiness. It is a process concerned with reducing the level of vulnerability and hazard, by building internal capacities. It covers all aspects and stages of the disaster cycle, including measures to prevent, prepare for, respond to and recover from the impact of disasters.(PDMDT, SEMP,TDD)

Disaster prevention: Activities designed to provide permanent protection from disasters by removing the vulnerability and/or reducing the intensity or frequency of a hazardous event.(SEMP,TDD)

Disaster risk reduction (disaster reduction): The systematic development and application of policies, strategies and practices to minimize (mitigation and preparedness) or avoid (prevention) vulnerabilities, hazards and the unfolding of disaster impacts throughout a society, in the broad context of sustainable development. UN-ISDR, UNDP

Disaster mitigation: A range of policy, legislative mandates, professional practices, and social adjustments that are designed to reduce or minimize the impact of disasters, in terms of loss of life, health, livelihood, environment, either by reducing vulnerability or by modifying the hazard, where possible.(IDRM, NEMO, PDMDT)

Assessment: a survey of a real or potential disaster to estimate the actual or expected damages and to make recommendations for preparedness, mitigation and relief action.

Vulnerability: a set of prevailing or consequential conditions composed of physical, socio-economic and/ or political factors that increase a population's susceptibility to loss, damage, injury and death due to a disaster, and adversely affect their ability to respond to such a disaster. Vulnerabilities can be physical, social, economic, political, technical, ideological or cultural and can be primary or secondary in nature.

Disaster (synonym; catastrophe): An unforeseen and often sudden event, either man-made or natural, sudden or progressive, the negative impact of which is so intense that it exceeds the affected community's capability to cope using its own resources, and is on a scale sufficient to warrant an extraordinary response from outside the affected community area. It results in significant loses of life, severe life-threatening disruption, great human suffering and distress and large-scale material and/ or economic damage. Essential social structures and functions are disrupted. DR, IDRM, Oxfam, WHO

Crisis: Any situation in which there is an exceptional threat to life, health or basic subsistence which is beyond the coping capacity of individuals or the community. MHO

References

1. Addis Ababa Development Plan, (2001- 2010), An executive summary to the city's Master Plan, Addis Ababa.
2. BCECOM and Seureca, (June 2000), A study report on Adaa-Becho Groundwater potentials, Addis Ababa.
3. Braja M. Das, (2006), Principles of Geotechnical Engineering, 3rd ed., Cenegage Learnning, 200 First Stamford place, Suite 400, Stamford, CT06902, USA.
4. Caninghum Canningham, (2007), Principles of Environmental Science, Inquiry and Application, 4th edition, Tata McGraw-Hill Publishing company limited, 7 west patel, Negar, New Delhi 110008, India.
5. Carlo W.Montgomory, (2003), Environmental Geology, 6th edition, McGraw Hill companies Inc., 1221 Avenue of the Americas, New York, NY10020, USA.
6. CSA, population Data 1994
7. CSA, population Data 1994
8. CSA, population Data 2007
9. Daniel D.Chiras, (2001). Environmental Science: creating a sustainable future,6th ed.Jones and Bartlett Publishers,Inc. 40 Tall Pine Drive, Sudbury, MA01776,USA.
10. DereK Keir, et al., Lower crustal earthquakes near the Ethiopian rift induced by magmatic processes; Journal of the Earth sciences, (2009), V10, a0AB02, doi: 10.1029/2009 GC002382, ISSN: 1525-2027.
11. EBCS-8, (1996) Design of Structures for Earth Quake Resistance 1995 Ethiopian Building Code standards, design of structures for earth quake resistance, Ministry of works and urban development Addis Ababa Ethiopia.
12. ESCP-1: 1983, Ministry of Works and Housing, Addis Ababa, Ethiopia.
13. Fred G.Bell, (199), Geological Hazards; Their Assessment, Avoidance, and Mitigation, Taylor and Francis, an imprint of Routledge 2 park sqare, Milton park,Abingdon, Oxon, Ox144RN, 270 Madison Ave, Newyork, NY 10016.
14. Graham A.Tobin and Burrel E. Montz, (1997), Natural Hazards Explanation and Integration, The Guilford press Inc., Newyork; London; 72 spring Street, Newyork, NY, 10012.
15. Graham A.Tobin and Burrell E.Montz, (1997).Natural Hazards Explanation and Integration, The Guilford press, 72 Spring street,New York, NY 10012.

16. Kieth Smith, (1991), Environmenytal Hazards, Assessing Risk and Reduicing Disaster, 4th ed., Rouledge 2 Park Square, Milton park, Abingdon,Oxon, ox144RN, Newyork, NY10016.

17. Laeke Mariam Assefaw, (1990), Seismicity and earthquake risk in the Addis Ababa region, Sinet, Journal of science, 13(1), p15-35, Addis Ababa, Ethiopia.

18. Marland P. Billings, (1972), Structural Geology, 3rd ed., Printece-Hall, Inc.,Upper Saddle River, Newjersy 07458, USA.

19. Martin Beniston, (2000), Key issues in Environmental change: Environmental change in mountains and up-lands; Hodder Arnold publisher, Great Britain,338 Euston Road, London NW13BH.

20. Oglethorpe J. Ericson; J. Bilsborrow; R.E. and Edmond J, (2007), People on the more: Reducing the impacts of Human migration on Biodiversity, DC: World Wild Life Fund and Conservation International Foundation,Washington,USA.

21. Pierre Gouin, (1979), Earthquake history of Ethiopia and the horn of Africa, International Development Center, Ottawa, Canada, IDRC,118e,259p.

22. Regulation No. 16/2004., Regulations for the approval and implementation of the Addis Ababa City Government Structural Plan page 317

23. S.M Berhe,B. oesta, M. Nicoletti, and M. Tefera, (1987), Geology, Geochronology and geodynamic implications of cenezoic magmatic province in Western and South East Ethiopia, Journal of the geological society, doi: 10.1144/gsigs.144.2.0213,V.144, no.2, p.213-226.

24. Tenalem Ayenew , (2004), Principles of Engineering Geology; AAU, Department of Geology and Geophysics, Addis Ababa University Press, Addis Ababa.

25. Tilahun M., (2005) Site-Specific Ground Motion Simulation and Seismic response analysis at the proposed bride sites within the city of Addis Ababa, Ethiopia Science Direct, Elsevier, 127-150

26. Tsegaye Girmay and Dawit Solomon, (2004) Commission, Green Frame Unpublished Document,

27. William J.Deutsch, (1997). Ground Water Geochemistry Fundamentals and applications to contamination, CRC Press LLC, N.W. Corporate Blud., Boca Raton, Florida 3431

28. William P.Cunning ham. And Wood Worth Saigo, Environmental Science, A global concern, 3rd edition, WCB WM.C.Brown publishers

29. Willima B.Honachefsky, (2000) Ecologically based Municipal Land Use Planning, CRC Press LLC, N.W. Corporate Blud., Boca Raton, Florida 3431.