Engineering Geological Mapping Of Abaya Campus Compound, Gamogofa Zone, South Ethiopia

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Abstract: In Ethiopia most of the buildings and roads are constructed without thorough investigation of geological environment and materials. This is due to during all civil engineering structures site investigations and constructions on the odd occasion engineering geologist are involved. This made different problems on engineering structures in Ethiopia such as subsidence, cracking and settlement of buildings and roads. Not only this but also less experience of designing and consulting engineers in the construction company. To reveal that the root cause of this problemthe detail research finding was needed to solve these difficulties in construction around Arbaminch town. To characterize the area this research work used visual observations of the geology, geo-botanical condition, measuring of horizontal and vertical variation of the lithology, drilling trial test pits and trenches as well as engineering characterization of soil in the laboratory. Based on these, different zones of engineering geological maps were produced depending on different situations. The parameters were geological structural measurements, surficial geo-dynamic activities, geotechnical characteristics of geological materials, and geo-botanical conditions.The basic scenario identified during this research is soil types and its thickness, the undulating surface of sound rock surface and groundwater fluctuation. Based on these results it is better to use deep foundation or deep excavation to get sound rock with uniform bearing capacity or to replace weak geological materials by better geological materials.

Key wards: Arbaminch,engineering, Ethiopia, geo-dynamic, geo-botanic, geotechnical, investigation, lithology, subsidence

1. Introduction

1.1. Background

Any given area (e.g. college, town, city, country, or the planet Earth itself) can support a limited human population at any given time. If people overpopulate an area, they will not enjoy a good standard of living, and more importantly, their interaction with the environment will be changed for the worst. In order to estimate the optimum human-accommodating capacity of an area such as a town or city, administrative bodies of the area need to come up with a becoming plan for the area. This means, to know how many people can rightfully settle in that area, the administrative bodies have to know where to put the required facilities (e.g. residential buildings, roads, dams, green belts, landfills, etc.) such that much part of the area will be allotted for human use in the best possible way (i.e. inhabiting as much part of the area as possible without causing significant harm to nature and compromising the safety of the inhabitants), and zoned engineering geological mapping can provide an invaluable input for such planning work (i.e. urban planning). Commonly, un-zoned engineering geological maps or geotechnical maps, which show the suitability of the soils and rocks found in an area for putting civil engineering structures, can aid urban planning, and they are known to work fine. Zoned engineering geological maps, however, can do better as they can give information about not only the engineering behaviors of the foundation rocks and soils but also some other geological aspects that pertain to construction works (e.g. geodynamic and groundwater conditions). For all its vital importance in urban planning, the concept of engineering geological mapping doesn't seem to get enough attention from administrative bodies and geologists of Ethiopia alike. Thus, this research project aims at creating enough awareness regarding the great potential of such mapping techniques in urban planning, using a practical example from Abaya Campus.

1.2. Statement of the problem

Abaya Campus does not have a single engineering geological map that can give a generalized insight about the engineering geology of the campus. In addition to this, the civil engineering structures found at the campus are being suffered from some problems resulting from inadequate site characterization (e.g. settlement and cracking). As a result, it is relevant to produce an engineering geological map for the campus which can be used in planning future construction works and future scientific researches. This research has come up with a zoned engineering geological map that can present an overview of the engineering geology of Abaya Campus, and it shows an approach that can be used in making such maps.

1.3. Description of the study area

1.3.1. Location

Abaya is one of the six campuses of Arba Minch University, which is one of the long- established universities of Ethiopia. It is located in SechaKifleKetema of Arba Minch town, a town located 500km south of Addis Ababa in the Southern Nations, Nationalities, and People's Region (SNNPR). Abaya Campus was established in 2004 Eth. C., and it is where the College of Natural Sciences resides. The study area of this research project comprises the entire Abaya Campus and its near environs and covers an area of 1km^2. It is located in the UTM zone of 37N, and it is geographically bounded by 0664000m to 0665000m north and 0339200m to 0340200m east (*Figure 1.1.*).

1.3.2. Topography

Arba Minch town is situated within the southern segment of the Main Ethiopian Rift Valley. Similarly, Abaya Campus is also built within a depression that has an overall northward inclination. The depression is bounded by a long fault scrap to the west, and its floor is plane with minor undulations. The elevation of the study area ranges from 1317m to 1366m, variation in relief is 49m.

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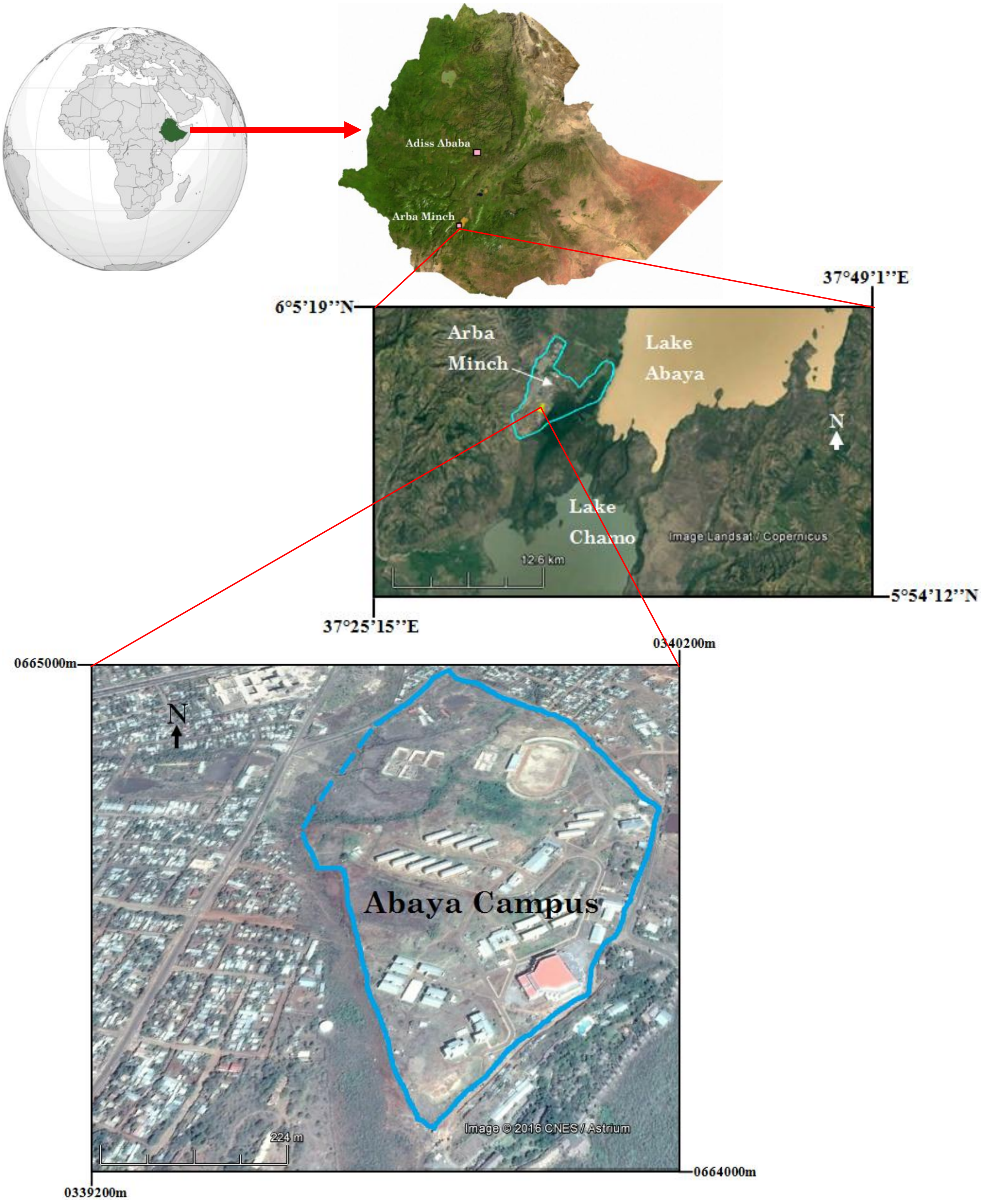


Figure 1.1 *Location map of the study area.*

Figure 1.2 *The fault scarp that borders the campus.*

1.3.3. Climate and vegetation

According to the National Meteorology Agency of Ethiopia, Arba Minch town enjoys six months of dry seasons (October to March) and six months of wet seasons (April to September). Although there are many buildings in the campus, their total areal coverage is not substantial. However, construction debris produced during the construction of those buildings has been dumped within the campus' compound, covering quite a large area. The combined effect of the buildings and the dumps has resulted in low vegetation cover at the campus, especially during the dry seasons. At a particular spot at the campus (*Figure 1.3.*), however, there is a thick vegetation cover. There, plants are grown on the floor of the depression where the campus lies, and they are known to persist even during the driest months of the year. Consequently, a shallow groundwater table might be responsible for the presence of the unusual lush green vegetation there. The areas surrounding the campus are occupied by residents of the town, and they are also characterized by low vegetation density.

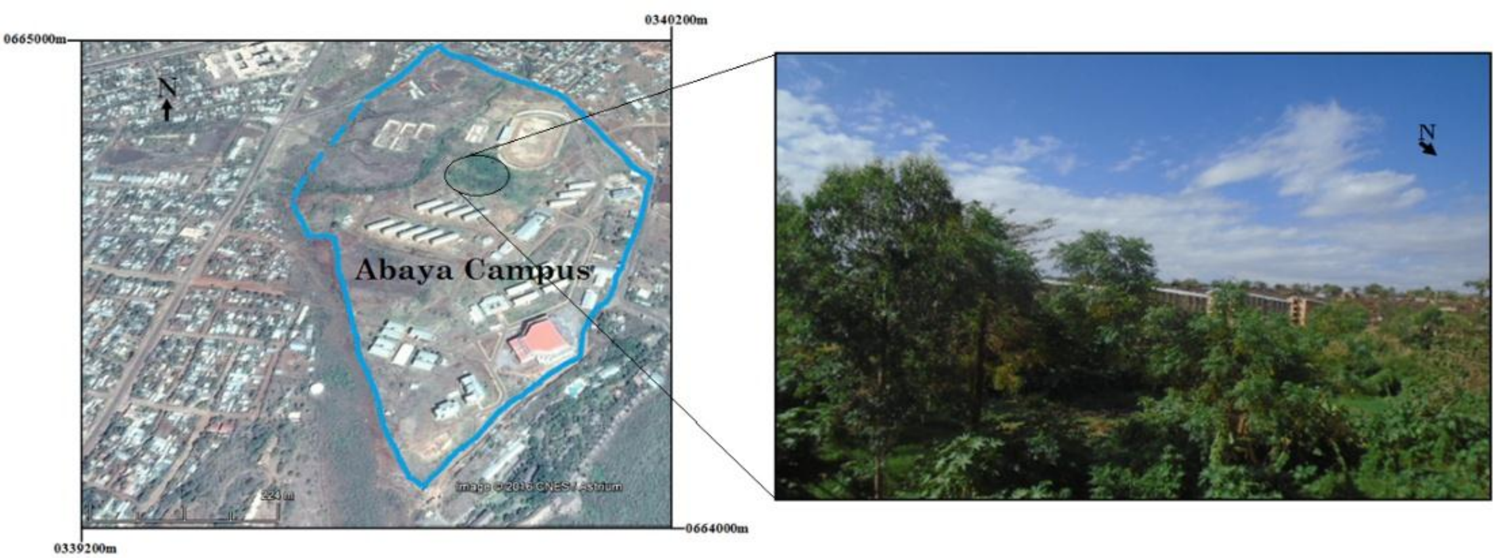


Figure 1.3 *The anomalous thick vegetation cover at the campus.*

1.4. Objectives

1.4.1. General objective
The major objective of this research project is to prepare a zoned engineering geological map of Abaya Campus at a scale of 1:15,000.

1.4.2. Specific objectives
The specific objectives of the research are given as follow.
- To construct the geological, hydrogeological, and geomorphological maps of the study area;
- To classify the soils and rocks based on their engineering parameters and show the distribution of each class on the base map (i.e. geotechnical map preparation), and
- To combine the four maps using the concept of zoning and present them on a single map.

2. Methods

2.1. Data collection methods

2.2. Pre- field work activities
Prior to beginning sampling from the field, the base map on which the four maps (i.e. geological, geomorphological, hydrogeological, and geotechnical maps) were plotted was prepared. To prepare the base map, available topographic map of the study area was manipulated using the mapping software ArcMap. In addition, available secondary data relating to the research work were collected and studied.

2.3. Field work
Four days of field work were conducted in order to collect important primary data (i.e. geological, geotechnical, geomorphological, and hydrogeological data) from the field. During those days, the study area was mapped geologically and geomorphologically through field observations, and the hydrogeological map of the study area was made through inferences made based on presence/absence of discharge zones (e.g. springs) and vegetation anomalies. In addition, representative soil samples and important notes regarding sampling sites were also taken from four soil sampling points (Figure 4.4.). The collected samples were then labeled and taken to the laboratory for some tests. Moreover, Schmidt hammer test or rebound hammer test was conducted on the vesicular basalt unit at five test points. During this test, a rebound hammer having impact energy of 2.207kJ was used in accordance with ASTM D 5873 to assess the relative hardness of the basalt outcrops exposed at the five test points (Figure 4.4.). Some pits found in the campus, which were dug for dumping rubbish or for some construction purpose, were used for taking soil samples and conducting rebound hammer tests. Besides dump pits, big gullies found in the study area (Figure 4.1.) made a good soil sampling sites.

2.4 Laboratory work
Upon reaching the laboratory, the soil samples were air-dried and prepared for some laboratory tests. These tests were sieve analysis, water content determination, direct shear test, and Atterberg/ consistency limits test. Before air- drying the soil samples, some portion was taken from each sample to determine the moisture content of the soils. The collected soil specimens were then oven- dried at 105°C for 24h and the water contents of the soil specimens were computed in accordance with ASTM D 2216. Direct shear test was also conducted on undried fresh soil specimens following ASTM D 3080. Sieve analysis and consistency limits test (i.e. plastic limit test and liquid limit test) were conducted on air- dried soil samples, which were air- dried for 72h. ASTM D 422 and ASTM D 4318 were referred respectively during those tests. The results of the plastic limit and liquid limit tests were then used to determine other index properties of the soils such as plasticity index.

(a) (b)

Figure 2.1.(a) *A dump pit which was used for sampling soil from the reddish- brown soil unit.* ***(b)*** *An abandoned construction pit on the vesicular basalt unit which is used for rebound hammer testing.*

2.5. Data interpretation methods
The data obtained from each laboratory tests (i.e. the particle-size characteristics, plasticity characteristics, water contents, and shear strength parameters (C and ф) of the soil samples) were used in interpreting the engineering geological behavior of each soil sample using different graphs (e.g. cumulative particle-size plot and plasticity chart) and classifying the sample according to an appropriate soil classification system. In this research project, USCS and AASHTO soil classification systems

were implemented following ASTM D 2487and ASTM D 3282 respectively. The rebound numbers obtained from the rebound hammer test were used for calculating the uniaxial compressive strength of the rocks. Then, the distribution of all the identified geotechnical units was plotted on the base map, and the geological, geomorphological, and hydrogeological data obtained from the field were added to the already- made geotechnical map by applying the concept of zoning such that a zoned engineering geological map of the study area was produced. The approach implemented to prepare the zoning map of the study area involved the following steps. First, a separate map was made for each of the four components (i.e. geological, geomorphological, hydrogeological, and geotechnical maps) at the same scale (i.e. 1:15,000). Then, the geotechnical map was used as a base map, and the boundaries made on the other three maps were plotted on it. The boundary lines intersected with each other, leaving distinct zones in between, and each distinct zone defined a unique engineering geological zoning unit where the three conditions (i.e. geological, geomorphological, and hydrogeological conditions) are homogeneous. Eventually, the resulted engineering geological zones were labeled and the required key for the map was appended as shown in Figure 4.12.

3. Literature review

3.1. Regional geology

The Main Ethiopian Rift (MER) is the northernmost part of the Great East African Rift Valley. The MER extends from the Kenyan Rift in the south to the Afar depression in the north, and it trends NE- SW. Traditionally, the MER has been divided into three sectors based on surface geology and geomorphology (viz. the northern (NMER), central (CMER), and southern (SMER) sectors). The NMER extends south from the Afar depression to near Lake Koka, with border faults that trend on average at N50°E. The CMER extends from Lake Koka through the lakes region to Lake Awasa, with border faults trending on average N30°E–N35°E. The SMER extends south from Lake Awasa into the broadly rifted zone of southern Ethiopia with faults trending north–south to N20°E. (Keranen and Klemperer, 2008) The SMER shows a progressive southward narrowing accompanied by a more complex topography, as in the Lake Abaya region where the main depression is bifurcated by the Amaro Horst separating the Ganjuli basin to the west from the Galana basin to the east. South of Lake Abaya, the rift structures attain a pure N-S trend and propagate into the 300-km-wide system of basins and ranges (i.e. broadly rifted zone) that characterizes the overlapping area between the Ethiopian and Kenya rifts. The structural complexity of the broadly rifted zone is related to the interaction between the MER fault trends and the N-S striking structures of the Kenya Rift. (Bonini et al., 2005) In the SMER, rifting began at 21– 25 Ma. Dating of fluvio-lacustrine deposits indicates that rifting was well established at 17 – 15 Ma. Volcanic activity started earlier than in the other MER sectors, since the oldest rocks were dated at about 45 Ma (Amaro-Gamo basalts). Such an initial mainly basaltic activity ended around 30 Ma. A second phase of mainly basaltic volcanism started in the early Miocene. Volcanic activity continued in this area during the Miocene up to 11 Ma, with eruption of basalts, trachytes, and rhyolites. After these events, volcanic activity drastically decreased in the upper Miocene-lower Pliocene, with only limited eruption of 7 Ma-old basalts that crop out scarcely in the plateau above the Chencha escarpment. Volcanic activity resumed then in the late to early Pleistocene with bimodal volcanism on the rift floor. This late activity started with the eruption of widespread Pleistocene ignimbrites (1.6 – 0.5 Ma). The volcanic succession is closed by the NechSar olivine basalts (1.34 – 0.77 Ma) and by few pumiceous tuffs and obsidian flows overlying the Quaternary basalts in the Bridge of God area. (Bonini et al., 2005)

3.2. Engineering geological site investigation

Life time, performance, and compatibility of civil engineering structures largely depend on the quality of geotechnical investigations. Besides these factors, the safety of the structures lies on information from geotechnical surveys, and this information can be retrieved with the help of engineering geological maps (Fekerte et al., 2009). Engineering geological maps can be made for bedrocks or superficial deposits (i.e. soils) or both, and they help in planning environmental and civil engineering works. (Dobbs et al., 2012) The task of engineering geology is to provide engineers, planners, and designers with such information as will help them to create engineering structures and to develop the country in the best possible harmony with the geological environment. Without harmony, every civil engineering work, and these are mainly buildings, dams, tunnels, highways, cities, industrial agglomerations and big open pit mines, interferes often to a considerable extent with the dynamic equilibrium of the geological environment. This may result in detrimental consequences which can affect not only the economy and durability but also the safety of the works. (CEGMIAEG, 1997) The geological environment is a very complex multicomponent dynamic system which cannot be studied in its entirety in connection with construction works or other engineering activities. Using the method of model analysis a simplified picture has to be created of this system comprising only those components of the geologic environment which from the point of view of engineering geology are of a decisive significance (i.e. the distribution and properties of rocks and soils, groundwater, characteristics of the relief, and present geodynamic processes). An engineering geological map, showing the distribution and spatial relationships of these basic components, can be of two major types (viz. analytical and comprehensive). (CEGMIAEG, 1997) Analytical engineering geological maps show individual components of the geological environment, and thus the content of analytical maps is usually obvious from their title. For example, an analytical map may be a map of intensity and pattern of jointing, or may show slope angles, or slope stability, or landslides. Conversely, comprehensive engineering geological maps depict all the principal components of the geological environment. (Bell, 1983) Comprehensive maps, in turn, are of two basic kinds. They may show on one map sheet all the components of the engineering geological environment, or they may depict on one map sheet those areas which have been grouped for zoning purposes on the basis of the uniformity of their engineering geological conditions (zoning maps). (CEGMIAEG, 1997) Engineering geological zoning involves delineation of individual territorial units on the basis of uniformity of the most significant engineering geological conditions (e.g. geodynamic and groundwater conditions), and the detail and degree of homogeneity of each engineering geological zoning unit will depend on the scale and purpose of the map. (CEGMIAEG, 1997)

3.3. Engineering geological soil characterization

The physical properties of soils which serve mainly for identification and classification purpose are commonly known as index properties which can be determined by simple laboratory tests. Index property tests are grain size analysis, Atterberg limits, free swell and specific gravity. (Hanna, 2008) The standard method of soil water content measurement is the oven drying method. This method involves taking a physical sample of the soil, weighing it before any water is lost, and drying it in an oven before weighing it again. The mass of water lost on drying is a direct measure of the soil water content. This measure is normalized either by dividing by the oven-dry mass of the soil sample or by converting the mass of water to a volume (by dividing the mass of water by the density of water) and dividing this volume of water by the volume of the sample. This method is standard and reliable but there are some problems to look out for if high accuracy is required. (IAEA, 2008) The strength of a soil depends of its resistance to shearing stresses. It is made up of basically the components: frictional (due to friction between individual particles) and cohesive (due to cohesion between the soil particles). The shear strength of soils can be determined using different tests including unconfined compression test, torsional ring- shear test, plane strain triaxial test and direct shear test. (Terzaghi et al., 1996) The grain size distributions (GSD) are one of the basic and most important properties of soil. It is primarily used for soil classification and provided a first order estimate of other soil engineering properties such as permeability, shear strength, and compressibility. In practice, the GSD of the full size spectrum of soil grains is determined by integrating data obtained from two inherently dissimilar tests, mechanical sieving for the coarse grained soil fraction and hydrometer tests for the fine fraction. In sieve analysis, the particle size is characterized by a single linear dimension representing the minimum square sieve aperture that which the particle just passed through. The results of sieving are dependent upon the shape of the particles. (Arasan et al., 2011). Plastic behaviour of soil is an element of concern in civil engineering as it highly affects construction design. Soils with high plasticity index may result in sudden and unpredictable structural failures due to volumetric changes in soil by moisture infiltration through surface cracks. The liquid limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dried soil, at the boundary between the liquid and plastic states of consistency, and The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semisolid states of consistency. The plasticity index of a soil is the numerical difference between its liquid limit and its plastic limit, and is a dimensionless number. (Arbaaz et al., 2015).

3.4. Engineering geological rock characterization

The physic-mechanical properties of rocks are the most important parameters in the design of ground workings and in the classification of rocks for engineering purposes. The measurement of rock strength has been standardized by both the American Society for Testing and Materials (ASTM, 1984) and the International Society for Rock Mechanics (ISRM, 1981a). Standard sample preparation is time consuming and expensive. For these reasons, indirect tests such as Schmidt rebound number, point load index, and Shore Scleroscope hardness can be used to estimate rock strength. The indices and methods are easy tests to conduct because they need no sample preparation and the testing equipment used is less sophisticated and is also portable. The determination of all physical and mechanical properties of rock by using the Schmidt hammer and Shore Scleroscope tests are very important. In addition, determination mechanical properties are essential for classification of rock materials and judgment about their suitability for various construction purposes. Both Schmidt hammer hardness and Shore Scleroscope tests would be very valuable for at least the preliminary stage of designing a structure. (Yasar and Erdogan, 2003). The Schmidt hammer was originally devised by E. Schmidt in 1948 for carrying out in situ, non-destructive tests on concrete hardness. Since then the advantages and disadvantages of the device for measuring rock characteristics have become apparent, and the Schmidt Hammer has been used for an increasing range of purposes including measuring the strength of rocks. The instrument measures the distance of rebound of a controlled impact on a rock surface. Readings of rock hardness have often been found to correlate well with other measures of rock character, such as uniaxial compressive strength and Young’s Modulus of Elasticity. (Goudie, 2006).

3.5. Hydrogeological conditions and engineering works

Hydrogeological conditions affect land-use, planning, site selection and the cost, durability and even the safety of structures. Ground and surface waters play a prominent part in such geodynamic processes as weathering slope movements, mechanical and chemical suffusion (i.e. a kind of internal erosion in soils), the development of karstic conditions, and volume changes by shrinking and swelling. Rock and soil properties are often changed by groundwater. Groundwater may influence excavation and construction methods by flowing into excavations, by producing seepage forces and uplift pressures and by its corrosive action. Hydrogeological conditions may also affect underground waste disposal. (CEGMIAEG, 1997)

4. RESULTS AND DISCUSSION

4.1. Geological Mapping

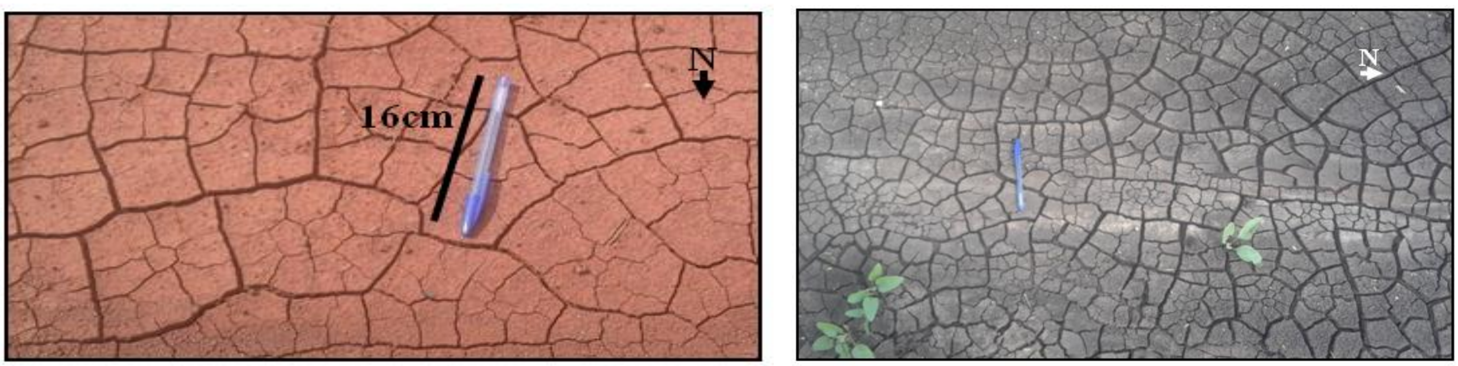
4.1.1. Lithology

In the study area, three lithologic units have been identified (viz. dark reddish- brown soil, black soil, and vesicular basalt). The dark reddish- brown soil is the second most abundant lithologic unit in the study area. It is fine grained, and it exhibits mud cracks. This unit reaches a thickness of 4m on the surface. The black soil is very similar to the reddish- brown soil as both are characterized by fine-grained texture and mud cracks. Nonetheless, this unit is more thick (up to 6m), and it covers a smaller area.

(a) (b)

Figure 4.1.(a) *The black soil exposed along a deep gully.* ***(b)*** *An exposure of the reddish- brown soil (right).*

Vesicular basalt, which is the most abundant lithologic unit in the study area, is the only rock unit exposed in the study area. It is dark grey in color, and it is exposed along the periphery of the study area, surrounding the two soil units (Figure 4.4.). On the whole, this lithologic unit is highly weathered and highly jointed; several non- systematic joints have dismembered the unit into countless basaltic boulders. The boulders are very big, and they are mainly found on the fault scrap that exists in the study area. At a few places in the study area, however, slightly- weathered and slightly- vesicular verities of this unit have been encountered.



(a) (b)

Figure 4.2.*Mud cracks in the reddish- brown soil (a) and in the black soil (b).*

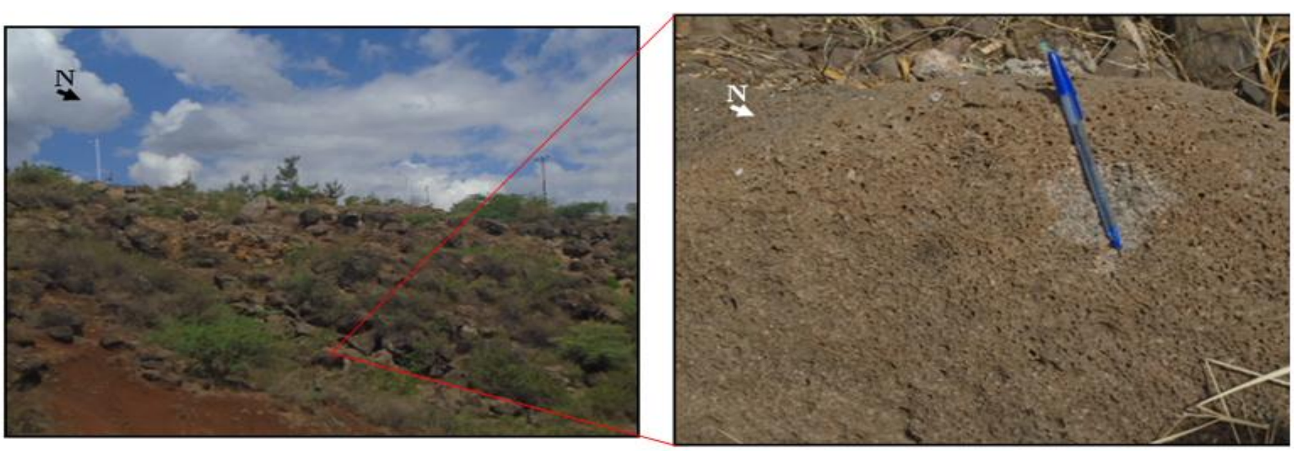


Figure 4.3.*Big basaltic boulders on the fault scarp.*

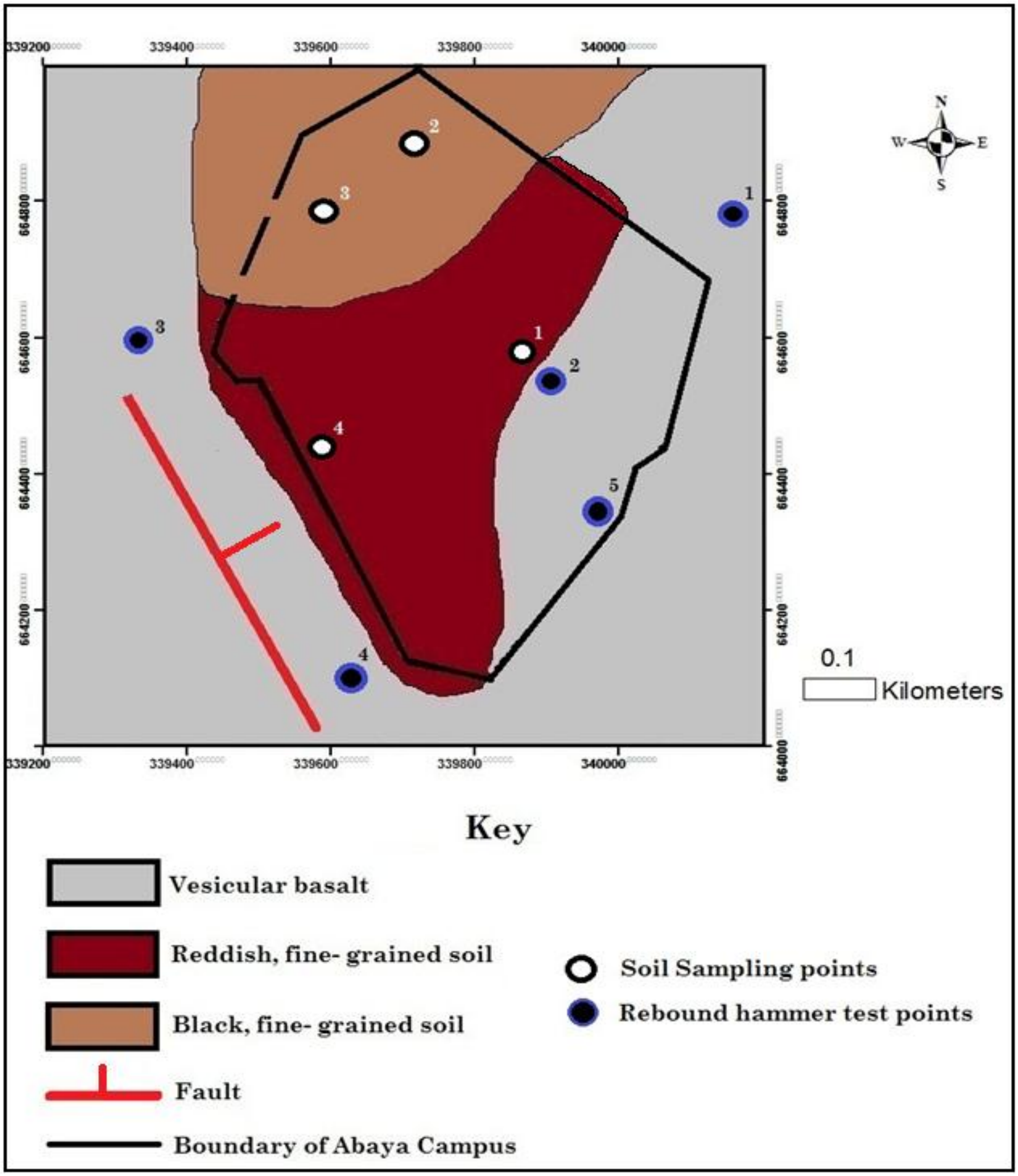


Figure 4.4.*The geological map of the study area.*

4.1.2. Geological structure

In the study area, there is an inferred normal fault that has an attitude of N35°W, 32°NE (Figure 1.2.). This fault extends for quite a long distance, and it is inferred based on its steep scarp.

4.2. Geodynamic phenomena mapping

Geomorphologically, the study area has been divided into three distinct parts (viz. rock fall area, high erosion area, and low erosion- low landslide area). The rock fall area comprises the normal fault found in the study area. The fault scrap is characterized by slightly steep slope (i.e. 32°) and big basaltic boulders, which tend to roll down into the campus. The high erosion area mainly covers the black soil unit, and it is characterized by wide gullies (Figure 4.1.). The majority of the study area is gentle, and it has been identified as a low erosion- low landslide area.

4.3. Hydrogeological mapping

Since there were no existing hydrogeological data for the study area, hydrogeological conditions of the study area were inferred based on field observations (i.e. identification of discharge zones like springs) and satellite imagery studies, which were supplemented with the analysis of basic climatic data of the study area. As mentioned previously in section 1.3.3., the anomalous vegetation cover found in the study area (Figure 1.3.) has been linked to a shallow groundwater table. The two satellite images shown in Figure 4.6.are also in favor of this inference. The two images were taken during December (one of the driest months in the study area) and May (one of the wettest months in the study area). As it is patent from the images, the anomalous thick vegetation in the study area was green both during May and December, whereas the other vegetations in the study area dried out during the dry month December.

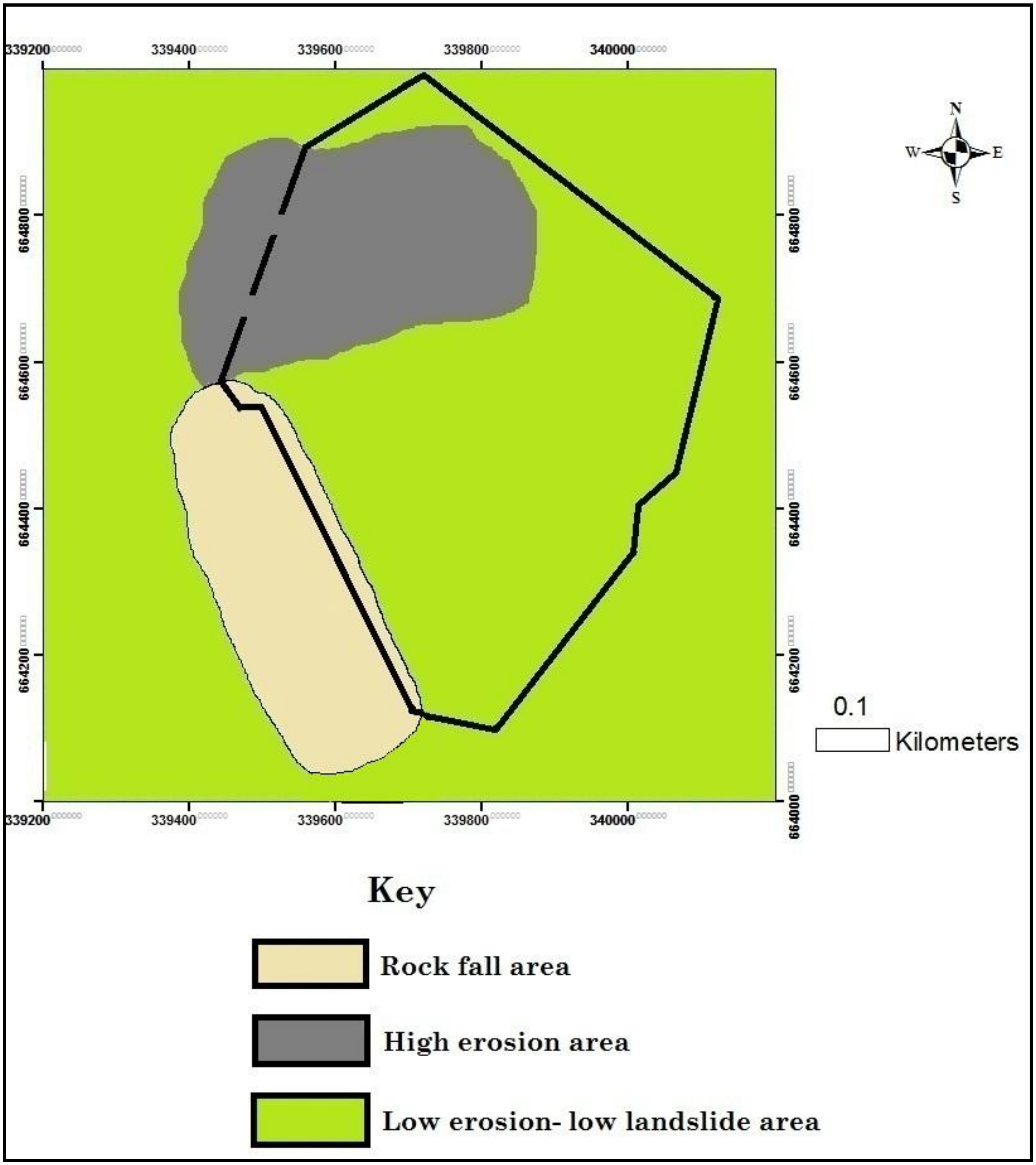


Figure 4.5.*The geomorphological map of the study area.*

Figure 4.6.*The vegetation cover in the study area on 05 May, 2016 (top) and 17 December, 2016 (bottom). The area with the anomalous vegetation is shown by the black circle.*

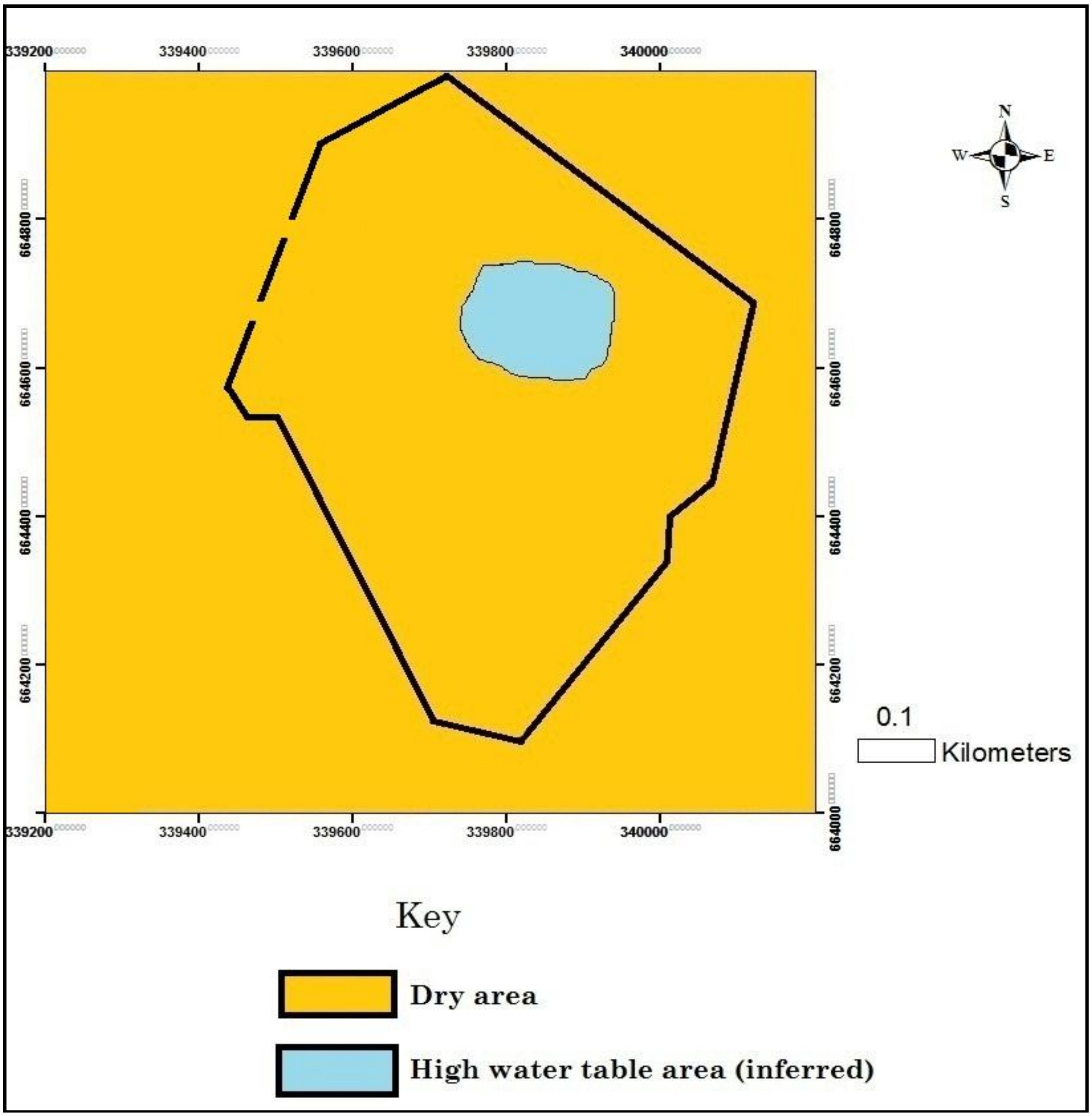


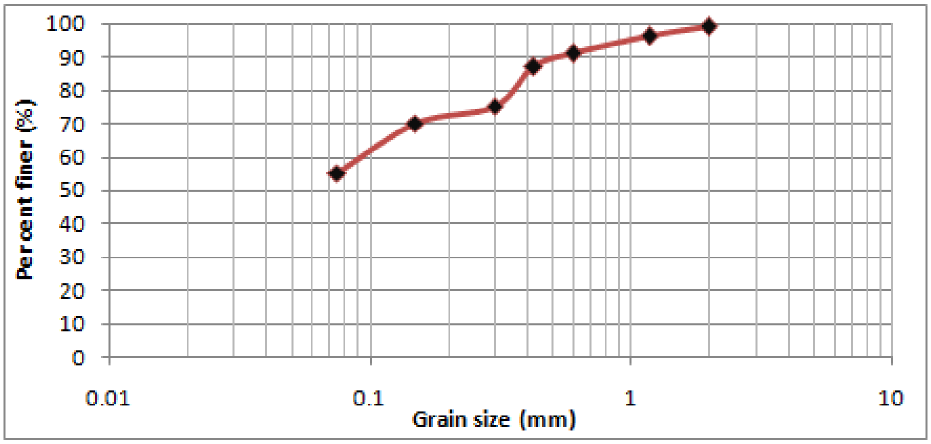
Figure 4.7.*The hydrogeological map of the study area.*

4.4. Geotechnical mapping

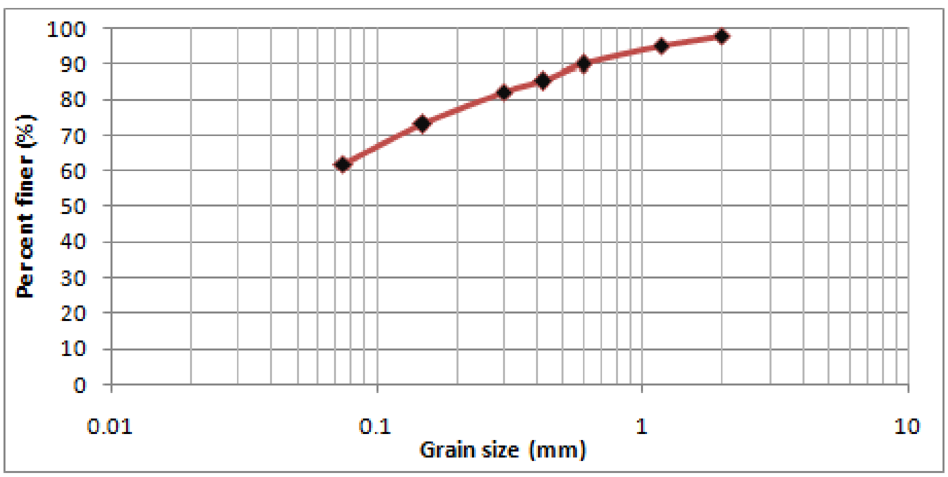
4.4.1. Engineering geological soil characterization

4.4.1.1. Sieve analysis

Sieve analysis was conducted on two air- dried soil samples taken from the two soil units (sample-3 and sample-4). From the grain size analysis results, it has been established that both the reddish and black soil units are fine- grained soils whose > 50% constituents pass the no. 200 sieve. The black soil unit (sample-3) is characterized by 1.4% gravel, 44.2% sand, and 54.4% fines (silt and clay) and is gap graded, while the reddish soil unit (sample-4) consists of 2.4% gravel, 35.6% sand, and 62.0% fines and is well graded (Figure 4.8.).



(a)



(b)

Figure 4.8.*Grain size distribution curves for sample-3 (a) and sample-4 (b).*

4.4.1.2. Water content determination

The water content of the four soil samples (i.e. sample-1 to sample-4) were determined by oven- drying the samples at 105°C four 24h. As shown in Table 4.1., the water content of the black soil (sample-2 and sample-3) is significantly higher than that of the reddish soil (sample-1 and sample-4), yet both soil types are exposed to the same surface conditions in the study area.

Table 4.1.*Water contents of the soils*

Soil sample	1	2	3	4
Water content (%)	33.90	58.39	48.52	24.29

4.4.1.3. Atterberg/ consistency limits tests

Liquid limit test and plastic limit test were conducted on the four soil samples after they had been air dried. As shown in Table 4.2., the liquid limit (LL) of the soils found in the study area ranges from 93.55 to 47.7% and the plastic limit (PL) of the soils ranges from 55.4% to 31.5%.

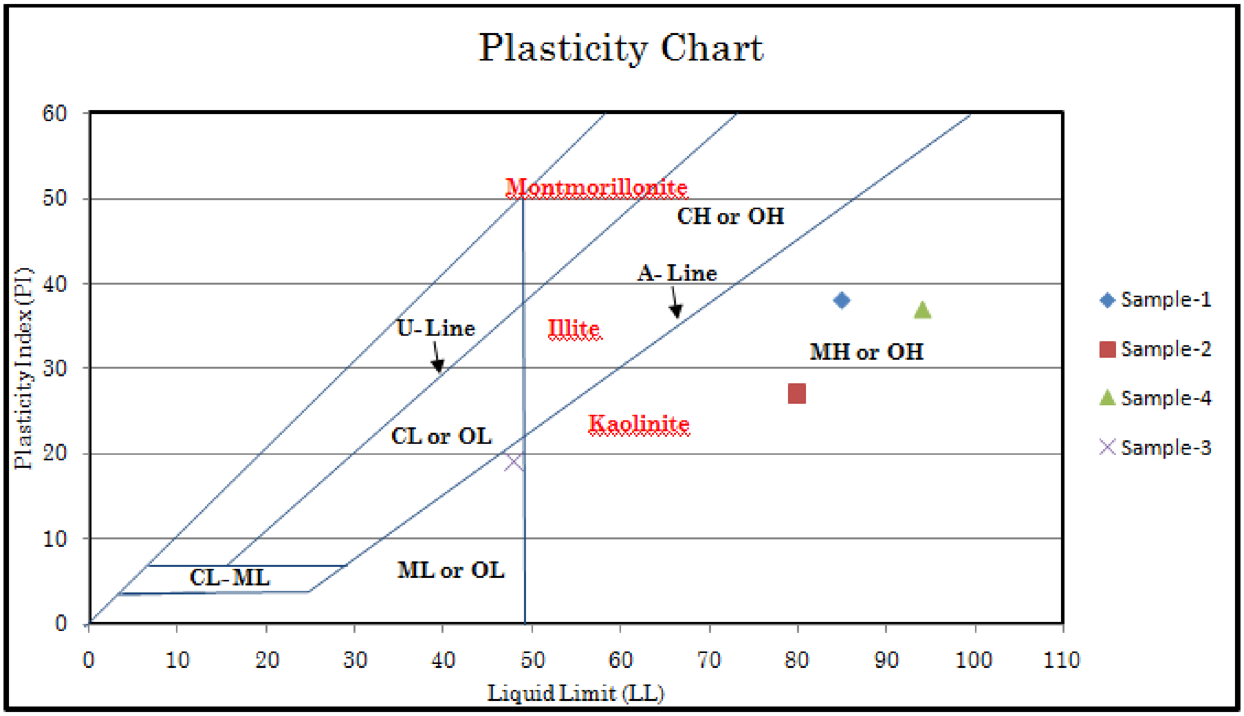
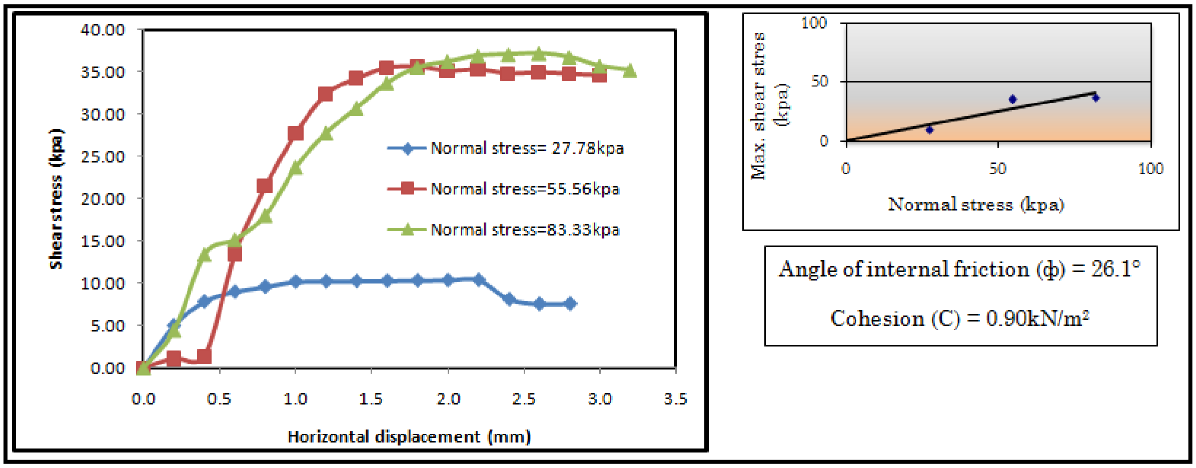


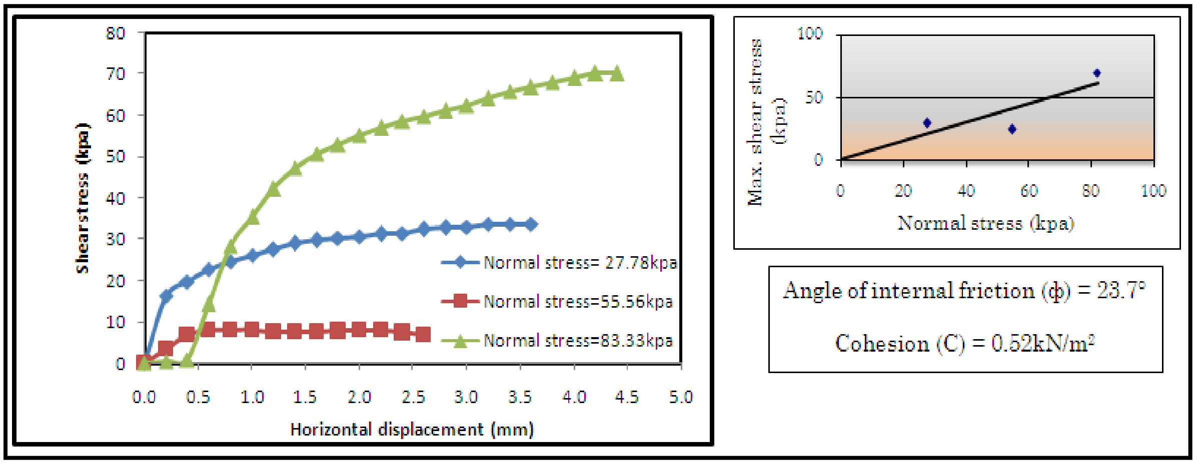
Figure 4.9. *The results of the consistency limits tests plotted on the plasticity chart.*

4.4.1.4. Direct shear test

In this research project, direct shear test was conducted to determine the shear strength parameters (C and ϕ) of the soils found in the study area on two soil samples taken from the two soil units. From the test, it was observed that the reddish soil (sample-1) has a cohesive strength of 0.52kN/m^2 and angle of internal friction of 23.7°, while the black soil (sample-3) has a cohesive strength of 0.90kN/m^2 and angle of internal friction of 26.1°.



(a)



(b)

Figure 4.10.*Shear strength parameters for soil sample-3 (a) and soil sample-1 (b).*

4.4.2. Engineering geological soil classification

As shown in Table 4.2., the soils found in the study area are classified according to the USCS as sandy elastic silt (MH) And sandy silt (ML). The majority of the soils of the study area belong to the MH class (Figure 4.11.). According to ASSHTO soil classification system, the soil units found in the study area belong to the A-7-5 group, and they are fair to poor as a subgrade.

Table 4.2.*Classification of the soils of the study area according to USCS and ASSHTO*

Soil samples	Lithology	LL (%)	PL (%)	PI (%)	Classification according to USCS	Classification according to AASHTO
1	Reddish, fine-grained soi	85.5	46.7	38.8	MH (Sandy elastic silt)	A-7-5
2	Black, fine- grained soil	47.7	31.5	16.2	ML (Sandy silt)	A-7-5
3	Black, fine- grained soil	80.7	53.8	26.9	MH (Sandy elastic silt)	A-7-5
4	Reddish, fine-grained soil	93.5	55.4	38.1	MH (Sandy elastic silt)	A-7-5

4.4.3. Engineering geological rock characterization

4.4.3.1. Schmidt/ Rebound hammer test

Schmidt/ Rebound hammer test was conducted at five test points on the vesicular basalt unit (Figure 4.4.). The median rebound of the test points ranges from 21.2 to 33.8, and their unconfined compressive strength (UCS) ranges from 25.25 to 41.76Mpa (Table 4.3.). All the test points have been rated as moderately strong as a result.

4.4.4. Engineering geological rock classification

Rebound hammer test results accompanied by visual descriptions of the test points were used to classify the vesicular basalt unit for engineering purpose. Accordingly, the vesicular basalt unit has been divided into two geotechnical units (viz. slightly- vesicular, moderately-strong basalt and highly- vesicular, moderately- strong basalt). The first geotechnical unit has a smaller area coverage and exhibits minute degree of weathering, whereas the second unit is widespread and slightly- to highly- weathered (Figure 4.11.).

Table 4.3.*Engineering classification of the rock units of the study area*

Test point	Lithology	Median rebound	UCS (Mpa)*	Qualitative strength**
1	Slightly- weathered, slightly- vesiculated basalt	33.8	41.76	Moderately strong
2	Highly- weathered, highly- vesiculated basalt	21.2	25.25	Moderately strong

3	Slightly- weathered, slightly- vesiculated basalt	31.9	39.27	Moderately strong
4	Highly- weathered, highly- vesiculated basalt	22.6	27.09	Moderately strong
5	Slightly- weathered, highly- vesiculated basalt	23.8	28.66	Moderately strong

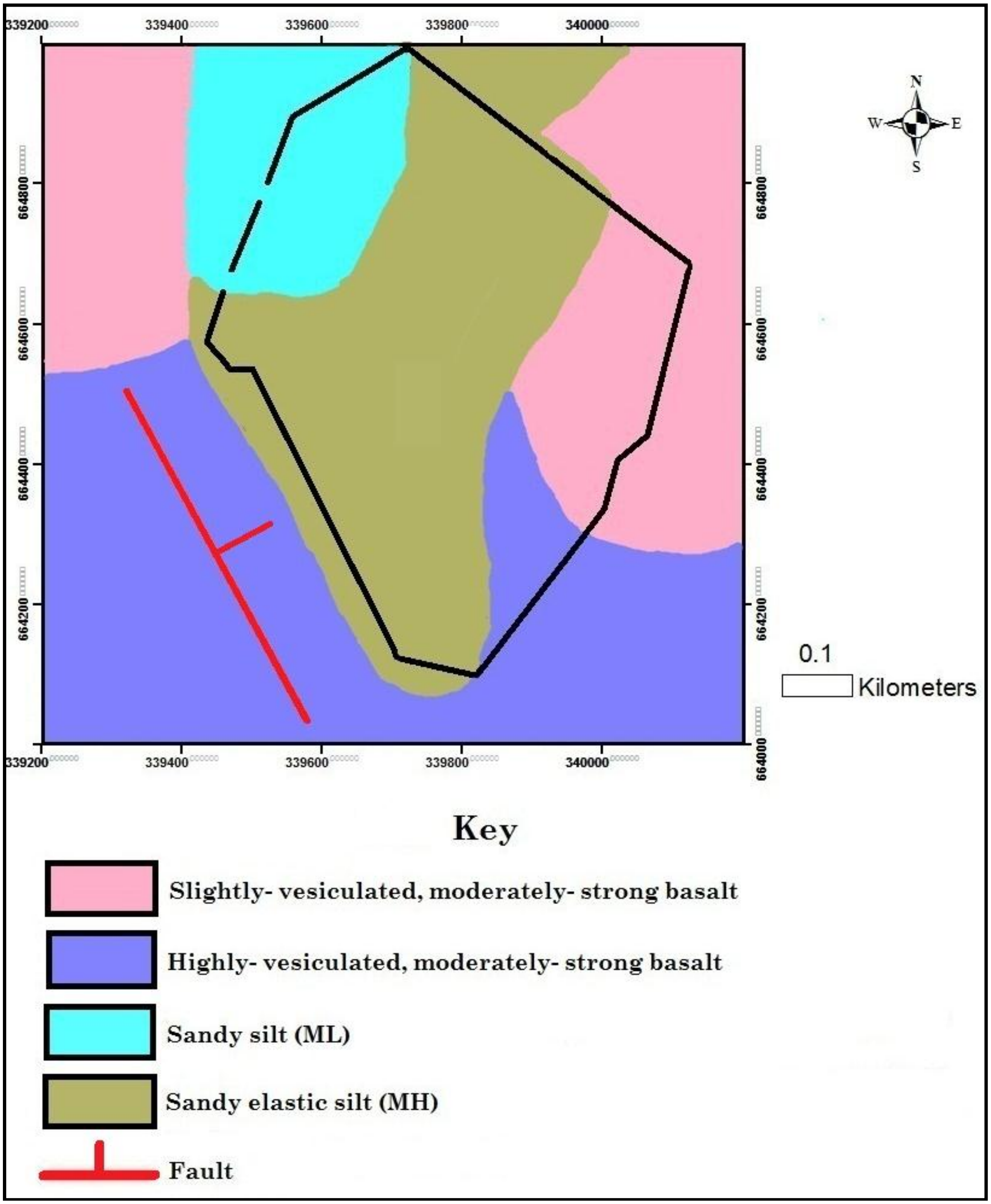
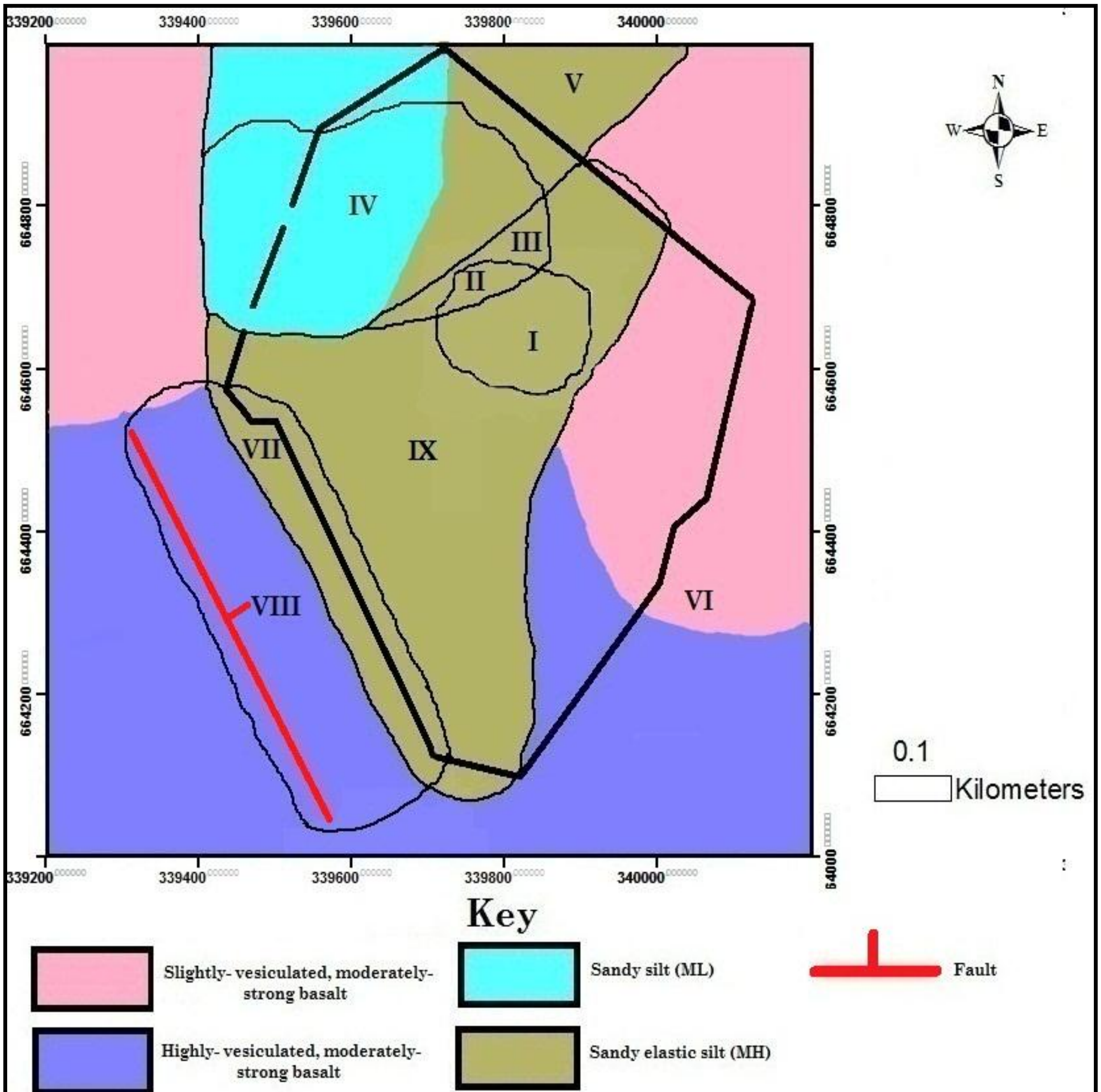


Figure 4.11.*The geotechnical map of the study area.*



Engineering geological zones	I	II	III	IV	V	VI	VII	VIII	IX
Geology (lithology)	Reddish, fine-grained soil	Reddish, fine-grained soil	Reddish, fine-grained soil	Black, fine-grained soil	Black, fine-grained soil	Vesicular basalt	Reddish, fine-grained soil	Vesicular basalt	Reddish, fine-grained soil
Geomorphic condition	Low erosion, low landslide area	High erosion area	High erosion area	High erosion area	Low erosion, low landslide area	Low erosion, low landslide area	Rock fall area	Rock fall area	Low erosion, low landslide area
Hydrogeologic condition	High water table area	High water table area	Dry area	Dry area	Dry area	Dry area	Dry area	Dry area	Dry area

Figure 4.12.*The zoned engineering geological map of the study area.*

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In the study area, three lithologic units have been identified: two soil units and one rock unit. Basalt is the only rock unit exposed in the study area, and it is characterized by vesicular texture and high degree of weathering. The two soil units found in the study area are two of a kind, the only differences between them being color and extent (i.e. one is dark reddish brown in color and covers lager area, while the other is black in color). Both units exhibit fine- grained texture and mud cracks. In addition, a long normal fault has been inferred in the study area, having an attitude of N35°W, 32°NE. Three distinct geomorphological zones have been recognized in the study area. These are rock fall area, high erosion area, and low erosion- low landslide area. The low erosion- low landslide area comprises most part of the study area, and it is where most of currently-existing civil engineering structures found in the study area lie. Hydro-geologically, the study area has been classified into two (viz. high water table area and dry area). Most part of the study area is classified as dry, as it does not show any manifestation of shallow groundwater condition (i.e. it is devoid of discharge zones like springs). Conversely, the high water table area is characterized by anomalously thick green vegetation that is untypical of the study area, and this anomalous vegetation is considered to hint at a shallow water table. In the study area four engineering geological units have been defined. The two soil units of the study area have been classified in to two engineering geological units (viz. MH (sandy elastic silt) and ML (sandy silt)) according to USCS, and both engineering geological units belong to the A-7-5 group according to AASHTO soil classification system and make fair to poor subgrade. Based on field and laboratory data, the study area has been divided into nine engineering geological zones (i.e. zone-I to zone- IX). Zone- VI is the largest and it is characterized by vesicular basalt, low erosion rate, low landslide vulnerability, and deep ground water table. The smallest zone is zone- II which is characterized by reddish fine-grained soil, low erosion rate, low landslide vulnerability, and shallow ground water table.

5.2. Recommendation

- Probably, the reason why zoned engineering geological mapping has been underused in Ethiopia is that geologists of the country do not know about it or they have overlooked its importance. Thus, to change this reality and make the best use of such a mapping technique in the development of the country, geology students of the country need to be familiarized with the concept of zoning in engineering geology through their university studies, and to achieve this, university instructors should play their imperative role.
- As discussed, both of the soil units found in the study area exhibit extensive mud cracks, which might be indications that the soils are expansive. Hence, it is recommended to test the soils for their expansiveness, which this research project could not do, so that the damage that could possibly cause the soils would be kept to minimum.
- The people living near the fault scrap found in the study area need to be given caution regarding the risk of falling rocks, as they are living within the rock fall area.
- If future groundwater exploration is going to take place in the study area, it is better to give priority to the area with the anomalous thick vegetation.

References

[1] Arasan S., Akbulut S., Hasiloglu A.S. (2011): Effect of particle size and shape on the grain size distribution using Image analysis. International Journal of Civil and Structural Engineering, Volume 1, No 4, pp. 968.

[2] Arbaaz S., Quddus M.A., Hussain M.I., Upadhyay G. (2015): An Experimental Study on the Atterberg Limits of Soil around HussainSagar LAKE, Prospective Location for Tall Structures. International Journal of Research in Engineering and Technology, eISSN: 2319-1163 | pISSN: 2321-7308, pp. 337.

[3] ASTM D 422- D5876: Standard Test Methods for Soil and Rock (I). ASTM International, Annual Book of ASTM Standards, Vol. 04.08.

[4] Bell F.G. (1983): Fundamentals of Engineering Geology. Butterworth & Co. Ltd, England.

[5] Bonini M., Corti G., Innocenti F., Manetti P., Mazzarini F., Tsegaye A., and Pecskay Z. (2005): Evolution of the Main Ethiopian Rift in the frame of Afar and Kenya rifts propagation. TECTONICS, VOL. 24, TC1007, doi:10.1029/2004TC001680.

[6] CEGMIAEG (The Commission on Engineering Geological Maps of the International Association of Engineering Geology) (1997): Engineering geological maps: a guide to their preparation. The UNESCO Press, Paris, pp. 17- 26.

[7] Dinçer I., Acar A., Çobanoğlu I., and Uras Y. (2004): Correlation between Schmidt Hardness, Uniaxial Compressive Strength, and Young's Modulus for Andesites, Basalts and Tuffs. Bull EngGeolEnv, 2004, 63:141-148, pp. 142.

[8] Dobbs M. R., Culshaw M. G., Northmore K., Reeves H. J., and Entwisle D. C. (2012): Methodology for creating national engineering geological maps of the UK. Quarterly Journal of Engineering Geology and Hydrogeology, 45, 335–347.

[9] Fekerte A.Y., Freek van der Meer, and Harald van der Werff (2009): Prediction of Volumetric Shrinkage in Expansive Soils (Role of Remote Sensing), Advances in Geoscience and Remote Sensing, Gary Jedlovec (Ed.), ISBN: 978-953-307-005-6, InTech, pp. 347. Available from: http://www.intechopen.com/books/advances-in-geoscience-and-remot-sensimg/prediction-of-volumetricshrinkage-in-expansive-soils-role-of-remote-sensing (accessed on 31 December, 2016 @ 6:00 p.m.).

[10] Goudie A.S. (2006): The Schmidt Hammer in geomorphological research.Progress in Physical Geography30, 6 (2006) pp. 703–718.

[11] Hanna Tibebu (2008): Study of Index Properties and shear Strength Parameters of Laterite soils in Southern Part of Ethiopia the case of Wolayita – Sodo. MSc thesis, Addis Ababa University, Addis Ababa. (Unpublished), pp. 29.

[12] http://www.ethiomet.gov.et/climates/climate_of_city/2467/Arba Minch (accessed on 02 May, 2017 at 6:00 pm).

[13] Keranen K. and KlempererS.L. (2008): Discontinuous and diachronous evolution of the Main Ethiopian Rift: Implications for development of continental rifts. Earth and Planetary Science Letters 265 96–111, 97

[14] Terzaghi K., Peck R.B., and Mesri G.(1996): Soil Mechanics in Engineering Practice. John Wiley & Sons, Inc., United States of America.

[15] Yasar E. and Erdogan Y. (2003): Estimation of rock physicomechanical properties using hardness methods. Engineering Geology 71 (2004) 281–288, pp. 282.