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Research Paper

Engineering Geological Investigation of Adama Town: Implication to Engineering Practice

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Abstract

Adama was founded hundred years ago and is one of the major and densely populated towns in Ethiopia. It is located 100 km south–east of Addis Ababa and the hub of a vast region of immense economic potentials accessible by means of rail way and expressway. Due to the mentioned reasons, the urbanization is rapid. However as in many towns of Ethiopia, very little is known about the engineering properties of soils and rocks underlying the town. Moreover, the town is located in the southern extreme of the active volcano-tectonic segment of the northern Main Ethiopian Rift (MER). The present research work is, therefore, aimed at assessing and evaluating the geological and engineering geological condition of the rocks and soils of the town. Detailed field investigation, in-situ rock strength test and laboratory tests were carried out. A total of 30 soil samples were taken from 16 test pits, which were dug manually to 3 m depth. The natural moisture content of the soil of the study area ranges from 6.34% - 25.2%, liquid limit 26.06% - 54%, plastic limit 7.5% - 40.83%, plasticity index 2.22% - 26.83%, free swell 0% - 40%, specific gravity 2.12 - 2.67, and pH 4.48 - 6.7. Low to medium plastic silty sand and sand are the dominant soil type in the study area. The rocks of the study area were classified into Low Strength, Medium Strength and High Strength rock mass units based on the strength (Unconfined Compressive Strength) of intact rock and discontinuity characteristics. Gully erosion, land slide, seismic activity and flooding are the main geo-hazard that need attention in the study area.

1. Introduction

Adama was founded hundred years ago and is one of the major and densely populated towns in the region and in Ethiopia as well. It is located about 100 km south–east of Addis Ababa and at the heart of both Ethiopia and the National Regional State of Oromia as well. The town is the hub of a vast region of immense economic potentials accessible by means of railway and expressway. Due to these facts, the urbanization is rapid in the different directions of the town and investors are attracted to invest in the town and the nearby areas. Currently, many civil engineering structures such as roads, bridges, Industry Park and multistory buildings including international hotels and commercial centers are under construction in the town. On the other hand, the town has been vulnerable to geological hazards like erosion and associated landslides, ground fissure and flooding during rainy season. These hazards caused damages to dwelling houses, roads, bridges, farm land and other infrastructures like power and communication lines due to unplanned expansion of the town. In addition, the town is situated in a seismically active area, Main Ethiopian Rift (MER), where there is active

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internal tectonic movement as evidenced by recent ground crack in the southern part of the town.

Site investigation is a prerequisite for the successful and economic design of civil engineering structures (Bell, 2007). In other word, deep knowledge of the geomorphological, geological and geotechnical condition of an urban area is necessary to provide basic information about the ground conditions to local authorities, engineers and contractors (Bowles, 1996). In addition, unplanned expansion of towns can exposed people and economic assets to the risk of natural disaster.

Despite the rapid urbanization and construction activity in Adama town, no work was done in engineering-geology aspects. Regional geology of the area, the Rift in general, is covered at a very small scale (Wolde Gabriel et al., 1990; Morton et al., 1979, etc.) which provide limited information for engineering applications. Asfaw Erbelo and Hassen Shube (2019) mapped the faults around Adama and assessed their activity and potential to trigger earthquake. Dejene Tesema et al. (2017) investigated the flood hazard risk in Adama town using Analytical Hierarchical Process (AHP) and multicriteria approach. According to their finding, 10.4% of the total area of the town, which composed of different urban land uses, lies within high flood hazard zone. The only research to be mentioned in geotechnical aspect is the work of Dagnachew Debebe (2011), in which he has studied some of the engineering properties of soils of the town. However, the work missed some important details viz. geomorphological, structural, geo-hazard and geological information. More importantly, the engineering properties of rocks is not investigated and the engineering geological map of the town has not produced as well. An engineering geological map is the best way to depict the natural environment for engineering purpose (IAEG, 1981; Bell, 1987). Medium to large scale geological and engineering geological maps and data are widely used for urban land use planning, engineering site selection and other related works. The present work is, therefore, aimed to obtain information on the type, characteristics and distribution of rocks and soils and geodynamic conditions by integrating engineering geological and geotechnical investigation.

2. Methodology

2.1. Description of the study area

The study area, Adama town, is located in the Main Ethiopian Rift, East Showa Zone of Oromia National Regional State (Figure 1). Geographically, the town is located between 52500 to 534000 m E Longitude and 937000 to 950000 m N Latitude. The town is 100 kilometers far from Addis Ababa along the road that connects Addis Ababa with eastern towns of the country and Djibouti port. According to the climatic zones of Ethiopia, the study area with an altitude ranging from 1500 - 2000 m above mean sea level is classified as sub-tropical climate. It receives maximum rainfall during summer season (i.e. July and August). Topographically the area is situated in graben which is bounded by fault escarpments in western and eastern directions. The study area is characterized by flat to gently slope which ranges from 0° to 64°. All the streams flow into the depression bounded by fault. There is no perennial river and the peak discharge from intermittent surface runoff is attained during summer.

2.2. Desk study and reconnaissance survey

Exhaustive and thorough systematic literature review with regard to site investigation, description and classification of soil and rock for engineering purposes, procedures for engineering geological mapping, similar and related works in the world, Ethiopia and particularly in the study area was done. Similarly, a review on unpublished and published geological map and geodynamic processes was done. Later conceptual frame work and general methodology was developed from the knowledge acquired through literature review. In order to understand the general conditions of the study area such as topography, soil distribution, land slide manifestations, information was gathered and field reconnaissance survey was undertaken. The first reconnaissance field survey was done from May 08/2017 to July 5/2017 and during this field survey, some preliminary geological mapping, geomorphological and land form assessment and soil distribution identification were done.

2.3. Detailed field survey and sampling

In this stage, detailed field description of rock and soils, in-situ strength tests and soil sampling were carried. Different traverses were made along rock and

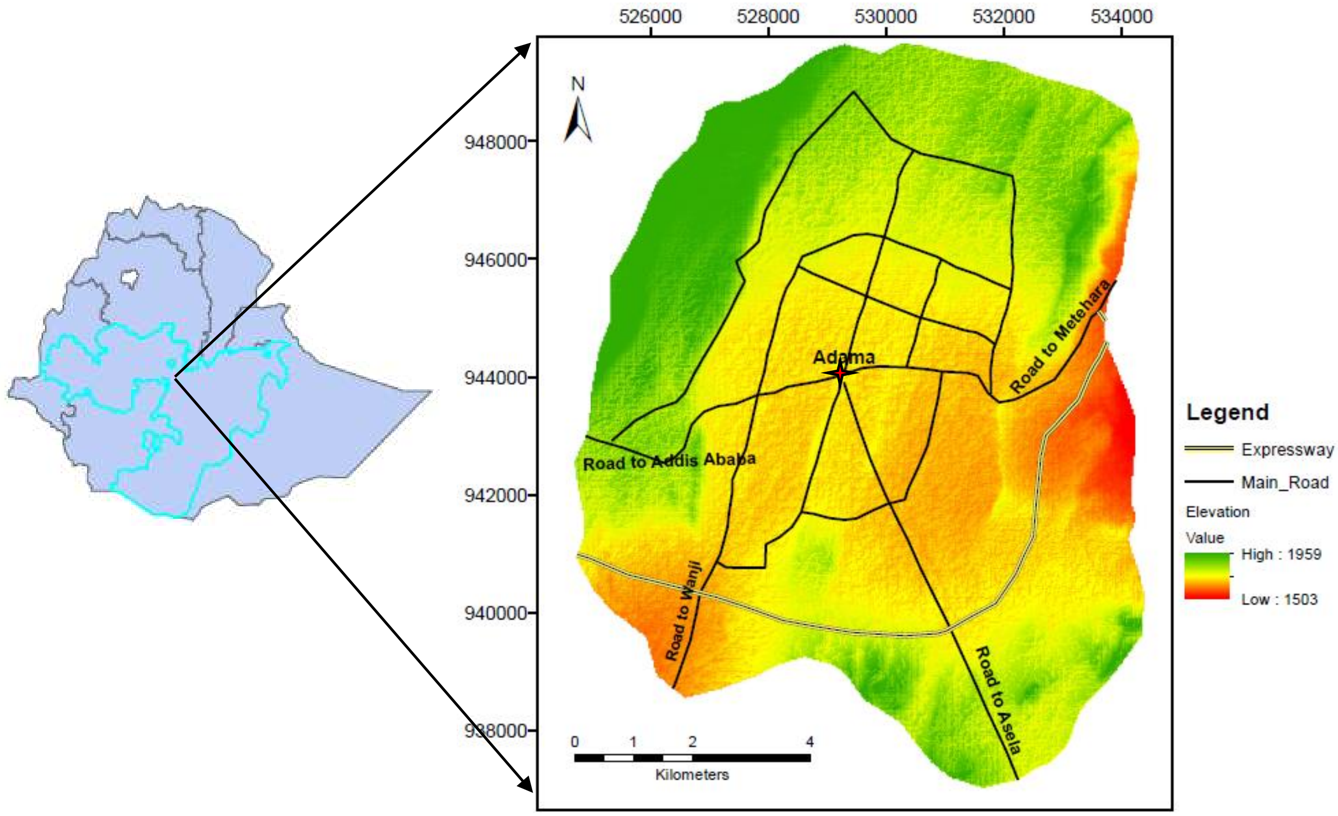

Figure 1: Location map of the study area

soil exposures in different parts of the study area for identification and mapping of lithological units. Surface mapping of geological structures was undertaken by measuring orientations (dip and dip directions) of discontinuities using Brunton compass. Similarly, conditions of discontinuity such as joint roughness, aperture, infill and weathering conditions were visually estimated on the field. In selected rock outcrops, the unconfined compressive (UCS) rock strength was estimated by using a digital Schmidt hammer (N-type). A minimum of twelve Schmidt hammer rebound value was applied perpendicularly on fresh exposed rock surface and joint wall at each rock outcrops. The test was conducted according to the standard suggested by Barton and Choubey (1977) and ISRM (1978) as follow: Schmidt hammer rebound value on fresh and un-weathered rock surface was recorded, the rebound value ordered in ascending order and then discard the first four lower values and take the average of higher value.

Representative soil samples were collected from 16 test pits (Figure 2) which were excavated up to three meter depth. Visual description and soil sampling were carried out at two different depths (1.5 m and 3 m). Due to the nature of the soil, only disturbed soil samples were taken for laboratory tests. The soil samples were kept in plastic immediately after sampling to keep their natural moisture content and then brought to laboratory.

2.4. Laboratory Tests

Laboratory testes where conducted to determine index properties of soil such as Atterberg limit (liquid limit, plastic limit and plasticity index), soil gradation and other parameters of soils (moisture content, specific gravity, free swelling, pH). Laboratory tests were done according to ASTM standards as summarized in Table 1 in Adama Science and Technology University geotechnical laboratory.

Table 1: Laboratory tests and standards

Laboratory test type	Number of samples	Standard
Moisture content	30	ASTM D-2216
Sieve analysis	30	ASTM D-421
Liquid limit (LL)	30	ASTM D 4318
Plastic limit (PL)	30	ASTM D 4318
Free swell	30	ASTM D-4546
Specific gravity (SG)	30	ASTM D-854
pH	16	ASTM D-4972

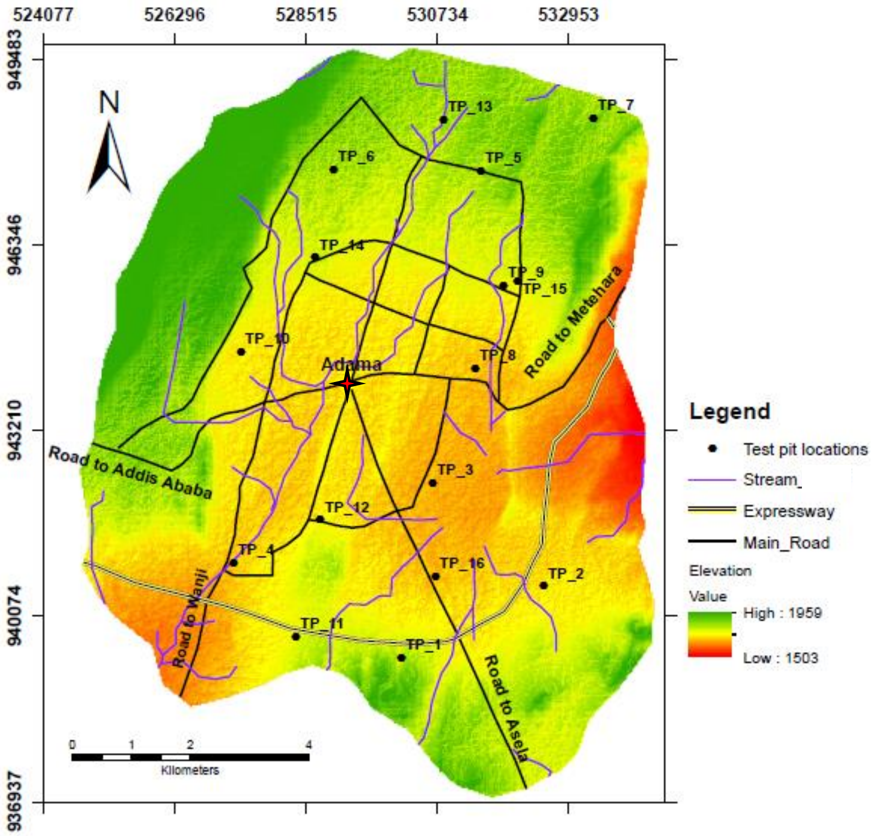

Figure 2: Test pit locations

3. Results and discussion

3.1. Geology of the study area

The study area is covered by Quaternary sediments and different types of volcanic rocks which includes, Scoria, Rhyolite, Basalt, Volcanic ashes, Pumice and Ignimbrite.

3.1.1. Quaternary deposits

The recent sediments in the study area consist of alluvial, colluvial and residual soils. The residual deposit are common along the gentle slopes on the top of the ridges. These residual soils are derived from in-situ weathering of volcanic rocks such as ignimbrite, basalt and volcanic ashes with pumice. The thicknesses of these units vary from about 0.5 to 0.8 meter, so for the current purpose it is mapped as a bedrock. Colluvial deposits are common along foot of steep slopes (east and west of the town) and are not mappable. Alluvial deposit is widespread and mainly exposed in the central, northern and southern part of the town (Figure 3). It is light gray to brown in color, loose to dense and in some places it is stratified.

3.1.2. Scoria

The scoria rock unit is exposed in south-eastern part of the study area (Figure 3) as systematically distributed scoria cone. It is highly vesicular and has porous and very rough surface. The nature of exposure of scoria cones varied from place to place where it is mainly vesicular and red in color. But in some places it is exposed as gray in color. This variation in exposure color could be related with oxidation reaction intensity of the rock with the available atmospheric oxygen.

3.1.3. Rhyolite

The rhyolite rock unit is one of the fine grained extrusive volcanic rocks. It is exposed in the south-east and south-west part of the study area as a volcanic ridge. It is fresh to slightly weathered and at some places it is interlayered with obsidian. It is felsic in composition and light in color. This rock unit is fractured by two sets of joints (NE and SE striking), which are dominantly vertical, and fault.

3.1.4. Basalt

This rock unit is another type of extrusive volcanic rock and texturally fine grained and vesicular. The fine grained basalt is exposed in the north-west part of the study area. While the vesicular basalt is exposed at south-western and central part of the study area. It is mafic in composition and light gray in color. It is slightly to medium weathered. It is fractured and jointed (both horizontally and vertically). It is exposed as steep cliff along fault scarp. Some of the vesicles of vesicular basalt are filled by secondary materials (silica or calcite).

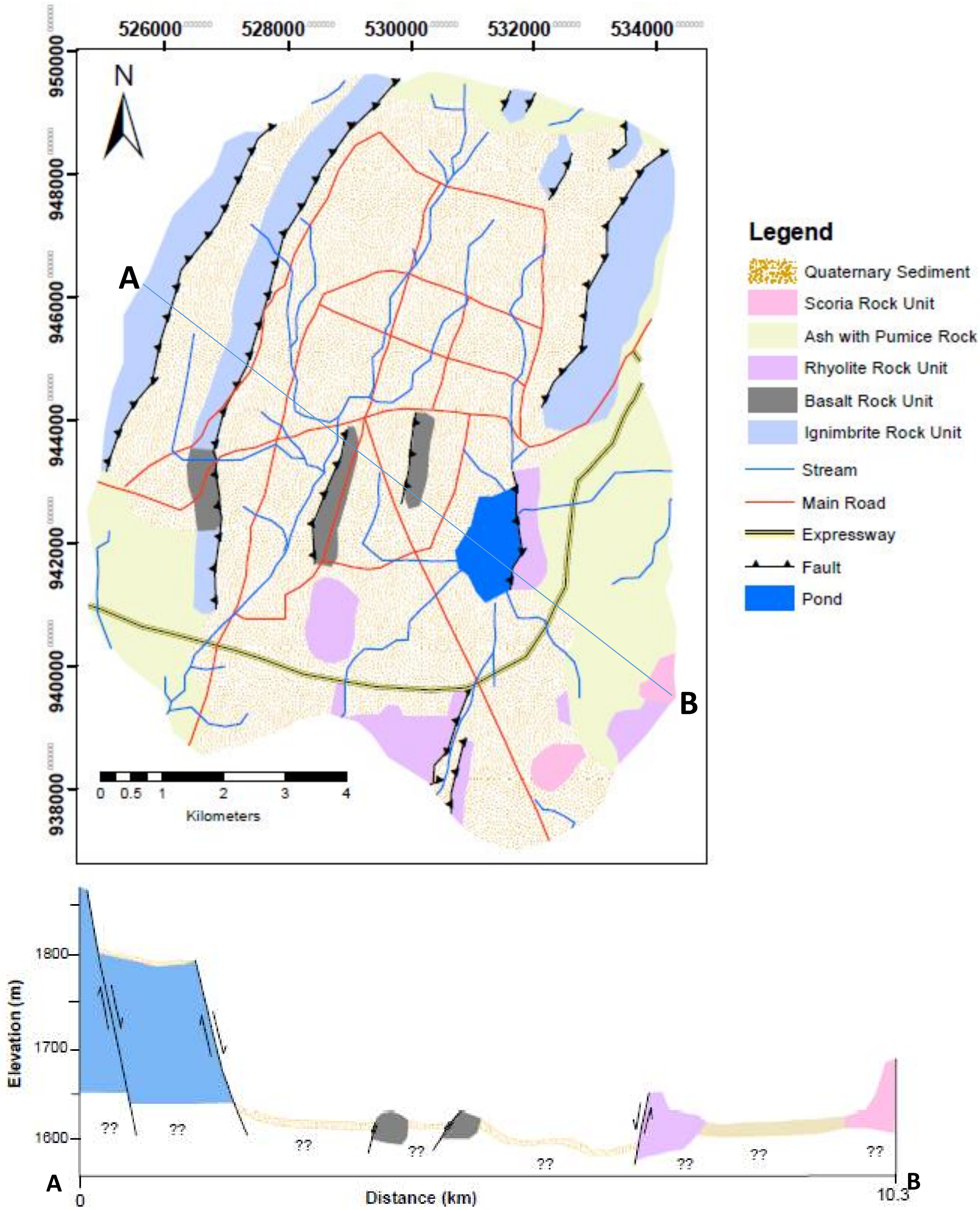

Figure 3: Geological map of the study area (The scale is reduced from 1:10000) and geologic cross-section

3.1.5. Volcanic Ash

This rock unit is a type of pyroclastic rock (pyroclastic fall) and covered large part of the study area (Figure 3). The volcanic ashes rock unit is loose, fine to coarse grained and found at eastern, northern, north-western, southern and south-western sides of the study area. It is well exposed along deep stream/river cut gullies. It is light brown in color. An alternating thin layer of pumice is common in this lithological unit. At some places it is very difficult to differentiate this deposit from alluvial soil.

3.1.6. Ignimbrite

This rock unit is found dominantly in the eastern and western part of the study area along a fault scarp (Figure 4). In some places it is interbedded with paleosol layers, indicating frequent breaks in the volcanic activity. It is characterized by stretched glassy 'fiamme', showing a pantelleritic composition and by abundant basaltic lithic fragments. It is felsic in composition and the color varies from brownish to greenish. It is jointed both horizontally and vertically.

3.2. Geological Structures

The geological structures of the study area are identified both from desk study using Landsat image, DEM and followed by later field checks. The dominant geological structures found in the study area are brittle type structures such as faults and joints.

The study area is located within most active region of the MER ((EBCS, 1995)) which is affected by a series of parallel normal fault. Specifically, the Adama town is found in Wonji Fault Belt, which is rift floor concentrated younger fault. In the field the fault is identified from physiographic features such as sharp cliffs which face towards the rift. In the west and south of the town, it forms narrow horest and graben structures. The overall orientation of the fault in the study area ranges from N-S to NNE-SSW strike (Figure 3) and mainly vertical.

The joints are the second common geological structure observed on all types of rocks found in the study area except volcanic ashes/pumice and scoria. About 117 joint orientation measurements and characterization are conducted at different part of the study area for the regularly oriented joint systems. Most of the joints are vertical (steeply dipping) and parallel to the local faults. The major joint sets observed are N to NE strike. Not only this common range of structural orientations, but also there are some exceptional NW and E-W striking joints as shown on rose diagram (Figure 4).

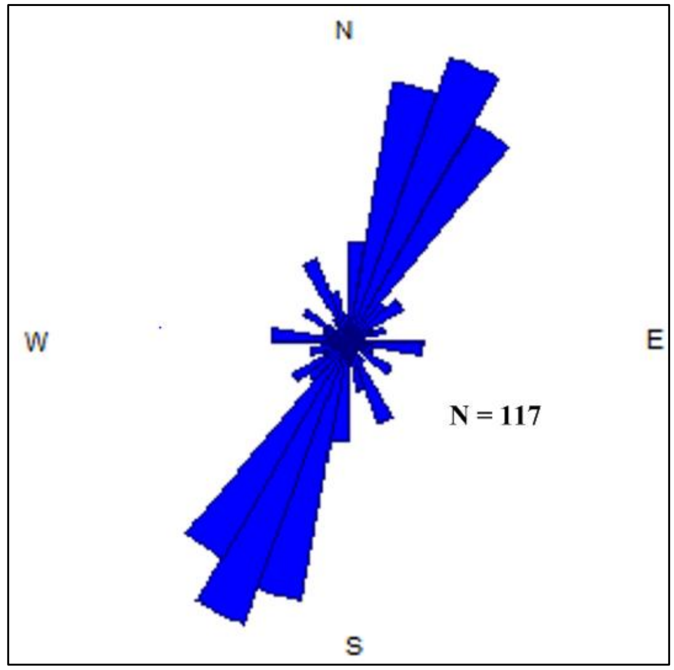

Figure 4: Rose Diagram of joints

3.3. Geomorphologic process and Geo-hazard

Erosion, volcanism and tectonic structures are the major and common geomorphologic processes identified in the study area. On the other hand, earthquake, landslide and flooding are some of the geological hazards observed or expected in the study area.

3.3.1. Erosion

Erosion is the detachment and removal of soil and rock by the action of running water, wind, flowing ice, and mass movement and the relationships between the factors which influence erosion is extremely complex (Selby, 1993). It is the function of erosivity (what factor causes erosion) and material erodibility (the susceptibility of geological material to erosion). The main causes of erosion in the study area are: the presence of steep slope (fault escarpment and volcanic ridges), seasonal intense rainfall and soft geologic materials (like volcanic ashes and alluvial soil deposit). The runoff from high land erode the soil from top of ridge and slope (sheet erosion) and spread the sediment on flat land. The other common types of erosion in the study area is gully erosion. It formed deep gorges (gully) in different part of the town along drainage line by eroding loos soil and ash deposits. It posed major problem on land use of the town by modifying the land scape (Figure 5). Construction of cheek dams and gabions can considerably reduce the erodabilty and further increase of width of gully.

Figure 5: Partial view of active gully erosional features in southern (top) and south western (bottom) part of the town

3.3.2. Volcanism and Geological Structures

The common types of landforms formed by volcanism in the study area are volcanic ridge and systematically distributed scoria cones and cliff (steep slope). The Main Ethiopia Rift (MER) which started to develop in Miocene time is part of the East African Rift System (EARS) and comprises a series of rift zones extending over a distance of about 1000 kilometers from the Afar Triple Junction (Boccaletti et al., 2000). As part of the MER, the topography of the study area is affected by the NNE-SSW running fault sets, which are responsible for the formation of the different landforms, especially for the NNE-SSW trending cliff (escarpment), horst and graben. The section is also characterized by complex extensional tectonics features manifested with associated quaternary volcanic outpourings.

3.3.3. Earthquake

An earthquake is the vibration of Earth produced by the rapid release of energy and it is the most devastating earth process. According to Bolt (1988), the important step in geological assessment of earthquake hazard of a site is the location and mapping of all geological structures and ascertainment of whether they are active or not. The study shall also include the assessment of soil condition and likelihood of landslides, subsidence, and liquefaction. Concerning the location, the study area is located in the southern extreme of the active volcano-tectonic segment of the northern MER and in zone 4 of the seismic hazard map (EBCS, 1995). The design ground acceleration for the study area (zone 4) is considered to be 0.1g for 100 year return period. The study area also dominated by NNE-SSW striking extensional related normal faulting. The geomorphological features of the fault scarps reveal the normal faults in the study area are active (Asfaw Erbelo and Hassen Shube, 2019) requiring due attention when evaluating seismicity.

Liquefaction is the loss of strength of saturated loos cohessionless soils due to pore water pressure build-up during earthquake shaking. Liquefaction commonly occur in loos coarse grained (cohessionless) soil and at depth shallower than 15 m (i.e. shallow ground water). Even though the soil of the study area is dominantly coarse grained soil (silty sand and sand), which is susceptible to liquefaction, liquefaction hazard in the study area is less probable as the groundwater table is located at a great depth (> 150 m).

3.3.4. Land slide

Slope movement can be classified based on mode and rate of movement, the shape of sliding plane, type of sliding material and other criteria (Bell, 2007). From different types of slope movement, debris slide is observed in the north-east part of the study area on the fault scarp and ridge (Figure 6) in which fragmented rock (debris) slide down slope. Intense fracturing, weathering and human interference (quarrying at the base of ridge) are causative factors.

3.3.5. Flood

Floods represent one of the most threatening types of natural hazards. However, the likelihood of flooding is more predictable than other types of geological hazards (Bell, 2007). The geomorphological characteristics (presence

Figure 6: Land (debris) slide in the North-East part of the study area

of numerous steep slope faults scarp and volcanic ridges) make the Adama town vulnerable to flooding hazard during rainy season. Flooding in Adama town is an after effect of high precipitation (which is more common during summer), clogged canals (due to improper waste disposal), and poor drainage. According to Dejene Tesema et al. (2017), 10.4% of total area of the town, which composed of different urban land uses, lies within high flood hazard zone. In addition, 32,670 residents are living in flood risk zone and 867.6 ha of land functioning for different land uses (176.1 ha industrial, 571.1 ha residential, 120.4 ha mixed built up, and 1.8 km paved road) are located in high flood risk zone.

3.4. Index properties and classification of soils

3.4.1. Natural moisture content

The natural moisture content, which is the ratio of the mass of water to the mass of dry solid, ranges from 6.34% to 25.2% (Table 2). The result implies, the soil of the study area dominantly has low water holding capacity as the coarse fraction is dominant grain size. Such soils are expected to exhibit lower volume change (swelling and shrinkage) in association with moisture content variation.

3.4.2. Grain Size Analysis

The grain size analysis is used to determine the percentage of different grain sizes contained within a soils which in turn is useful for classification and evaluation of the engineering characteristics. The percentages of different particle size for the 30 soil samples collected from 16 test pits are summarized in Table 2. The result shows that the predominant size of soil particle in the research area is coarse-grained soils, which have the gravel, sand and fine (silt and clay) fraction ranging from 3.2-32.4%, 62.8-93.1% and 2.9-26.4%, respectively.

3.4.3. Consistency Limits and swelling potential

The consistency (Atterberg) limits of the soils are summarized in Table 3. From the results, one can observe that the liquid limit, plastic limit and plasticity index of soil of the study area ranges from 26.06% – 49%, 7.5% – 40.83% and 2.22% – 23%, respectively. According to Chen (1975), as he classified swelling potential based on plasticity index, about 86.7% of the soil samples fall in low and about 15.3% soil samples fall in medium swelling potential. The larger the plasticity index, the greater will be the engineering problems associated with using the soil as an engineering material, such as foundation support for residential building and road sub grades (Bowles, 1992).

The free swell value of the soil of the study area ranges from 0% to 40% (Table 3). According to free swell classification of soils, the soil which has free swell value less than 50% is non-expansive, 50-100% is marginal and greater than 100% is expansive (BIS IS 1498: 1970(R2002)). Accordingly, the soils of the study area is considered as low in degree of expansion and expected not to pose significant damage on engineering structures.

3.4.4. pH of the soils

The knowledge of chemistry of soil, such as pH, is essential to determine the aggressiveness of the soil to the engineering structure. Dissolution reaction is higher at acidic and alkaline pH condition that can deteriorate (corrode) concrete of engineering structure. According to laboratory results (Table 3), the pH values of soils of the study area (at 1.5 m) vary from 4.48 (acidic) to 6.7 (weak acidic) indicating their corrosive nature. Further chemical test such as electrical conductivity (EC) and sulphate content shall be conducted to assess the constituents that can cause concrete to deteriorate.

3.4.5. Engineering Classification of Soil

Engineering classification of soils is the arrangement of soils into different groups and subgroups according to their engineering behavior. Its main purpose is for preliminary assessment of the engineering behaviors of soils using simple tests. Among the different classification system, Unified Soil Classification System (USCS) is used in this study as it is the popular system for use in all types of engineering problems involving soils (Arora, 2003). It considers textures and plasticity and classifies soils into two broad categories: coarse and fine grain. Accordingly, the soils of the study area were classified as: SM, SW-SM, SP-SM, SP-SC, SC, SW, and SP (Table 4). According to general engineering suitability of the soils (Arora; 2003), most of the soils of the study area characterized by negligible to low compressibility, good to excellent shear strength and good to excellent in engineering workability. The results indicate that they are not problematic soils for engineering application with lower swelling-shrinkage potential.

Table 2: Natural Moisture Content, Specific gravity and Grain Size Analysis results

Sample Designation	Depth (m)	NMC (%)	SG	% grain fraction		
				Gravel	Sand	Fines (silt & clay)
TP-1-1	1.41	18.72	2.14	10	82.4	12.6
TP-1-2	3.00	14.80	2.33	8.8	83.2	8.0
TP-2-1	1.50	6.43	2.50	10	82.6	7.4
TP-2-2	3.00	11.47	2.33	10	82.8	7.2
TP-3-1	1.50	12.75	2.50	18.6	67.4	14
TP-3-2	3.00	15.61	2.12	32.4	63.6	4.0
TP-4-1	1.30	12.07	2.33	16.6	76.8	6.6
TP-4-2	1.70	11.47	2.33	13.6	77.6	8.8
TP-5-1	1.40	11.36	2.00	28.8	62.8	8.4
TP-5-2	3.00	11.64	2.00	20.8	71.2	8.0
TP-6-1	1.20	10.35	2.33	12.2	77.2	10.6
TP-6-2	3.00	11.31	2.33	5.8	89.4	4.8
TP-7-1	1.51	16.72	2.14	12.2	77.2	10.6
TP-7-2	3.00	13.48	2.14	5.8	89.6	4.6
TP-8-1	1.30	12.46	2.54	5.8	89.6	4.6
TP-8-2	3.00	6.34	2.57	24.8	64.0	11.2
TP-9-1	1.35	11.02	2.54	20.68	66.72	12.6
TP-9-2	3.00	18.31	2.55	4.0	90.1	5.9
TP-10-1	1.48	17.1	2.58	13	77.6	9.4
TP-10-2	3.00	25.2	2.61	13.38	74.02	12.6
TP-11-1	1.50	14.82	2.50	7	70.4	22.6
TP-11-2	3.00	22.93	2.14	3.4	70.2	26.4
TP-12-1	1.45	13.36	2.35	6.2	75.2	18.6
TP-12-2	3.00	15.37	2.14	3.2	81.8	15
TP-13-1	1.50	22.32	2.14	3.2	91.2	5.6
TP-13-2	3.00	15.69	2.29	17.6	72	10.4
TP-14-1	1.42	21.03	2.29	12.4	71.8	15.8
TP-14-2	3.00	20.51	2.33	14.2	81	4.8
TP-15	3.2	-	2.37	4.0	93.1	2.9
TP-16	2.6	-	2.67	4.9	91.2	3.9

Table 3: Atterberg limits, free swelling and pH results of soils of the study area

Sample Designation	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Free Swell (%)	pH
TP-1-1	26.06	23.81	2.25	10	5.56
TP-1-2	34.44	29.83	4.61	0	
TP-2-1	28.59	23.47	5.12	10	5.2
TP-2-2	28.04	20.13	7.91	10	
TP-3-1	32.68	28.89	3.79	10	4.48
TP-3-2	27.50	22.22	5.27	20	
TP-4-1	31.39	24.24	7.15	20	6.2
TP-4-2	35.00	32.30	2.70	30	
TP-5-1	31.75	28.04	3.70	10	6.7
TP-5-2	26.46	21.48	4.97	20	
TP-6-1	31.35	27.59	3.76	10	5.62
TP-6-2	28.6	23.21	5.39	30	
TP-7-1	45.14	40.83	4.31	0	5.4
TP-7-2	28.05	22.71	5.34	5	
TP-8-1	49.05	37.82	11.23	10	6.5
TP-8-2	36.01	33.80	2.22	10	
TP-9-1	41.14	31.4	9.74	17	5.3
TP-9-2	34.84	29.04	5.8	19	
TP-10-1	34.2	25.8	8.4	28	5.8
TP-10-2	33.64	26.11	7.53	39	
TP-11-1	36.94	27.42	9.51	18.2	6
TP-11-2	43.79	29.81	13.98	8.3	
TP-12-1	43.98	32.78	11.2	22.7	5.5
TP-12-2	38.41	15.57	22.84	25	
TP-13-1	30.37	7.5	22.87	16.7	6.5
TP-13-2	37.24	29.41	7.83	9.1	
TP-14-1	41.14	31.4	9.74	8.3	5.5
TP-14-2	42.25	29.41	12.83	9	
TP-15	31.35	27.59	3.76		6
TP-16	30.15	26.49	3.66	16	6.4

3.5. Engineering Geological and Geotechnical Characterization of Rocks

The rocks of the study area were classified according to international society of rock mechanics (ISRM, 1981). Based on the strength (unconfined compressive strength) of intact rock; rock of the study area are classified into three major engineering geological subunits: Low Strength rock mass units, Medium Strength rock mass units and High Strength rock mass units. In addition, visual description and estimation of their weathering grade and discontinuity surface conditions were conducted. During the time of investigation, the groundwater conditions of all the joints were dry for all outcrops.

3.5.1. Low Strength Rock Mass Unit

The strength of this unit is very low to measure using Schmidt hammer. Even though it is not the weathering product, similar to engineering soil it can be excavated using simple hand tools. It includes scoria and volcanic ashes.

3.5.1.1. Scoria

This rock unit covers limited area in the south-eastern part of the study area (Figure 7) in the form of volcanic cone. Its color varies from dark to red color depending on the degree of weathering. Texturally it is vesicular/highly porous and fragmented due to explosive mode of eruption. The fragmented grains are not cemented together. The individual grains are characterized by rough surface and sub rounded.

Table 4: Classifications of Soils of the study area based on unified soil classification (USCS)

Sample Designation	Percent of particle size			LL (%)	PI (%)	Group symbol	Group name
	Gravel	Sand	Fine				
TP-1-1	5	82.4	12.6	26.06	2.25	SM	Silty Sand
TP-1-2	8.8	83.2	8.0	34.44	4.61	SP-SM	Poorly graded sand with silt
TP-2-1	10	82.6	7.4	28.59	5.12	SW-SM	Well graded sand with silt
TP-2-2	10	82.8	7.2	28.04	7.91	SP-SC	Poorly graded sand with clay
TP-3-1	18.6	67.4	14	32.68	3.79	SM	Silty Sand with gravel
TP-3-2	32.4	63.6	4.0	27.5	5.27	SP	Poorly graded sand with gravel
TP-4-1	16.6	76.8	6.6	31.39	7.15	SP-SM	Poorly graded sand with silt and gravel
TP-4-2	13.6	77.6	8.8	35.00	2.70	SW-SM	Well graded sand with silt
TP-5-1	28.8	62.8	8.4	31.75	3.70	SP-SM	Poorly graded sand with silt and gravel
TP-5-2	20.8	71.2	8.0	26.46	4.97	SW-SC	Well graded sand with clay and gravel
TP-6-1	12.2	77.2	10.6	31.35	3.76	SP-SM	Poorly graded sand with silt
TP-6-2	5.8	89.4	4.8	28.6	5.39	SW	Well graded sand
TP-7-1	12.2	77.2	10.6	45.14	4.31	SP-SM	Poorly graded sand with silt
TP-7-2	5.8	89.6	4.6	28.05	5.34	SW	Well graded sand
TP-8-1	5.8	81.6	12.6	49.05	11.23	SM	Silty sand
TP-8-2	22.8	64.0	13.2	36.01	2.22	SM	Silty Sand with gravel
TP-9-1	20.68	66.72	12.6	41.14	9.74	SM	Silty sand with gravel
TP-9-2	4.0	90.1	5.9	34.84	5.8	SP-SM	Poorly graded sand with silt
TP-10-1	13	77.6	9.4	34.2	8.4	SP-SM	Poorly graded sand with silt
TP-10-2	13.38	74.02	12.6	33.64	7.53	SM	Silty sand
TP-11-1	7	70.4	22.6	42.25	12.83	SM	Silty sand
TP-11-2	3.4	70.2	26.4	43.79	13.97	SM	Silty sand
TP-12-1	6.2	75.2	18.6	37.24	7.83	SM	Silty sand
TP-12-2	3.2	81.8	15	30.37	22.84	SC	Clayey sand
TP-13-1	3.2	91.2	5.6	38.41	22.87	SP-SC	Poorly graded sand with clay
TP-13-2	17.6	72	10.4	43.98	11.2	SP-SM	Poorly graded sand with silt and gravel
TP-14-1	12.4	71.8	15.8	41.14	9.74	SM	Silty sand
TP-14-2	14.2	81	4.8	36.94	9.51	SW	Well graded sand
TP-15	4.0	93.1	2.9	-	-	SP	Poorly graded sand
TP-16	4.9	91.2	3.9	30.15	3.66	SP	Poorly graded sand

3.5.1.2. Volcanic ash

This rock unit covered large part of the study area (Figure 7) and at some places it contains layers of pumice. It is fine to coarse grained in texture and brownish in color. It is loose and unconsolidated deposit, as a result it is easily eroded. As stated in Bell (2007), ashes are often highly permeable and frequently prone to sliding.

3.5.2. Medium Strength Rock Mass Unit

This engineering geological subunits include slight to moderately weathered ignimbrite, basalt and rhyolite.

3.5.2.1. Moderately Weathered Ignimbrite

Medium strength ignimbrite rock unit is found in the northern, western, south-western and north-western part of the study area (Figure 7) along the fault scarp. It is light brown and greenish in color. Texturally it is porphyritic in texture (i.e. clasts and ground mass) and moderately weathered. The strength of the rock material ranges from 25.7 to 58 MPa. Three sets of joints (strike NW, N-S and NE) are dominant which are steeply dipping and medium to widely spaced (21 cm to 2 m). The joint surface is both rough and smooth and planar. The aperture is variable and ranges from open to very wide (6 mm to 3 cm). The aperture is partially filled with fine materials and rock fragments.

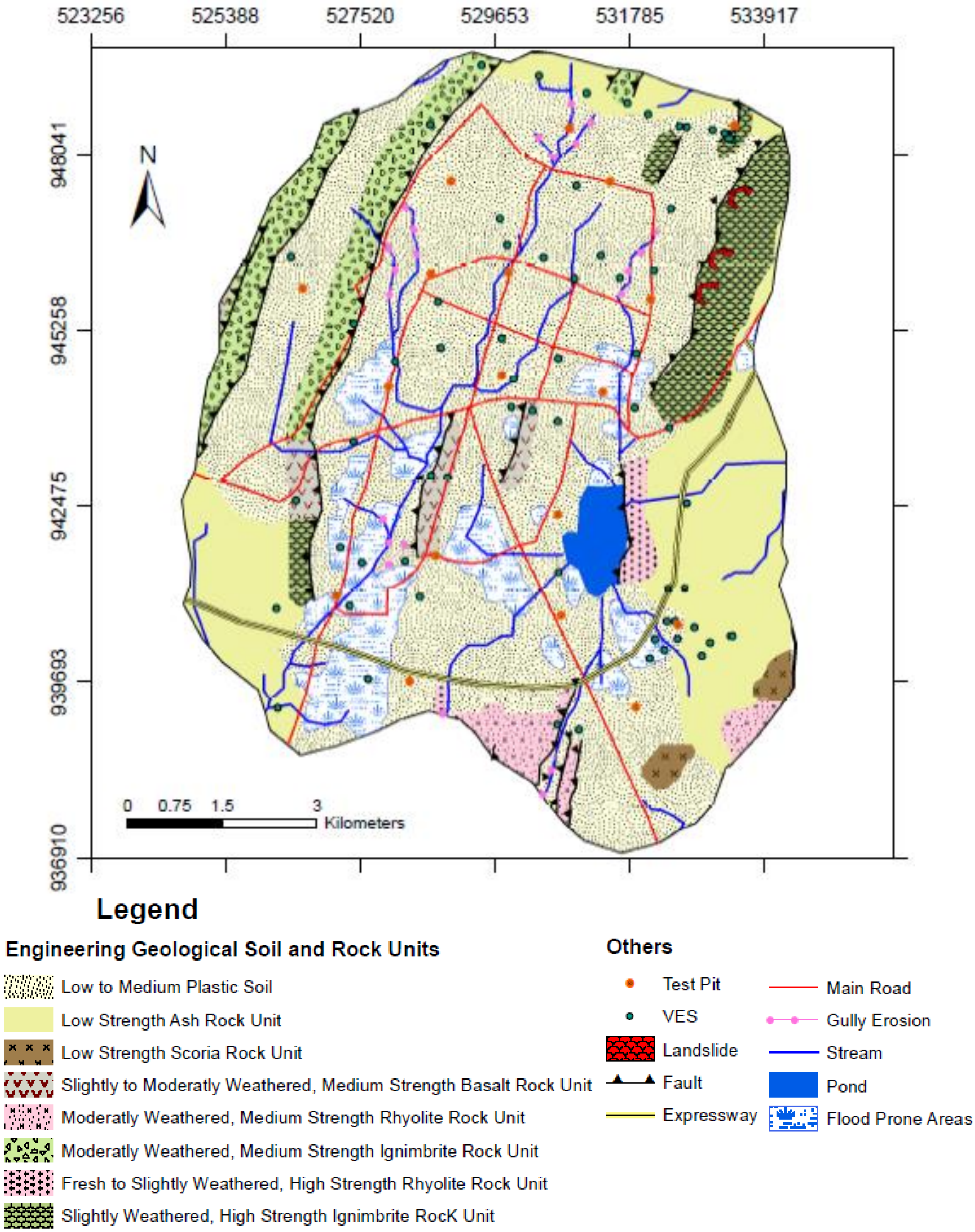

Figure 7: Multipurpose large scale engineering geological map of the study area (The scale reduced from 1:10000)

3.5.2.2. Moderately Weathered Rhyolite

Medium strength rhyolite rock subunit is found at the south-eastern part of the town around Adama industrial park and south-west (boku ridge) (Figure 7). It is light brown in color. It is fine grained and moderately weathered. The strength of the rock material varies between 36 to 54.2 MPa. Two sets of joints (NE and SE) are dominant which are vertical. The joint is medium to widely spaced (20 cm to 82 cm). The joint surface is rough and planar. The aperture is open and partially filled with rock fragments.

3.5.2.3. Slightly to Moderately Weathered Basalt

The basalt rock unit covers limited area in the western and central part of the town (Figure 7). It is light gray to light dark in color, fine grained, vesicular and slightly to moderately weathered. The strength of rock material varies from 33 to 58 MPa. Three sets of joints (E-W, SW and NE) are dominant. Most of the joints are vertical. The joints are medium to widely spaced (20.5 cm to 1.34 m). The aperture varies from tight to very wide (0.2 mm to 2.1 cm). The joint wall or surface is planar and rough. Some joints in fine grained basalt are partially and completely filled with fine soil material. The vesicles of vesicular basalt are filled by secondary materials (quartz/silica).

3.5.3. High Strength Rock Mass Unit

This engineering geological subunit includes fresh to slightly weathered high strength ignimbrite and rhyolite.

3.5.3.1. Slightly Weathered Ignimbrite

High strength ignimbrite rock subunit is found on the faults that bound the town at the east, northeast and southwest direction (Figure 7) and it forms steep cliff. The strength of rock material varies from 62.5 to 80.6 MPa. The joints are medium to widely spaced (22 cm to 1.53 m). Two sets of joints; (striking NW and SE) are dominant. The joint surface is both smooth and rough and planar. The aperture varies from partly open to moderately wide (0.5 mm to 8 mm). The aperture is open and partially filled with fine material.

3.5.3.2. Fresh to Slightly Weathered Rhyolite

High strength rhyolite rock subunit is mainly found at the south-west and south-east part of the town (Figure 7). It is light gray in color. It is fine-grained and fresh to slightly weathered. The strength of the rock material varies between 64 to 79 MPa. Three sets of joints (striking NW, NE and SE) are dominant which are vertical. The joint is medium to widely spaced (22 cm to 86 cm). The joint surfaces are rough and planar. The aperture is variable and ranges from open to very wide. Some joints are filled with fine materials and the other is partly filled with rock fragments.

4. Conclusions and recommendations

The soils of the study area are dominantly coarse grain with the content of gravel, sand and fine fractions range from 3.2% to 22.8%, 62.8% to 93.1% and 2.9% to 26.4%, respectively. The natural moisture content varies from 6.34% to 25.2%, indicating the water holding capacity of the soils is very low. The liquid limits, plastic limit and plasticity index in percentage range from 26.06% – 49.05%, 7.5% – 40.83%, 2.22% – 22.84%, respectively. According to range of plasticity index, most of the soils (87%) of the study area are characterized as low plastic and low compressible soil. The potential expansion behavior or swelling nature of the soils is also found to be low with free swell value ranges from 0 to 40%. The soils are dominantly sand and silty sand engineering soil type and characterized by good to excellent engineering workability and don't pose significant damage on engineering structures. However, the acidic nature of the soils can deteriorate (corrode) concrete of engineering structure. The main lithological rock units exposed in the study area are ignimbrite, rhyolite, basalt, scoria and volcanic ashes with pumice. These lithological rock units are classified into three major engineering geological subunits: rocks with low mass strength (which include volcanic ashes with pumice and scoria), rocks with medium mass strength (medium strength ignimbrite, basalt and rhyolite) and rocks with high mass strength (high strength ignimbrite and rhyolite). The study area is exposed to multiple geo-hazards such as flooding, land slide, gully erosion and earthquake.

The weathered rock fragments accumulation along the slope of the fault planes especially in the eastern part of the town can result landslide by earthquake occurrence. From the safety point of view, it is, therefore, recommended to avoid settlement and construction in such areas. Construction of cheek dams and gabions are recommended to reduce gulley erosion. The design of any engineering structure in the town shall meet all necessary seismic resistant design parameters as the town is located in seismically active zone.

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