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Experimental Investigation and Mapping of Index and Shear Behavior of Soils a Case in Gimbichu Town, Ethiopia

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Abstract

Objectives: To study experimental investigation on index and engineering properties of fine-grained soils by conducting laboratory tests and to prepare a soil spatial map using ArcGIS software of Gimbichu town, Ethiopia. **Methods:** Hence, ten test pits were selected according to the variation of the soil and the distribution of the dwellings. The soil samples were collected by direct manual excavated to 1.5m and 3.0m depth on which both laboratory and field tests were conducted for index and shear properties. **Findings:** Index properties revealed that soils in the study area are mostly silt soils with high plasticity and partly low plasticity. It is indicated that the soils are medium to very stiff with unconfined compressive strength of 53.70 to 216.40kPa and undrained shear strength of 26.67 to 108.20 kPa. Permeability and consolidation investigation results presented soils in the town are silt group. The spatial soil property map is created for experimentally determined results at 1.50m and 3.0m depths using ArcGIS software to retain soil properties in order to earn time and cost of the investigation in the field and laboratory. These maps are required for recognizing, identifying, and classification of soil categories within delineated parts of the current study town. **Novelty:** Investigation and ArcGIS spatial mapping for soil properties are essential for future boosting of the design and construction buildings of this town that was not applied before in investigation lagged areas like Gimbichu town.

Keywords: ArcGIS Mapping; Experimental study; Index properties; Shear parameters; Soil class

1 Introduction

Investigations of soils are so important that all infrastructure constructions use naturally occurring soil materials as the foundation as well as construction material [1]. Unlike man-made materials, the soil properties are highly variable and a function of the complex natural processes like geological, natural and human activities, moisture alteration. This is hence soils are commonly heterogeneous, nonlinear material, and typically anisotropic instead of being isotropic. Consequence, construction activities and structures are facing difficulties associated with soil materials variability, whose properties are often unknown without investigation[2–4]. Fine-grained soils are usual in the practice of civil engineering activities that their engineering behaviors are highly affected by adverse environmental conditions like moisture variation than coarse-grained soils. Hence, they need better experience to use for engineering purposes. This is why the study and understanding of their characteristics have reliably been the effort of care in geotechnical engineering activities and practice[5–7]. The index and shear properties are essential areas of geotechnical engineering studies that are needed to identify, characterize, design, and construct on soil and soil material[8]. Those properties which help to assess the engineering behaviors of soil and which assist in determining its classification accurately are termed Index Properties[9]. The shear strength determines the stability of slopes, the bearing capacity of soils, and the earth pressure on retaining structures[10].

Gimbichu is capital of Soro Woreda, which is one of the woredas in Hadiya Zone, the Southern Nations, Nationalities, and Peoples' Region (SNNPR) of Ethiopia as Figure 1. This town has future development plan so that the expansion of numerous building infrastructure, like road and building projects. Currently, also there are structures under construction having uncertainty in foundation soil due to no enough investigation and understanding for the foundation material. This needs focus to change such ways of practice for future service of structures and development of the town[11]. Hence, the study mainly focused on an experimental investigation and mapping of the fine-grained soil in this town. This is to present experimental results of soil on map to have spatial soil behavior information system of the town. The inventory and interpretations of soil properties from map is easy mechanism by which map itself can describe index and engineering behavioral information produced from experimental study for the study area[12,13].

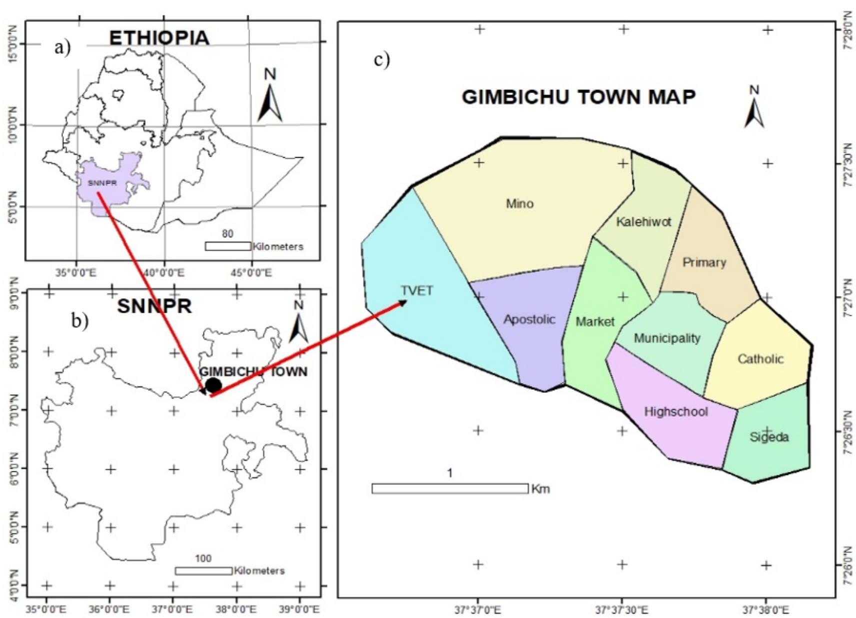

Fig 1. Map of a) Ethiopia, b) SNNPR and c) Gimbichu town

2 Methodology

Soils are variable from place to place, time to time with in horizontal and vertical positions. Thus, the investigating methods are also difficult and time-consuming for geotechnical engineering activities. Hence, soil investigation results were recorded as simple mathematical formulas to determine soil parameters through easy tests like index properties and as map form, which are easily accessed soil properties without conducting detailed investigation[14]. Study on the Gimbichu town, visual site investigation, and walk-over survey before selecting and collecting samples was done to identify and inspect general about the soil in the town. Information from resident and municipality were collected in order to consider the actual problem history, soil types in the town and to have soil sample that is representative for the town. Accordingly, ten sampling areas were selected from different locations of the town that could represent the whole town area.

Test pits were excavated to a maximum depth of three meters and soil samples, both undisturbed and disturbed soil, were collected at 1.5m and 3.0m depths from each pit for both field and laboratory investigations and field tests were conducted for index and shear properties [15]. Twenty samples (two from each ten test pits) were transported to the laboratory for experimental investigations. Field bulk and dry density samples were taken parallel to other test samples from the field by core cutter method to have the density of the soils [16]. Those collected samples were air-dried and prepared for different test tests prior to the testing. Various physical and engineering properties like grain size distribution, Atterberg limits, specific gravity, free swell, shear strength, permeability, and consolidation test were performed in laboratory that all the tests were conducted according to the American Society for Testing and Materials standards [17].

Soil mapping by ArcGIS is useful to demonstrate and present the information about soil behaviors that can be needed to know the suitability for various construction activities. These maps are required to recognize, identity, and classification of soil categories within delineated parts of the area. A soil map is a wide-ranging functionality package used by geotechnical engineers in work concerns to retain soil properties in order to earn time and cost of the investigation in the field and laboratory. Accordingly, experimental data were recorded and analyzed for required objectives that to determine and to present fine-grained soil behaviors of the town. Laboratory results were mapped to have spatial information on the foundation material/soil using ArcGIS software [18,19].

3 Results and Discussion

The selected test pit locations are presented in Table 1 to identify their specific location on the town with local positionings.

Table 1. Global coordinates of the sampling locations

Test pit	Local position	Northing (DMS)	Easting (DMS)
TP-1	Apostolic church	$07^{0}26'54.71''$	$37^{0}37'09.18''$
TP-2	Catholic church	$07^{0}26'48.73''$	$37^{0}37'58.13''$
TP-3	High school	$07^{0}26'44.8''$	$37^{0}37'29.18''$
TP-4	Kalehiwot church	$07^{0}27'14.81''$	$37^{0}37'36.82''$
TP-5	Market	$07^{0}26'57.79''$	$37^{0}37'24.89''$
TP-6	Mino school	$07^{0}27'10.57''$	$37^{0}37'11.14''$
TP-7	Municipality	$07^{0}26'57.45''$	$37^{0}37'39''$
TP-8	Primary school	$07^{0}27'08.88''$	$37^{0}37'42.4''$
TP-9	Sigeda school	$07^{0}26'32.50''$	$37^{0}37'59.02''$
TP-10	TVET college	$07^{0}27'01.82''$	$37^{0}36'43.44''$

3.1 Soil Index Properties

According to experimental investigation on the index properties, the natural moisture content varies from 17.36% to 25.38%, that decreases with increase in sample depth that the soil properties tend from clayey to silty sand behavior.

The bulk density and dry density results of the soils described that varies from 1.61g/cc to 1.83g/cc and 1.23g/cc to 1.37g/cc respectively, which is presented in Figure 2.

It was revealed that the most natural soils, which are sandy and gravelly in nature, may have water contents up to about15 to 20%. In natural fine-grained (silt or clayey) soils, water contents up to about 50 to 80% canbe found. The bulk density of the soil was done on the site by core- cutter method. The field results show that the bulk unit weight ranges from 16.18kN/m3 to 17.95kN/m3 [20].

As revealed in Figure 3 the results obtained from the grain size analyses indicated that the dominant proportion of soil particle in the research area was clay. The percentage of soil passed through sieve 0.075mm was ranging from 58.6% to 96.6%.

The Atterberg Limits test results give the soil plasticity ranges from low plasticity to high plasticity.From the study results the shrinkage limit ranges from 5.8 to 19.29% this shows the soil in the study area have slightly greater values of shrinkage limits for the silty clays and very small amount of shrinkage values for silty sand soils [21,22].

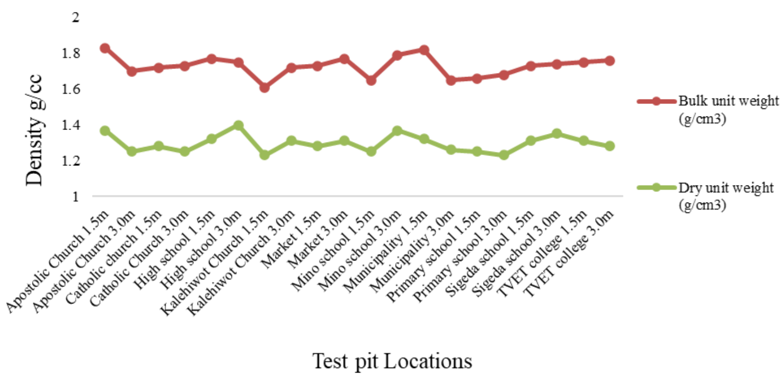

Fig 2. Bulk and dry densityof the soils

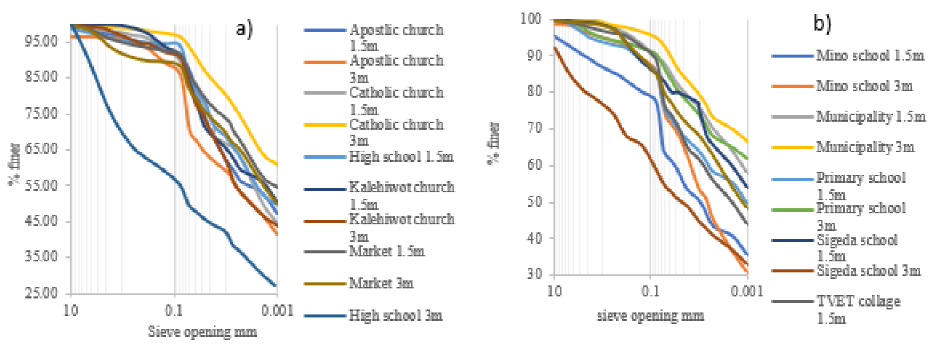

Fig 3. Grain size distribution curve a) test pits 1to 5 and b) test pits 6 to 10

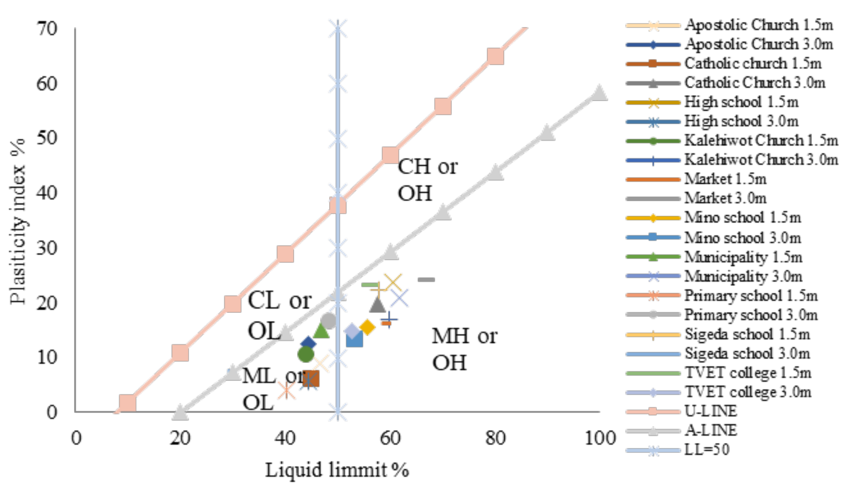

Fig 4. Plasticity chart

Accordingly, Soils of the study area, index properties revealed that soils are classified as per the Unified Soil Classification system that soils are dominantly silty soils with high plasticity (MH) and partly low plasticity (ML), except Sigeda school location at 3m depth, which was low plastic clay (CL) as described in Figure 4.

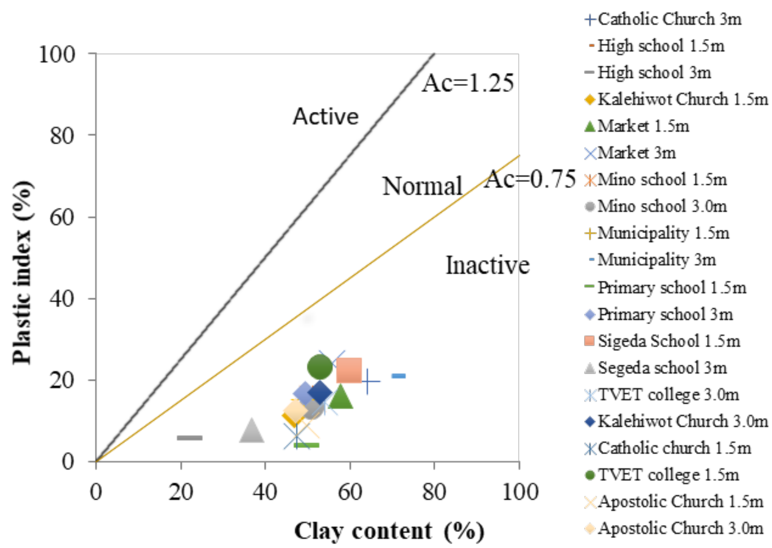

Fig 5. Combined standard compaction testgraph of soil samples

From the test results almost, all of the soil samples have the value of activity number less than 0.75 which are inactive with that of free swelling test for this specific area ranges from 10% to 60% (Figure 5). Those soils having a free swell less than 50% are considered as low in degree of expansion.

3.2 Shear Strength results

The test results show that the maximum dry density ranges from 1.29 to1.61 g/cm^3 and the OMC ranges from 20 to 40 % (Figure 6) (23–25).

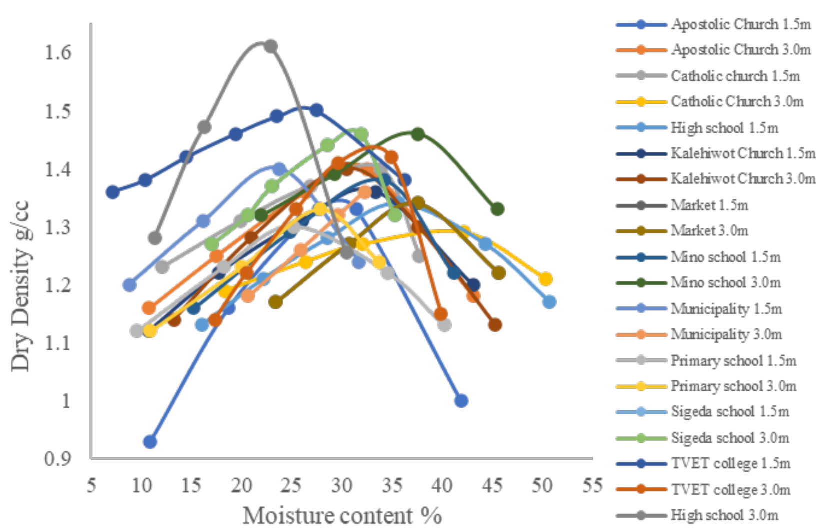

Fig 6. Combined standard compaction test graph of soil samples

The unconfined compressive strength test result and liquidity index indicates the soil consistency of the study area ranges from medium to very stiff that unconfined compressive strength of 53.70 to 216.40kN/m^2 with corresponding shear strength of 26.67 to 108.20kN/m^2 were indicated in Figures 7 and 8.

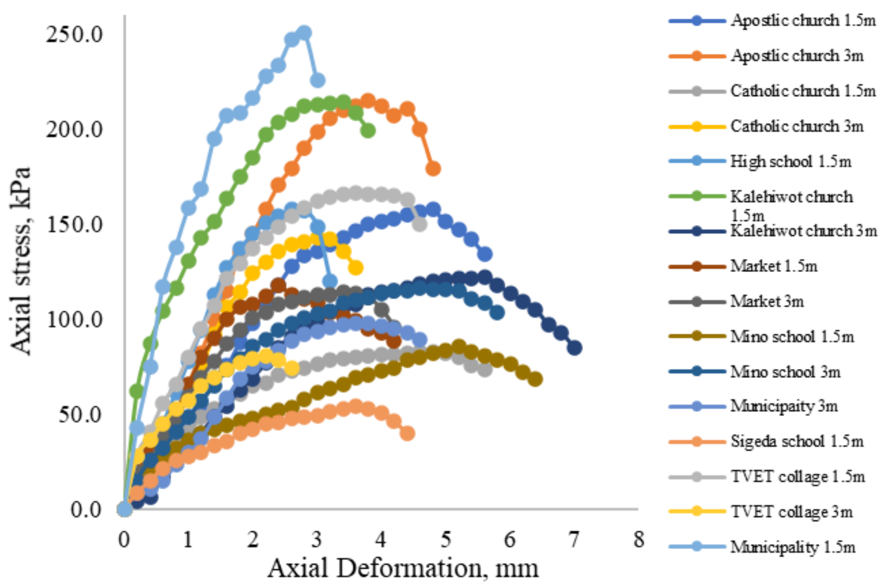

Fig 7. Unconfinedcompression shear strength test graph of soils

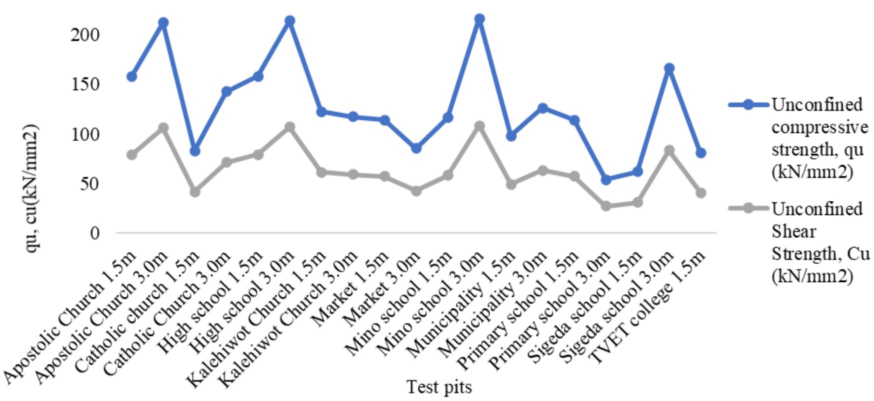

Fig 8. Compressive and shear strength of the Town

Test pit located at high school at 3.0m depth is silty sand soils, that the shear strength parameters (c and ø) determined by the direct shear test method are angle of internal friction (ø) and Cohesion (C) 30.10^0 and 8.0 kPa respectively[26].

3.3 Mapping of index and shear properties

As revealed, the study area soil samples were collected at depth of 1.50m to 3.0m, tested, analyzed and interpreted on ten test pits from Gimbichu town. Having these results, the soil index and shear properties maps were prepared by assembling the laboratory analysis and field observation using ArcGIS software[27].

Having index properties of soils in Gimbichu town, soil classes has been mapped for all ten locations at 1.5m and 3.0m depth as indicated in Figure 9a and b. It was described that this town is dominantly silt soil. Advantage of using this way is to represent

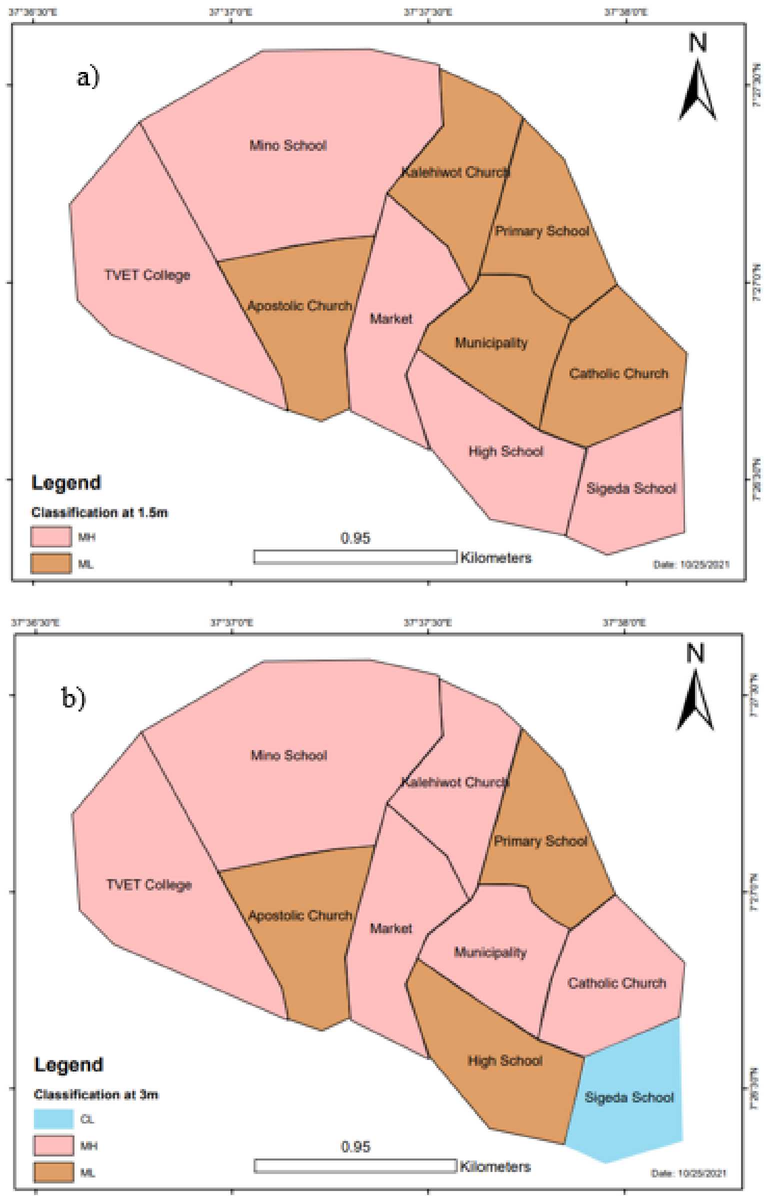

Fig 9. Soil classification/index properties map at a)1.5m and b) 3.0m depth

the parameters in a GIS platform for quick and fast integration of the results with respect to the test pits taken. The technological interpretation has added advantage for the site engineers to study the detail analysis and the mode of classification of the soil at par.

In additionally, soil shear strength of the area has also been incorporated for a detailed and accurate investigation in ArcGIS platform in Figure 10 a and b. With a single click of mouse on the pit results of the test pit sample can be retrieved which can further be studied for the characteristics of the soil collected from the respective pit. The results found from the GIS mapping provided a detail classification of the sample and its respective suitability for the soils for engineering use.

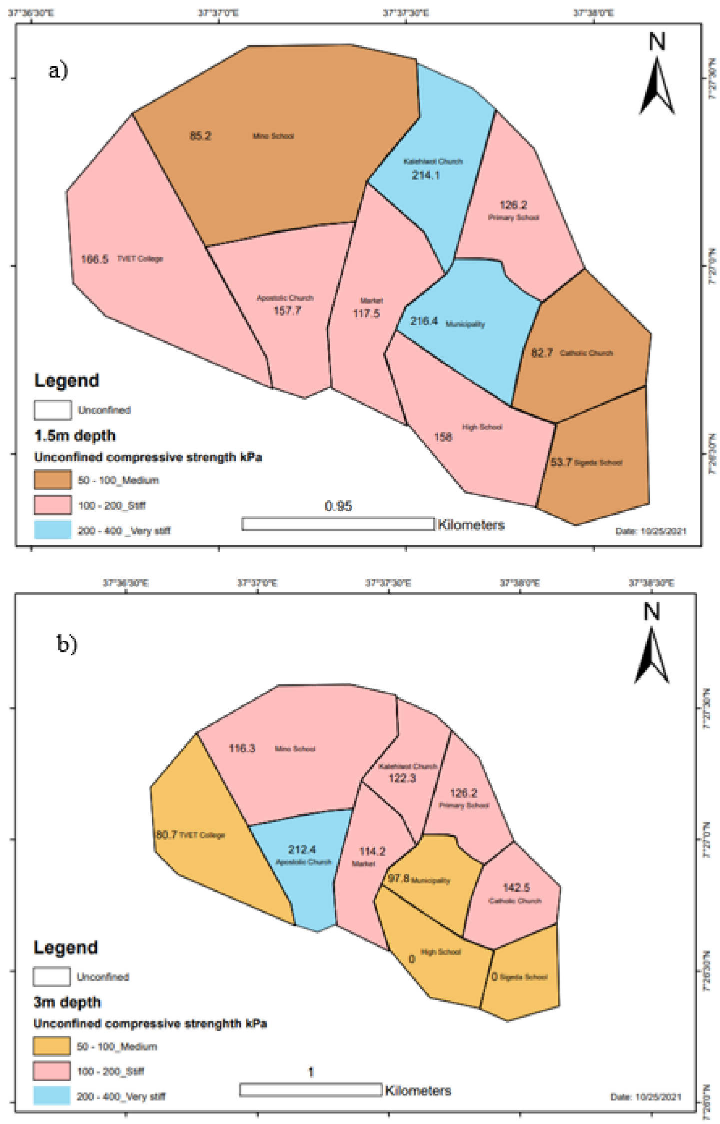

Fig 10. Soil shear property map at a) 1.5m and b) 3.0m depth

4 Conclusions

According to the experimental investigation soil found in Gimbichu town that the test results described the moisture content decrease with sample depth for the soil properties tend from more silt to silty sand mixture from upper to lower depths. Index properties revealed that soils are totally silt soils with high plasticity (55% of MH) and partly low plasticity (35% of ML) and 10% low plastic clay. Soils found in this town are totally fine-grained so-called silt category. The maximum dry density ranges from 1.29 to1.61 g/cc and the optimum moisture content ranges from 20 to 40 % by standard compaction effort. The unconfined compressive strength test results indicated the soils are medium to very stiff with ranging from 53.70 to 216.40kPa and corresponding shear strength of 26.67 to 108.20 kPa that can be used for support structures depending on type of footing and structure to be constructed in this town. Increasing depth from 1.5m to 3.0m, soils shear strength was increased slightly. The soils index and engineering properties were mapped at 1.50m and 3.0m depths by ArcGIS software for the town are required for foundation soil information to design and construct different buildings. It is hence recommended to use experimental investigation results and a spatial map of soils to identify and design the foundation specifically for current town.

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