Vol. 15(1), pp. 10-21, January-March, 2020
DOI: 10.5897/IJPS2020.4865
Article Number: 01F7D2C62950
ISSN: 1992-1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

Estimation of swelling potential of Enugu Shale using cost effective methods

Chidiebere Nnamani[1*] and Ogbonnaya Igwe[2]

[1]Department of Geology and Mining, Faculty of Applied Natural Science, Enugu State University of Science and Technology, Enugu State, Nigeria.
[2]Department of Geology Faculty of Physical Science, University of Nigeria, Nsukka, Enugu State, Nigeria.

Received 4 January, 2020; Accepted 21 January, 2020

The behavior of swelling soils is mainly governed by its mineralogical composition as well as its environmental factors and stress history. Enugu Shale is one of these shales that assessment of its soil swelling potential cannot only be based on its mineralogical composition alone. The identification of its clay mineral types is basic to understand the roles of other factors of swelling in the soils. The results of particle size distribution indicated that Enugu Shale is dominated by fine-grains with average mean of 69.65, 23.68 sands and 6.67% gravels. While the Atterberg's limit values are moderate to high, with liquid limit ranging from 22-66%, plastic limit 0-39% and plasticity index 0-39%, abundance of major elemental oxides show that SiO_2 (50.4-88.1%), Al_2O_3 (6.29-28.23%) and Fe_2O_3 (0.98-12.25%) constitute over 90% of the bulk chemical compositions of the studied area. The studied area is dominated by A-7 soils and low plasticity clay soils according to AASHTO and USCS classification system. The results of free swell ratio range from 1.02-1.45 which indicates that studied area is dominated by mixture of swelling and non-swelling clay minerals. The Van der Merwe's charts shows low to medium swelling potential. These results show that the study area is dominated by low to medium swelling soils which need to be modified and upgraded before it can be used as subgrade material.

Key words: Swelling potential, Enugu Shale, free swelling ratio, correlation and Van der Merwe's chart.

INTRODUCTION

The studies of expansive soils have in recent time attracted a great deal of attention from engineering construction practitioners. For example, Enugu Shale in southern Nigeria is mostly underlain by soft sediments which are prone to expansion in the presence of abundant precipitation in the wet season in addition to clay mineralogy of the soils and other environmental factors prevalent at a time in the history of the soils. The swelling and shrinkage phenomenon associated with the soils of this region can be detrimental to engineering projects such as pavement, foundation, slope stability etc. Shale exhibits a wide spectrum of geotechnical characteristics especially as the moisture content increases and has often been a cause for concern on environmental geotechnical issues (Aghamelu et al, 2011). Enugu Shale is one of these shales that significantly show changes in volume on addition of moisture. Severally studies have identified the characteristics of the Shale (Okagbue and Aghamelu, 2010; Ekeocha, 2015; Oyediran and Fadamoro, 2015;

*Corresponding author. E-mail: henry.nnamani@esut.edu.ng

Figure 1. Evidence of failure of engineering projects in the studied area.

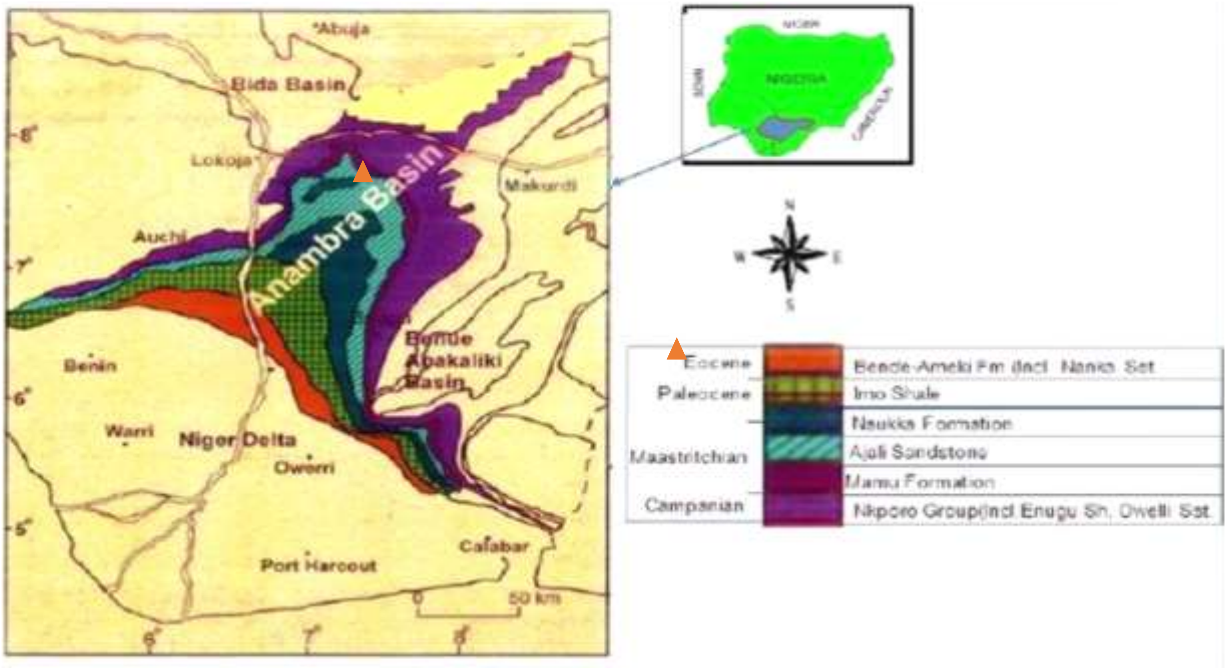


Figure 2. Geologic map of Anambra Basin showing Enugu Shale.
Source: Nwajide and Reijers (1999).

Tijani, 2012).

The geology, climatic conditions, environmental factors and drainage conditions provide a natural setting for the occurrence of swelling/shrinkage phenomena. Structural damage caused by swelling phenomena is evident in the soils of Enugu Shale in the Enugu metropolis (Figure 1).

Evaluation of swelling characteristics of the soils using empirical estimation will be of much help to the geotechnical engineers for ease, quick and affordable understanding of the problematic soils of the metropolis. The method adopted in the work of Sridharan and Prakash (2000) was employed to characterize the mineralogy characteristics of the soil using free swelling ratio in comparison with the existing knowledge.

Geology

Enugu Shale overlays the Agbani Sandstone/Awgu Shale. It is a lateral equivalent of Nkporo/Owelli formation and one of the oldest deposit of Anambra Basin (Nwajide, 1990). Enugu Shale consists of fissile, grey shale with extra formational clast capped on top by Ironstone with presence of pyrite.

The shale is associated with extensive synsedimetary deformation structures (Nwajide and Reigers, 1999) and lies in the eastern part of Anambra Basin (Figure 2). Enugu Shale is well exposed along Enugu-Onitsha Express Way by New-Market flyover and along Enugu-Port Harcourt Express Way by Ugwuaji flyover.

The highly weathered Enugu Shale consists of dirty brown lateritic regolith that is porous and varies significantly up to a maximum depth of 20 m, depending on the topography and drainage conditions (Ekeocha, 2015).

Climate, physiography and drainage

The Enugu metropolis is bounded by latitudes 6°22’ N and 6°30’ N; and longitudes 7°27’ E and 7°47 ’E; and lies within the rainforest belt of Nigeria. The two main seasons that exist in Nigeria are the dry season that runs through the months of October to March, and the rainy season that begins in the late March and ends in October (Nwankwor et al., 1988). The wet period is mostly characterized by moderate temperatures, and high relative humidity, while the dry seasons have high temperatures and lower relative humidity.

The strike of the geomorphic feature in the Enugu metropolis runs through north-south trending escarpment. The scarp slope of the Enugu escarpment rises sharply to the western side, and attains a maximum mean elevation of about 400 m above mean sea level. This elevation is continuous into the Udi Plateau.

Enugu metropolis is drained by Ekulu, Iva, Ogbete and Nyaba rivers which rises from near the base of the escarpment and flow towards the east into the Cross River Basin. The study area is well drained on the western side due to geomorphological feature of the area while it is poorly drained in the eastern side due to geomorphologic characteristics of the area.

MATERIALS AND METHODS

A total of thirty samples were collected from different places across Enugu metropolis (Table 1). The samples showed various degree of weathering ranging from slightly weathered to moderately weathered. The samples were collected with the aid of 6 inches hand auger, with sampling depths ranging from 0.5 m to 3.5 m. The sampling strictly followed standard procedure for soil sampling as specified in British Standard Institution (BSI) 1377 (1990). The sampling and laboratory testing were conducted between June and July 2017. The samples were taken to the laboratory for various tests such as Atterberg’s limits (plastic and liquid limit), free swell test and particle size analysis.

Particle size analysis was conducted on the samples by oven-dried at 105°C of 300 g of samples each. The oven-dried samples were sieved through the various set of BSI sieves, the sample retained on each sieve was weighed and cumulative weight passing through each sieve was calculated as a percentage of the total sample weight. Atterberg’s limits were done adopting the BSI 1377 (1990) test 1A.

Free Swelling Ratio (FSR)

Sridharan and Prakash (2000) proposed the classification of clay mineral type based on Free Swell Ratio (FSR) (Table 2). The free swell ratio gives realistic information about soil expansivity and clay mineralogy. The free swell ratio is calculated as follow:

$$FSR = Vd/Vk \qquad (1)$$

Where Vd = volume of soil in distilled water and Vk = volume of soil in kerosene.

RESULTS AND DISCUSSION

Particle size distribution analysis

Particle size distribution analysis showed the crushed samples consist of 21.67-93.97% fines and 6-72.52% sands with average mean values of 69.65, 23.68 and 6.67% for fines, sands and gravels respectively (Table 1). The particle size distribution curves are shown in Figure 3. The dominance of fines over sands and gravels is an indication of a non-uniform distribution of grain sizes which imply poor grading.

Atterberg’s limits

Consistency tests showed liquid limits, plastic limits and plasticity indices range from 22-66, 0-39 and 0-39% respectively. The soils plasticity range from low plasticity to high plasticity according to Bell (2007) with descriptive classification of lean to fat. Plasticity chart (Figure 4) shows the plasticity characteristics of the tested samples in the studied area.

Clay content and activity

Based on the results of index properties using Skempton (1953) and as modified by Savage (2007), clay content and activity were determined. Activity (A) values range from 0-2.02 and clay content ranges from 0-52.63% were obtained. With average means of 0.46 and 30.49% for activity and clay content respectively. The activity of the soils showed inactive to active with inactive dominating the soils of the studied area (Table 1).

Free Swell Index (FSI) and Free Swell Ratio (FSR)

Free Swell Index and Free Swell Ratio values as obtained by laboratory analysis and empirical evaluation showed range of values from 8-45% and 1.08-1.45 for FSI and FSR respectively (Table 1). All the tested samples have FSR above 1.0 (< 1.0 is regarded as nonswelling clay otherwise known as kaolinitic clay) but are within the range of 1.0-1.5 which are regarded as mixture of swelling and nonswelling clay and dominated mostly by kaolinitic and montmorillonitic clay minerals according to Prakash and Sridharan (2000) (Table 2). The results agree with reports of Ekeocha (2015), Oyediran and Fadamoro, (2015) and Tijani (2012) in the studied area.

Table 1. Physical properties of samples from the studied area.

S/N	Station No.	Depth (m)	Particle size distribution			Atterberg's Limits (%)			Clay content (%)	FSI (%)	FSR	Activity	USCS	AASHTO
			Gravels	Sands	Fines	LL	PL	PI						
1	2	0.5	4.06	20.94	75.01	59	28	31	39.74	45	1.45	0.78	CH	A-7-6(24)
2	3A	1	8.79	24.68	66.53	51	25	26	35.12	33.33	1.33	0.73	CH	A-7-6(16)
3	3B	2	2.13	72.52	25.35	56	17	30	19.31	27.27	1.27	2.02	SC	A-2-7(0)
4	4	0.5	4.17	14.86	80.97	66	31	35	43.75	20	1.2	0.8	CH	A-7-5(32)
5	5	2	3.43	12.37	84.20	63	27	36	37.11	11	1.11	0.97	CH	A-7-6(33)
6	6	1	6.99	20.86	72.15	59	39	20	52.63	18	1.18	0.38	MH	A-7-5(17)
7	7A	1	17.57	21.23	61.20	40	26	14	33	25	1.25	0.42	MH	A-6(9)
8	7B	2	6.33	27.35	66.31	44	27	17	37.78	13.04	1.13	0.45	MH	A-7-6(10)
9	8	3.5	2.77	11.80	85.43	48	25	23	35.94	8	1.08	0.64	CL	A-7-6(21)
10	9	3	0.03	6.0	93.97	27	-	-	0	13.64	1.14	0	ML	A-4(25)
11	10A	1	-	52.97	47.03	27	20	7	23.33	9.09	1.09	0.3	SM	A-6(4)
12	10B	2	1.03	33.93	65.03	24	12	12	17.14	13.64	1.14	0.7	CL	A-6(5)
13	11A	1	0.74	40.39	58.86	27	20	7	23.33	13.64	1.14	0.3	CL	A-4(2)
14	11B	2	0.07	56.87	43.07	28	-	-	0	13.64	1.14	0	SM	A-4(0)
15	12	1	2.50	15.53	81.97	22	13	9	18.37	11.54	1.12	0.49	CL	A-4(5)
16	13	1	2.06	8.90	89.04	38	28	10	32.26	12	1.12	0.31	MH	A-6(10)
17	14	2	-	23.97	76.03	34	23	11	30.56	16.67	1.17	0.36	CL	A-6(8)
18	15	3	4.80	15.46	79.74	46	29	17	43.59	27.27	1.27	0.39	MH	A-7-6(15)
19	16	1	11.97	12.63	75.4	28	12	16	16.49	9.1	1.09	0.97	CL	A-6(9)
20	17	1	6.73	18.97	74.30	42	22	20	31.75	23	1.23	0.63	CL	A-7-6(14)
21	18	2	0.5	6.03	93.47	38	20	16	28.57	26.92	1.26	0.63	CL	A-6(17)
22	19	0.5	0.83	10.13	89.03	50	24	26	34.21	11.11	1.11	0.76	CH	A-7-6(25)
23	20	1	1.93	26.63	71.43	42	22	20	31.7SSSS5	15.38	1.15	0.63	CL	A-7-6(13)
24	21	1	3.45	20.48	76.08	32	17	15	24.59	17.4	1.17	0.61	CL	A-6(10)
25	22	1	13.24	22.53	64.23	48	35	13	41.94	30.77	1.31	0.31	MH	A-7-5(8)
26	23	1	12.13	26.93	60.93	29	20	9	25.71	12.5	1.14	0.35	CL	A-4(0)
27	24	4	14.57	27.03	58.4	44	31	13	38.24	16.67	1.17	0.34	MH	A-7-5(6)
28	25	1	54.97	23.36	21.67	55	25	30	34.88	25	1.25	0.86	GC	A-7-6(0)
29	26	1	5.79	19.43	74.77	46	27	19	38	20.83	1.2	0.5	CL	A-7-6(15)
30	27	0.5	6.49	15.61	77.88	54	33	21	45.65	23.1	1.23	0.46	MH	A-7-5(19)
	Mean		6.67	23.68	69.65	42.23	22.60	17.80	30.49	18.79	1.19	0.57		
	Std. error		1.88	2.74	3.21	2.28	1.62	1.8	2.21	1.55	0.02	0.67		
	STD		10.29	0.15	0.18	12.48	8.88	9.87	12.13	8.50	0.08	0.37		
	Kurtosis		17.39	3.4	1.56	-1.02	1.29	-0.16	1.05	1.58	1.81	7.73		
	Skewness		2.82	1.75	-1.2	0.09	-0.91	0.37	-0.89	1.17	1.21	2.05		
	Min		0	6	21.67	22	0	0	0	8	1.08	0		
	Max		54.97	72.52	93.97	66	39	39	52.63	45	1.45	2.02		

Table 2. Classification of soils based on FSR.

FSR	Clay type	Soil expansivity	Dominant clay mineral type
= 1.0	Non-Swelling	Negligible	Kaolinitic
1.0 – 1.5	Mixture of Swelling and Non Swelling	Low	Mixture of Kaolinitic and Montmorillonitic
1.5 – 2.0	Swelling	Moderate	Montmorillonitic
2.0 – 4.0	Swelling	High	Montmorillonitic
> 4.0	Swelling	Very High	Montmorillonitic

Source: Sridharan and Prakash (2000).

Correlations of physical parameters

The correlation is significant at $P < 0.05$ (Table 3). Correlation between activity of the soils and other physical parameters is significant only for plasticity index and liquid limit. Activity of soils is positively correlated with plasticity index and liquid limit; also, strongest correlation was obtained between activity and plasticity index (r= 0.827) while between activity of soils and liquid limit is a moderate correlation (r= 0.463).

Correlation between plasticity index and other parameters is significant for soil activity, liquid limit and fines. The correlation between plasticity index and fines is a moderate positive correlation at r = 0.43.

Correlation between FSI and other parameters is significant only for FSR and liquid limit. Both FSR and liquid limit are positively correlated with FSI. The correlation between FSI and FSR is very strong at r= 0.998 while that of FSI and liquid limit is moderate at r= 0.429. Again, the correlation between FSR and liquid limit is moderately positive at r= 0.415.

Correlation between the liquid limit and other parameters is significant for activity of the soils, plasticity index, FSI, FSR, plastic limit and clay fraction. All the significant parameters have positive correlation with liquid limit. The correlation between liquid limit and; plasticity index is very strong at r= 0.858, plastic limit is strong at r= 0.705 and clay fraction is very strong at r= 0.755.

The correlation between plastic limit and other parameters is significant only for liquid limit and clay fraction. Correlation between plastic limit and clay fraction is very strong at r= 0.960.

Lastly, the correlation between percentage fines and other parameters can only be significant for percentage sands. This correlation is negatively very strong at r= -0.892.

Activity, plasticity index, FSI, FSR, plastic limit and clay fraction were correlated with liquid limit at significant level of 0.05 excellently. The correlation coefficients have considerable impact on predicting the swelling characteristics of the soils when related with report of Bell (2007).

Soil classification

Table 1 shows the classification of soils of the studied area using USCS and AASHTO classification systems. Figure 5a and b show distribution by percentage of soils by AASHTO and USCS classification system. Figure 5a shows the dominance of A-7-6 soils in the studied area with 36.67% of the entire samples population. The results also show that the studied area is mostly dominated by A-7 soils in the eastern part and this has contributed immensely to the state of roads in the area (Figure 1). Figure 5b shows that the studied samples are dominated by low plasticity clay, high plasticity silt and high plasticity clay with percentage distribution of 40, 26.67 and 16.67% respectively. The results also indicate that the studied area is characterized by swelling soils and caution should be applied before embarking on engineering construction in the studied area.

Swelling potential

Evaluation of swelling potential of studied soil samples were carried out based on the results of Atterberg’s limit, free swell test and empirical estimation. The work of Van der Merwe (1964) was applied to investigate the swelling potential of the studied soils. Figure 6 shows the k lines superimposed on the Van der Merwe swelling chart to determine the swelling potential of the studied soil samples in the studied area. The chart has a defined range of low – medium – high – very high zones for swelling potential. The Van der chart is a plot of gross clay fraction (P002) versus gross plasticity index (Pg). There is a mathematical derivation of line representing swelling potential by a factor k, which defined the

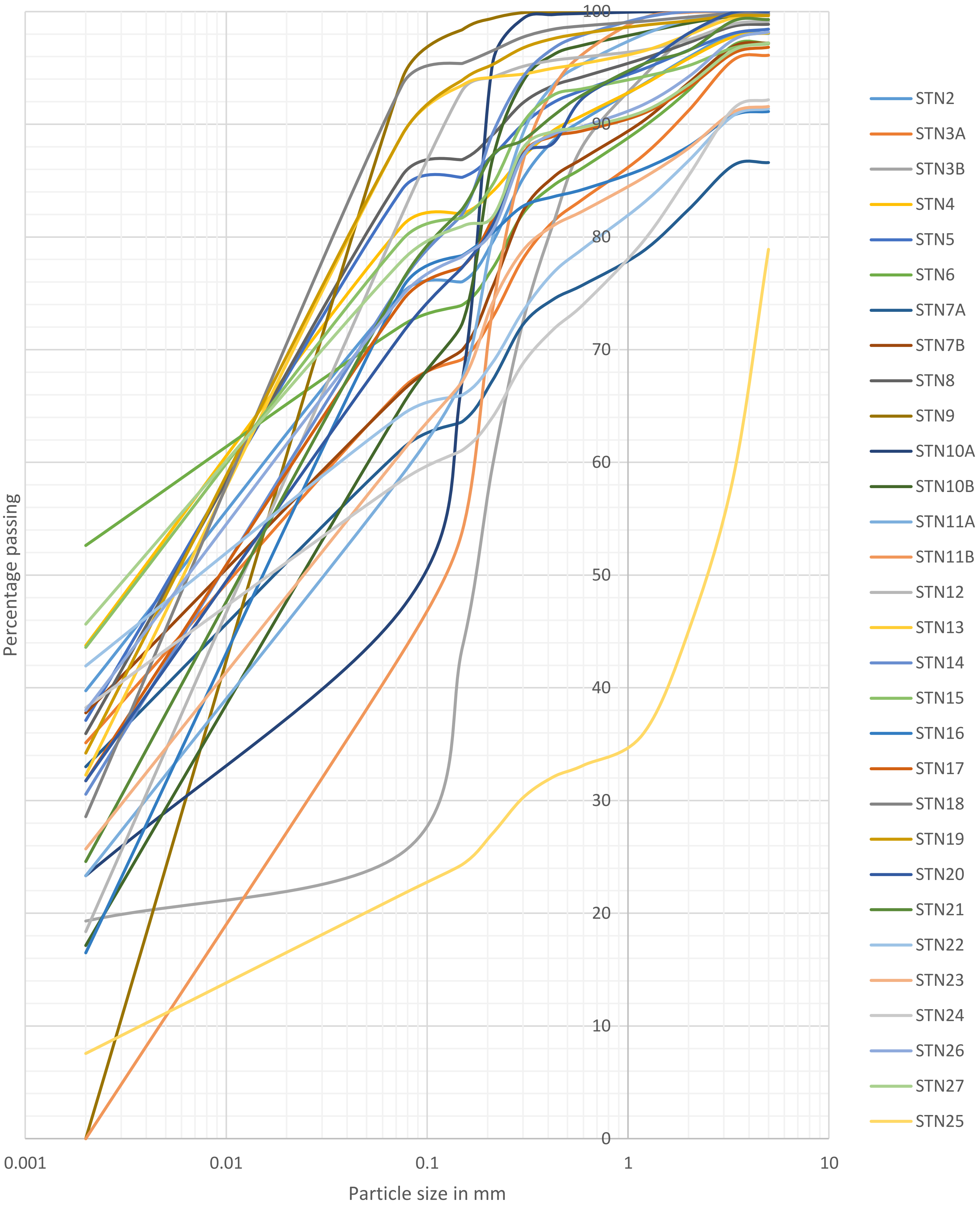


Figure 3. Particle size distribution curves of the soil samples.

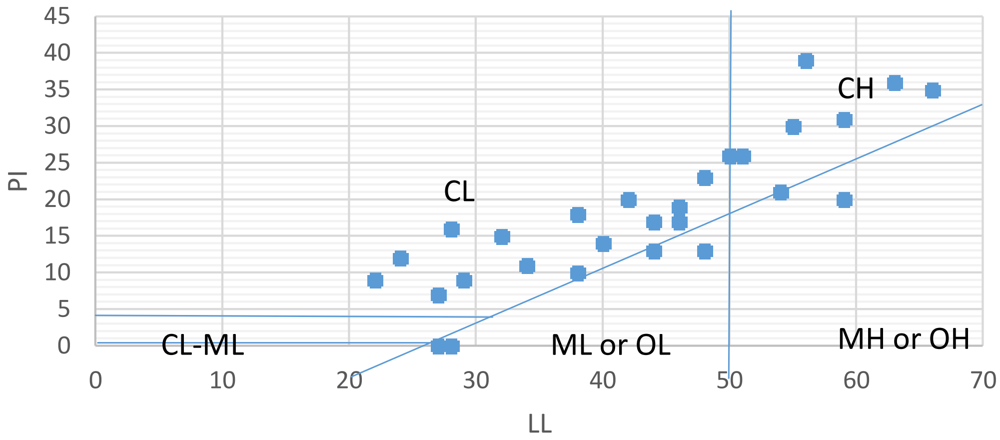
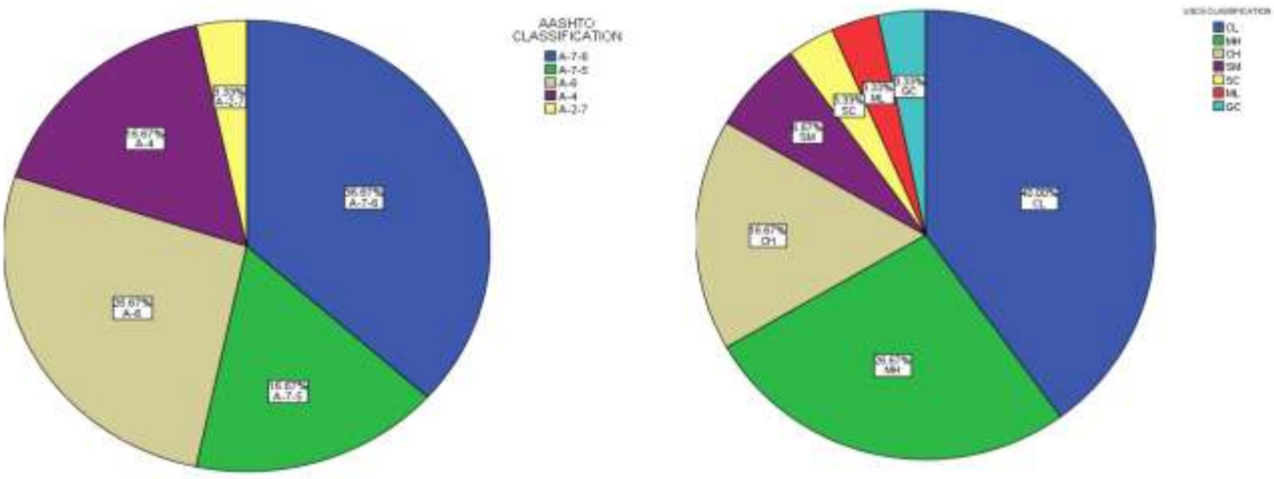


Figure 4. Plasticity chart of the studied soil samples.



(a) **(b)**

Figure 5. Pie chart showing soil classification of the samples by AASHTO and USCS classification system.

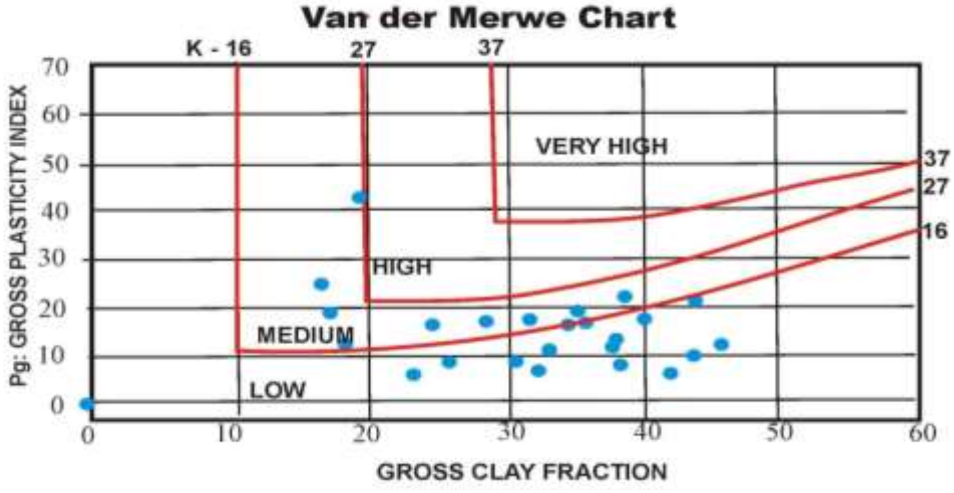


Figure 6. Swelling potential based on Van der Merwe's chart on the tested samples.

Table 3. Correlation between some physical parameters

Parameter	Activity of soil	Plasticity index	Free Swelling	FSR	LL	PL	% Fine	Clay fraction	% Sand
Activity of soil	1	0.829	0.046	0.024	0.463*	-0.270	0.361	-0.108	-0.003
		0.000	0.817	0.905	0.011	0.173	0.059	0.591	0.989
	29	29	28	28	29	27	28	27	26
Plasticity Index	0.829	1	0.339	0.320	0.858	0.223	0.385*	0.321	-0.049
	0.000		0.072	0.090	0.000	0.253	0.043	0.096	0.813
	29	30	29	29	30	28	28	28	26
Free Swelling	0.046	0.339	1	0.998	0.429*	0.331	-0.002	0.339	0.158
	0.817	0.072		0.000	0.020	0.091	0.994	0.083	0.450
	28	29	29	29	29	27	27	27	25
Free Swelling Ratio	0.024	0.320	0.998	1	0.415*	0.333	-0.024	0.335	0.182
	0.905	0.090	0.000		0.025	0.090	0.905	0.088	0.383
	28	29	29	29	29	27	27	27	25
Liquid limit	0.463*	0.858	0.429*	0.415*	1	0.705	0.282	0.755	-0.072
	0.011	0.000	0.020	0.025		0.000	0.146	0.000	0.727
	29	30	29	29	30	28	28	28	26
Plastic limit	-0.270	0.223	0.331	0.333	0.705	1	0.034	0.960	-0.048
	0.173	0.253	0.091	0.090	0.000		0.870	0.000	0.818
	27	28	27	27	28	28	26	28	25
%Fine	0.361	0.385*	-0.002	-0.024	0.282	0.034	1	0.167	-0.892
	0.059	0.043	0.994	0.905	0.146	0.870		0.416	0.000
	28	28	27	27	28	26	28	26	25
Clay fraction	-0.108	0.321	0.339	0.335	0.755	0.960	0.167	1	-0.078
	0.591	0.096	0.083	0.088	0.000	0.000	0.416		0.712
	27	28	27	27	28	28	26	28	25
%Sand	-0.003	-0.049	0.158	0.182	-0.072	-0.048	-0.892	-0.078	1
	0.989	0.813	0.450	0.383	0.727	0.818	0.000	0.712	
	26	26	25	25	26	25	25	25	26

*Correlation is significant at the 0.05 level (2-tailed).

Table 4. Elemental oxides of the tested samples.

STA	SiO_2	TiO_2	Al_20_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	LoI
2	84.98	0.75	12.53	1.3	1.39	0.51	0.26	0.43	0.02	5.35
3B	72.19	0.61	17.95	1.39	0.53	0.79	0.24	0.33	0.02	5.98
4	52	0.75	24.11	12.21	0.4	3	0.47	1.28	0.01	6.28
6	57.85	0.66	19.45	11.75	0.2	2.31	0.13	1.68	0.01	4.96
7B	62.6	0.83	21.57	6.21	0.06	0.51	0.39	0.95	0.01	6.87
10A	88.1	0.6	7.43	1.02	0.01	0.45	0.76	0.22	0.04	2.19
10B	86.5	0.53	7.31	1.15	0.01	0.4	0.69	0.19	0.03	3.2
11A	64.45	0.79	20.45	7.82	0.04	0.93	0.41	0.77	0.02	4.32
12	79.23	0.71	8.62	2.16	1.01	0.32	2.93	1.37	0.13	3.52
13	50.4	0.59	26.04	12.25	0.23	2.56	0.51	1.19	0.01	6.31
14	56.85	0.92	28.23	4.56	0.23	0.51	0.32	1.49	0.01	6.88
17	69.41	0.53	17.04	3.44	0.01	1.04	0.82	0.56	0.01	7.14
19	84.64	0.8	6.26	0.98	0.02	0.63	0.49	0.47	0.03	3.14
20	54.04	0.96	22.84	11.89	0.04	1.65	0.54	0.98	0.02	7.04
22	76.5	0.63	9.02	3.64	0.38	0.46	0.34	1.42	0.02	7.59
23	75.84	0.92	7.94	3.92	0.43	0.51	0.38	1.54	0.01	8.51
24	52.78	0.61	24.16	10.65	0.2	2.53	0.84	1.04	0.02	6.27
25	52.78	0.61	24.16	10.65	0.2	2.53	0.84	1.04	0.02	6.27
26	56.26	0.78	23.42	7.63	0.23	3.54	0.55	1.32	0.01	6.26
27	80.52	1.04	10.78	1.45	0.46	0.4	0.27	0.3	0.02	4.72

swelling zones approximately.

$$(P002 - 0.73k)\,(Pg - 0.16 \times P002 \times k^{0.4}) - k = 0 \qquad (3)$$

The swelling potential is defined by k as follows;

$K \leq 16$ Low swelling potential
$16 < k \leq 27$ Medium swelling potential
$27 < k \leq 37$ High swelling potential
$37 < k$ Very high swelling potential

Pg (Gross plasticity index) = 18.99R – 19.47 (Abbas, 2016) (4)
P002: Gross Clay Fraction.

The studied samples were dominated by low to medium swelling soils.

Free swelling test results were used to calculate free swelling ratio. Subsequently, the free swelling ratio (FSR) results were also used to identify the clay minerals present in the study area (Table 1) in comparison to the classification by Sridharan and Prakash (2000) (Table 2). The results of XRD showed that the studied samples consist of kaolinite, Hametite and quartz (Figures 7 and 8). The results obtained agree with work of Oyediran and Fadamoro, (2015) and Ekeocha (2015) on clay mineralogy of the studied area.

Soils elemental oxides

The chemical characteristics of shale are mainly the function of chemistry of the main minerals, cementing materials as well as cation exchange capacity of the clay minerals. Table 4 shows the elemental oxides of the samples in the studied area. Figure 9 shows the relationship between major chemical elements of SiO_2, TiO_2, Al_2O_3, Fe_2O_3, CaO, Na_2O, K_2O, MgO and MnO on the liquid limit of the soils. The relationship between elemental oxides and liquid limit show that increase in SiO_2, TiO_2,, Na_2O and MnO contents on the studied soil samples caused reduction of liquid limit while Al_2O_3, Fe_2O_3, CaO, K_2O and MgO increased significantly the liquid limit (Figure 9). This finding agrees with report of Mitchell (1993) which stated that the swelling and other engineering properties of the soils are controlled by the chemical composition of soil materials and water. Dontsova and Norton (1999) reported that high magnesium ions from magnesium oxides and other sources can cause surface sealing of the soil. This occurrence led to water logging of soil and subsequently soil swelling. It was observed that increase in magnesium oxide affects the swelling characteristics of the studied soils.

Conclusion

Field observations and experimental analysis identified that changes in geotechnical characteristics are consistent with changes in elevation in the studied area. Severally, other deductions are made from the interpretation of laboratory test results and field

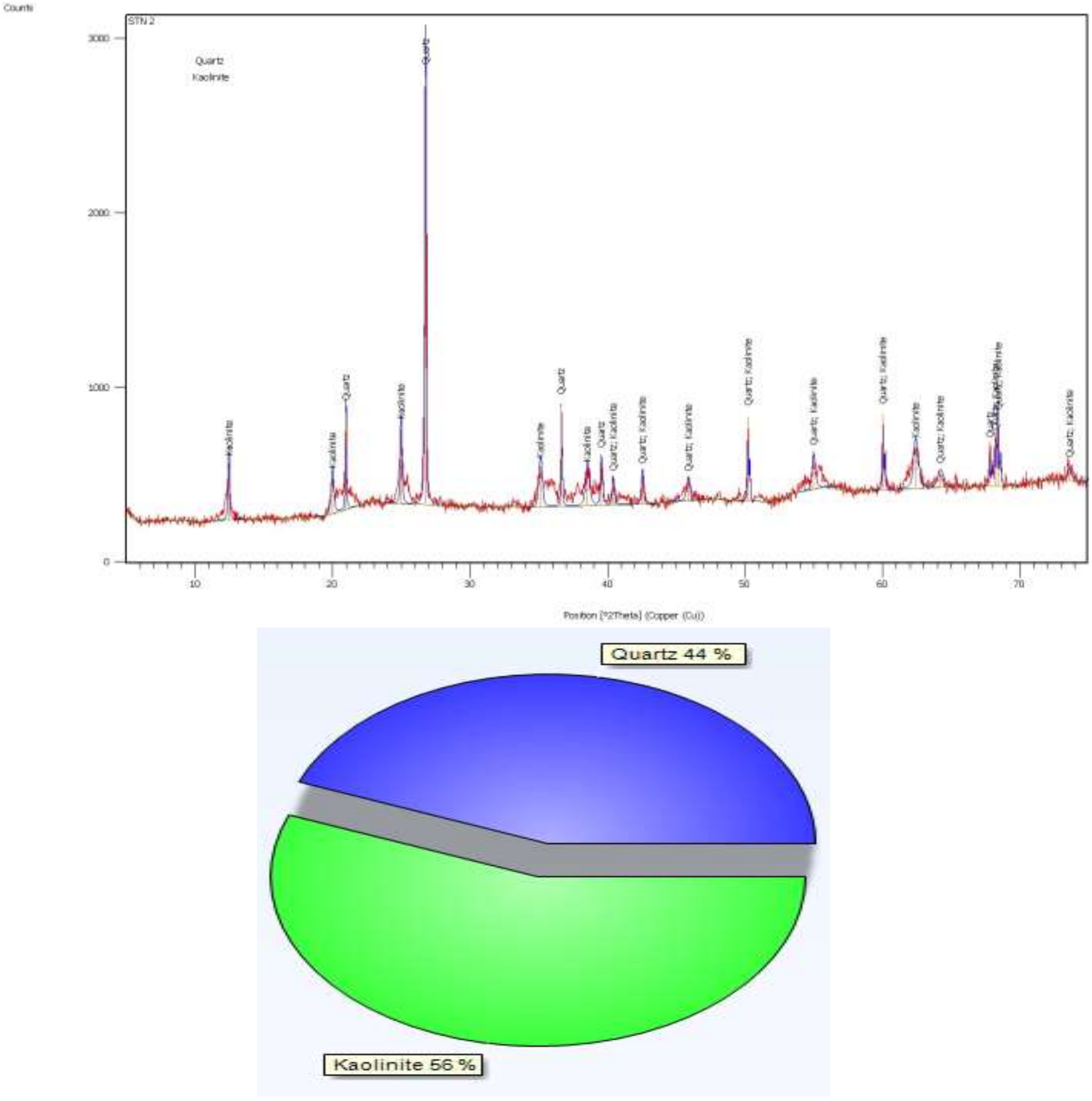


Figure 7. XRD result showing Kaolinite and Quartz in the studied area.

observations as follows;

1) The swelling potential of Enugu Shale is essentially medium swelling but abundant precipitation and prevailing climatic conditions kept continuously altering the soils of Enugu Shale to high swelling soil especially at low elevation where drainage conditions are quite poor.

2) The study revealed that a strong correlation exist between the activity of soils and plasticity index, FSI and FSR, liquid limit and plasticity index, liquid limit and clay fraction as well as plastic limit and clay fraction.

3) The dominance of A-7-6 soil based on AASTHO

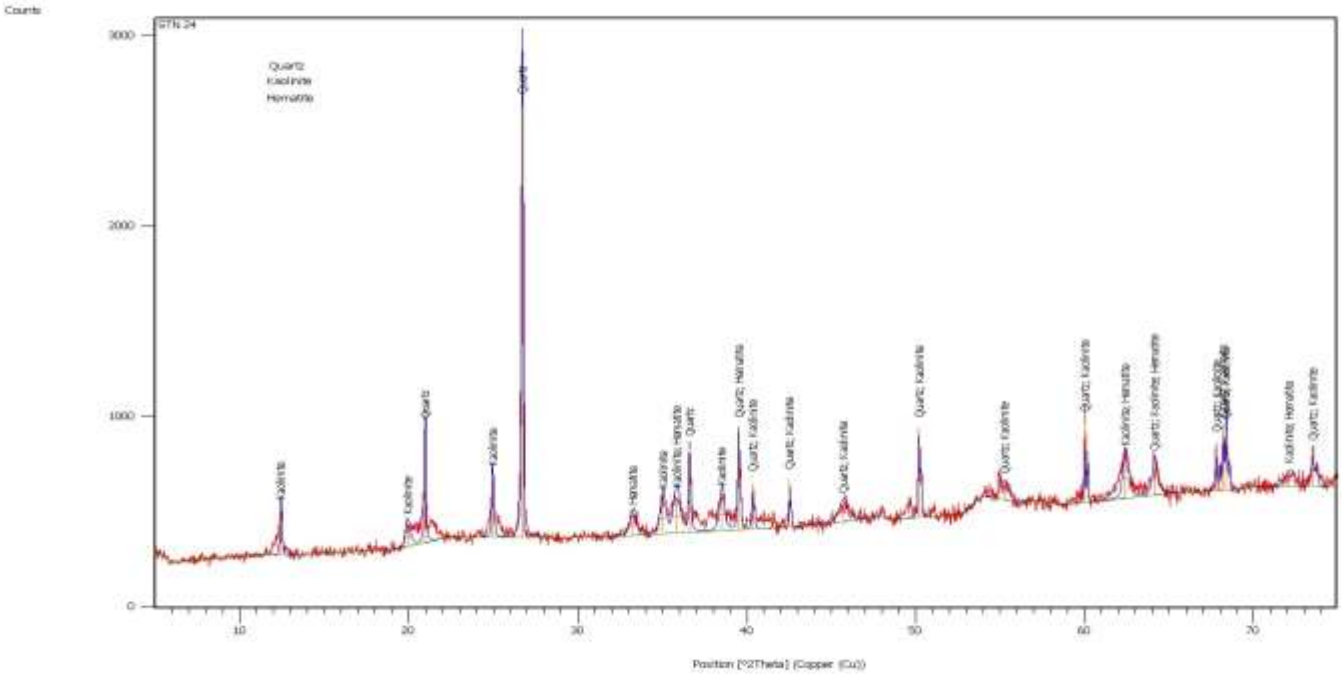


Figure 8. XRD result showing Quartz, Kaolinite and Hametite in the studied area.

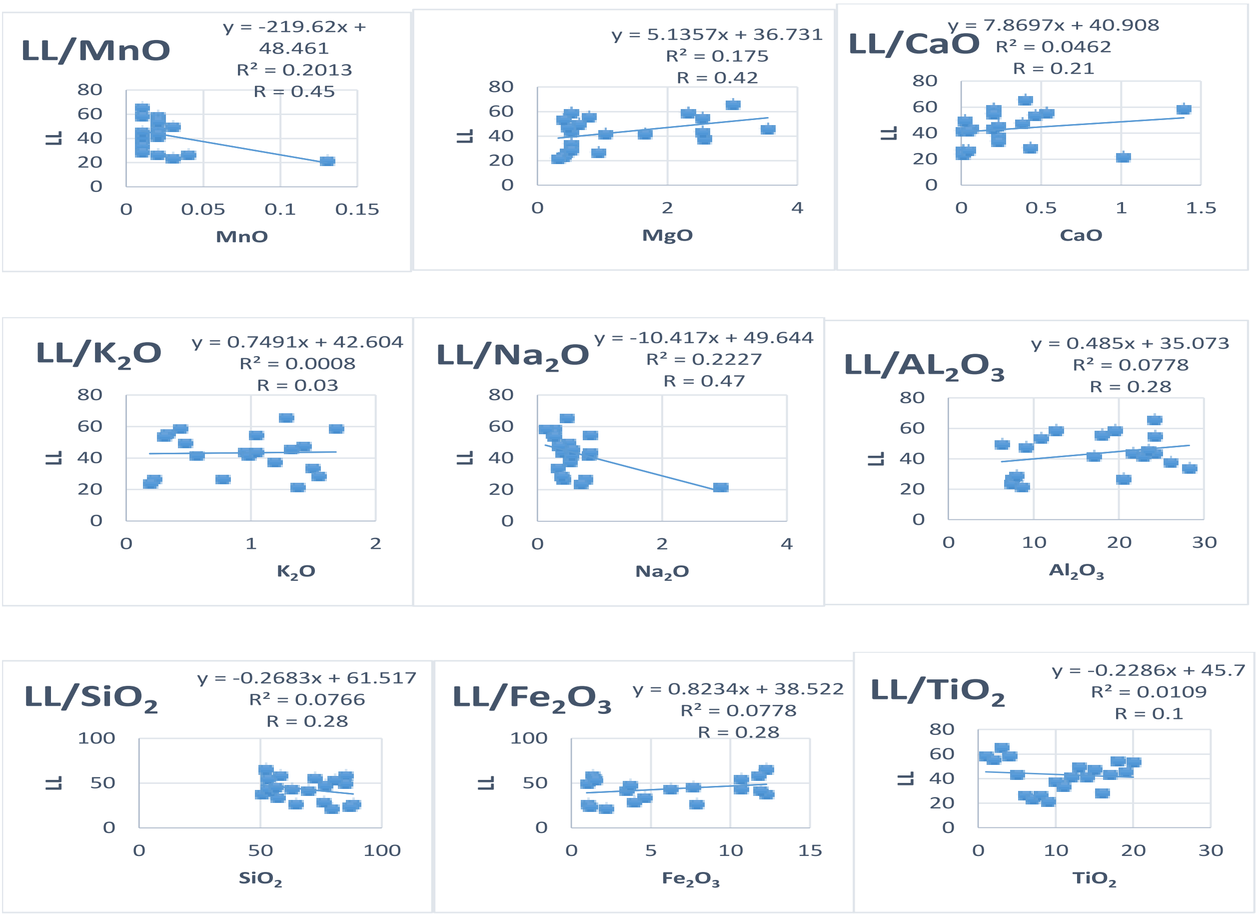


Figure 9. The relationship between liquid limit and elemental oxides in the soil samples.

classification of the soils of the studied area is an indication that such soil cannot be used as subgrade material.

4) Enugu Shale clay mineralogy is a mixture of kaolinite and montmorillonite. This was obtained using Free Swelling Ratio according to Sridharan and Prakash (2000). Although XRD test did not confirm the presence of montmorillonite, field observation and Van der Merwe's chart showed the presence of low to medium swelling clay in the studied area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abbas JA (2016). Practical aid to identify and evaluate plasticity, swelling and collapsibility of the soil encountered in Badrah, Shatra and Nassirya cities. Journal of Engineering and Development 20:38-47.

Aghamelu OP, Nnabo PN, Ezeh HN (2011). Geotechnical and environmental problems related to shales in the Abakiliki area, southeastern Nigeria. African Journal of Environment Science and Technology 5(2):80-88.

Bell FG (2007). Engineering geology, 2nd edition. Elsevier: London, UK. pp. 207-248.

British Standard Institution (BSI) 1377 (1990). Methods of testing soils for civil engineering purposes. British Standards Institution, London.

Dontsova K, Norton LD (1999). Effect of exchangeable Ca:Mg ratio on soil clay flocculation, infiltration and erosion, pp.580-585. In: D.E. Stott, R. H. Mohtar and G. C. Steinhardt (Eds), Sustaining the global farm. Selected papers from the 10th International Soil Conservation Organisation Meeting, Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Ekeocha NE (2015). The mineralogical and engineering characteristics of Cretaceous and Tertiary shales in the lower Benue Trough, Nigeria. Journal of Earth Science and Engineering 5:487-498.

Mitchell JK (1993). Fundamental of soil behavior. 2nd edition. John Wiley and Sons Inc. New York USA.

Nwajide CS (1990). Cretaceous Sedimentation and Paleogeography of the Central Benue Trough. In: Ofoegbu, C.O., (Ed.), The Benue Trough Structure and Evolution International Monograph Seriesw, Braunschweigh. pp.19-38.

Nwajide CS, Reijers TJA (1999). Geology of the southern Anambra Basin. In: Reijers TJA(Ed), Selected chapter on Geology SPDC Warri pp. 133-148.

Nwankwor GI, Egboka BC, Orajaka IP (1988). Groundwater Occurrence and Flow Pattern in the Enugu Coal-mine Area, Anambra State, Nigeria. Journal of Hydrogeological Sciences 33:465-482.

Okagbue CO, Aghamelu OP (2010). Comparison of the geotechnical properties of crushed shales from southeastern Nigeria. Bulletin of Engineering Geology and Environment 69:587-597.

Oyediran AI, Fadamoro OF (2015). Suitability of Ugbo-Odogu and Gariki Shale, Southeastern Nigeria as construction materials. International Journal of Pure and Applied Science Technology 26:1-13.

Sridharan A, Prakash K (2000). Classification procedures for expansive soils. ICE Proceedings Geotechnical Engineering (UK) 143:235-240.s

Tijani MN, Adesina RB, Wagner J (2012). Geotechnical and geochemical assessments of shales in Anambra Basin, SE-Nigeria as compacted clay Liner in landfill system. Conference: International Meeting. Clays in natural and engineering barriers for radioactive waste confinement. At: Montpellier, France 44:330-331.

Van der Merwe DH (1964). The prediction of heave from the plasticity index and percentage clay fraction of soils. Civil Engineer (S. Africa) 6:103-107.