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Geotechnical and chemical insights for sugarcane plantation irrigation: An environmental assessment of Bulk Water Supply area, Nigeria

Ibrahim OI¹, Akudo EO², Ibrahim BD³, Ali AY⁴, Adekunle
AO⁵

ABSTRACT

The study aim to elucidate importance of site investigation using geotechnical and chemical inference for project feasibility. Sugarcane varieties ie hybrids respond differently to different environmental condition of soil. Exploratory pit samples were collected for the purpose of laboratory inference to enhance the integrated analyses of the Bulk Water Supply area evaluation. About 0.2g of each sample was digested in a Teflon digestion bomb using ultra-pure NHO₃ and HF. An aliquote of the digestate was put on quartz sample carrier and dried under infrared lamp for Geochemical analysis. Findings revealed Shear box test of the soils revealed cohesiveness with angle of internal friction that ranged from a value of 18°-31° with shear strength (C) that varied between 2-18KN/m². P2-LAF sample recorded a liquid limit value of 17.14%, plastic limit of 21.4% and Plasticity index of 4.96% with adequate load bearing capacities for strip, pad and circular foundation types. pH of assessed samples were moderately acidic ranging from 1.80-4.14, Electrical conductivity ranged from 18.50 to 66.0 μS/cm, Sodium Adsorption Ratio gave a value that ranged from 0.004 to 1.56. The mean porosity of the soil medium ranged from 22.05% to 34.08%. Organic carbon measurement ranged from 18.50% to 66.00% while the maximum water holding capacity of the area is said to be moderate with recorded values ranging from 21.1% to 31.5%. The study concluded that the area is non-toxic, tectonically stable and non-hazardous, thus, feasible and viable for Bulk water supply area that will serve the proposed sugarcane plantation.

Keywords: Aliquote, Montmorillonite, Plastic limit, Strip, Electrical conductivity and Bulk water

1. INTRODUCTION

Lafiagi has an undulating plain with the topography within 2 miles containing only modest variations in elevation with a maximum elevation change of 276 feet and an average elevation above sea level of 308 feet. Within 10 miles it contains only modest variations in elevation (705 feet). Within 50 miles it contains significant variations in elevation (1,946 feet). The area within 2 miles of Lafiagi is covered by cropland (46%), shrubs (19%), trees (19%), and grassland (16%), within 10 miles by shrubs (47%) and cropland (34%), and within 50 miles by shrubs (36%) and cropland (32%).

It is 99 m above sea level and located at 8.87° N 5.42° E. It has a population of 102,779 people. Bulk water supply (BWS) evaluation of the selected area using defined exploratory pits is crucial to know the level of soil contamination as these areas will be designed with pipelines and sugarcane hybrids, Bulk water supply pipelines and a perfect foundational footing pumping station for irrigation purpose that will serve as raw materials for a proposed sugar refinery in the area is crucial for this site investigation Olaniran, (2002) and as reported by (Olanrewaju and Negedu, 2015).

Study area and Stratigraphy

The study area covers a part of the Lafiagi (Sheet 203) in the Nigerian topographical map. It is situated at the transition environment between the Nupe Basin and the Southwestern Nigerian Basement Complex. Four mappable stratigraphic horizons all of which are Campanian– Maastrichtian have been delineated and described in the northern Bida Basin by previous workers notably (Akande et al., 2005). The formations are Bida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Ironstone.

The Lafiagi deposit has been largely traced to the emplacement of the Bida Formation with most sandstone deposited facies traced to Jika member of the deposit Abimbola, (1997) and Akande et al., (2005) in that area (Table 1). The stratigraphic succession of the Mid-Niger Basin, collectively referred to as the Nupe Group Akande et al., (2005) and Ladipo et al., (1994) revealed a twofold ie Northern Bida Basin (Sub-Basin) and Southern Bida Sub-Basin or Lokoja Sub-Basin in the area with Lafiagi deposit largely inclined with the Northern Bida deposit (Table 1).

Table 1 Stratigraphy of the Deposit in Suthern and Northern Bida Basin.

Age	Southern Bida Basin	Northern Bida Basin		Depositional Environment
Maastrichtian	Agbaja Formation	Batati Formation		<p style="text-align: center;">Increasing Marine Influence ↑</p>
	Patti Formation	Enagi Formation		
Campanian	Lokoja Formation	Sakpe Formation	Jima Member	
		Bida Formation	Doko Member	
Precambrian	Crystalline Basement			

The origin of the oolitic ironstones in the Bida Basin has been a principal subject and debate of several workers notably (Abimbola, 1997; Akande et al., 2005; Ladipo et al., 1994). A detailed view of the origin of this oolitic ironstones as its emplacement and occurrence was traced to Lafiagi axis with large oolitic sandstone deposit around Gbugbu. This was discovered during detailed field mapping of the sediment in the area for agricultural research, further detailed study ongoing on this as Isothermal maps will be useful for such detailed study as advanced Abimbola, (1997) in a reviewed article.

2. FIELD WORK, MATERIALS AND METHODOLOGY

Test pits were bored along defined dimensions and coordinates using the excavator for sampling and bagging with laboratory inference (Figure 1). Samples that represented the total lithological profiles were penciled down for Geotechnical assessment. Geotechnical and Geochemical evaluation for further study on salient tests that will define the suitability of the area in question for the

BWS design was done. The result from this field work is expected to serve as a pilot test for a more detailed assessment of the study area (Figure 1 and Table 2).

Table 2 Coordinates and Dimensions of exploratory pits for sampling

Pits	Sample codes	Coordinates		Pit Length (m)	Pit Breadth (m)	Pit Depth (m)
		N	E			
P1	P1-LAF	755,505.02	992,869.16	3.2	2.9	2.7
P2	P2-LAF	755,522.49	992,669.92	3.2	3.1	2.8
P3	P3-LAF	755,539.95	992,470.68	2.6	2.7	2.6
P4	P4-LAF	755,557.42	992,271.45	3.6	3.2	3/4
P5	P5-LAF	755,574.89	992,072.21	3.2	2.5	2.6
P6	P6-LAF	755,592.35	991,872.98	3.1	2.7	2.8
P7	P7-LAF	755,438.58	991,724.54	3.5	3.1	2.9
	P8-LAF	755,294.68	991,585.64	2.6	2.7	2.8

All samples were air dried prior to chemical digestion and analyses. The chemical digestion of the samples were done using a mixture of nitric acid and hydrofluoric acids according to the procedure of International Atomic Energy Agency (IAEA-TECDOC.1996). About 0.2g sample was digested in a Teflon digestion bomb using ultra-pure HNO_3 and HF. An aliquote of the digestate was put on quartz sample carrier and dried under infrared lamp. The infrared analysis was carried out using a black scientific infrared spectrophotometer M500.

The KBr method of preparation was employed. An atomic absorption spectrometer uses these basic principles and applies them in practical quantitative analysis. A typical atomic absorption spectrometer that consists of four main components: The light source, the atomization system, the monochromator and the detection system were all used for laboratory analysis of the geochemical components of the samples. Similarly, varieties of laboratory procedures were followed for the Geotechnical analyses of the samples (Figure 1).

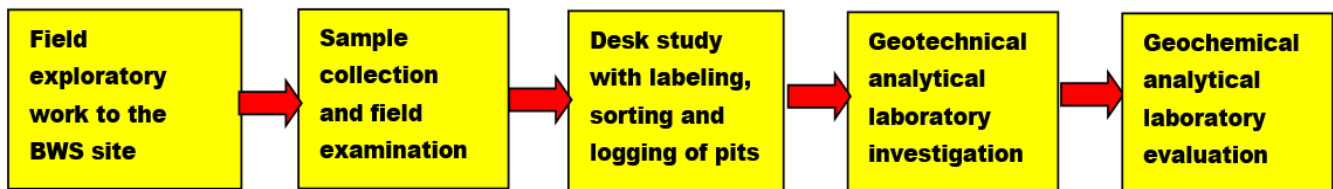


Figure 1 Flowchart of BWS work plan

3. FINDINGS

The results obtained from this study are hereby presented for further interpretation of the area on its suitability for the purpose of Bulk Water Supply for the sugarcane plantation and irrigation of the area. It is worthy of note that all inferences from the study are expected to shape the purpose and technical modalities for further agricultural activities in the area. While the Geotechnical assessment results will facilitate the Engineering design of the area, the Geochemical elucidated on the contamination status of the soil for the vast network of pipelines (that will carry bulk water to farmland to increase agricultural yield).

Grain size analysis

The grain size analysis of the collected samples was done and reported to enhance the type of soil grains contained in the area. This was done to evaluate the importance of such components of the soil for the purpose of its suitability for the Bulk Water Supply (BWS) of the area. The components of the collected soil from the area was diagnosed as gravel, sand, silt and clay in varying proportion (Table 3). The variation in the grain sizes contained in the study area has vividly shown there is massive emplacement of sandy components of

71% to 88% (Table 3) in the area over the silty and clayey fraction of 1-23% and 1-13% respectively (Table 3) and this lithological facies is good and desirable for the BWS.

Large amount of clay component especially when its more than 65% of the total soil components in the area is often not desirable for most Engineering structures like BWS, Roads, Dams and bridges etc. (Ibrahim et al., 2024; Umoren et al., 2016). This is commonly due to the swelling property of clay with large addition of water usually in the form of rainfall that causes large amount of destruction.

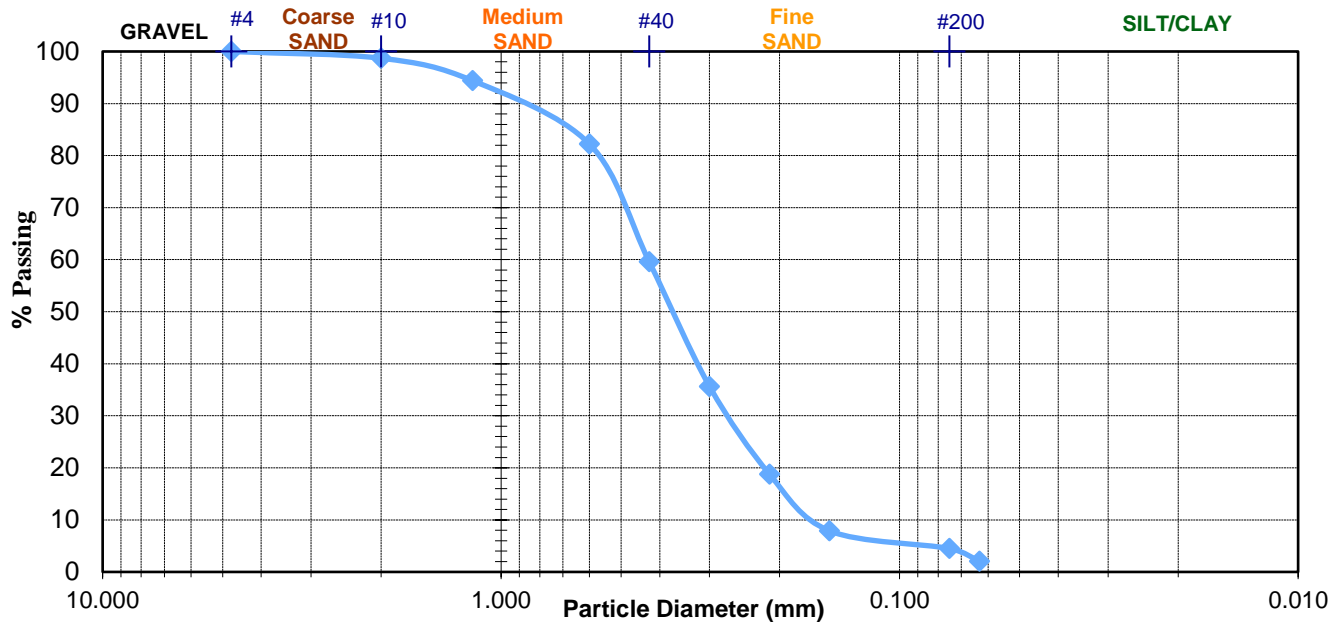


Figure 2 Grain size analysis composition chart for sample P3-LAF

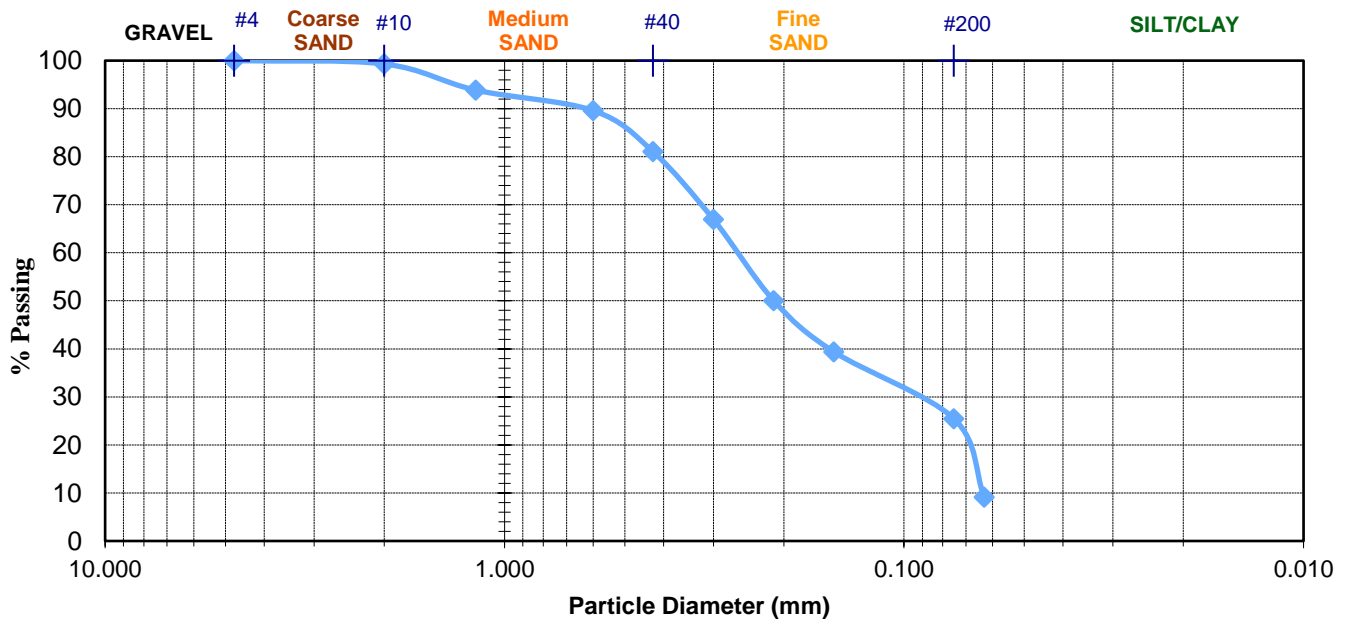


Figure 3 Grain size analysis composition chart for sample P4-LAF

The grain size analysis result (Figures 2, 3, 4) and the quantitative analysis presented (Table 3). The charts for samples 1, 2 and 7 are not presented but their quantitative analysis of each components are contained (Table 3). P3-LAF recorded the largest amount of sand

fraction of about 88%, while P2-LAF and P3-LAF recorded the lowest amount of sand fraction of about 72% (Table 3). More importantly, P1-LAF recorded 16% and 5% of silt and clay respectively with 77% sand fraction and this has qualified the investigated sample to be named silty sandy soil according to the USCS soil classification (Table 3).

Similar silty sandy soil diagnosed during the study included P2-LAF, P3, LAF, P5-LAF, P6-LAF and P8-LAF with 22%, 23%, 14%, 16% and 10% silty components respectively (Figures 2, 3, 4 and 5). The silt components of all these fractions in all investigated samples is not enough to cause settlement of the area with major sand fraction contained in all samples of the area. Sugarcane straw ash can improve on the geotechnical properties of the soil samples as advanced by previous workers (Amu et al., 2011).

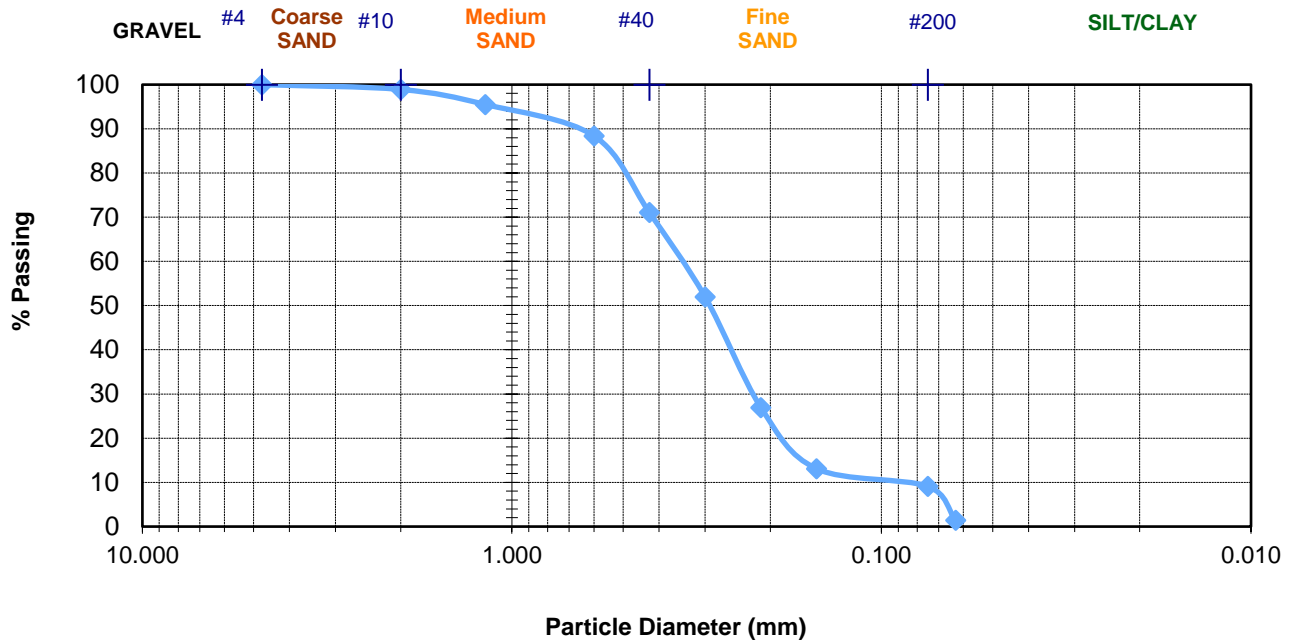


Figure 4 Grain size analysis composition chart for sample P5-LAF

Table 3 Percentage soil composition of the samples in the study area.

Pits	Sample codes	% Gravel	% Sand	% Silt	% Clay	Lithological facies Concluded
P1	P1-LAF	2	77	16	5	Silty-Sandy soil
P2	P2-LAF	1	72	22	5	Silty-Sandy soil
P3	P3-LAF	1	72	23	4	Silty-Sandy soil
P4	P4-LAF	1	88	1	10	Clayey-Sandy soil
P5	P5-LAF	0	84	14	2	Silty-Sandy soil
P6	P6-LAF	1	79	16	4	Silty-Sandy soil
P7	P7-LAF	1	83	8	8	Silty-Clayey-Sandy soil
	P8-LAF	2	87	10	1	Silty-Sandy soil

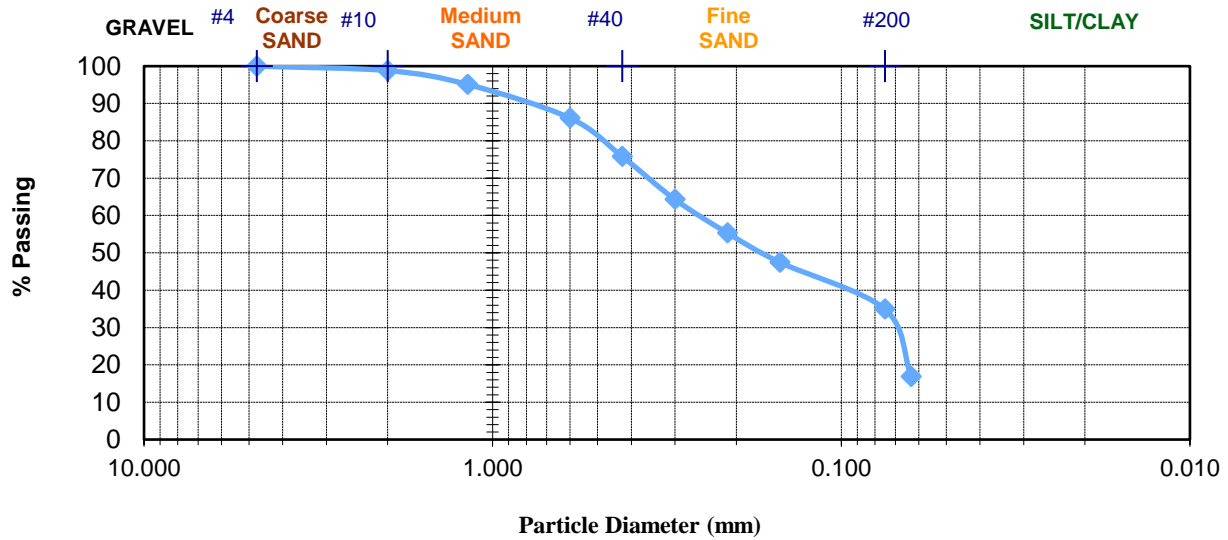


Figure 5 Grain size analysis composition chart for sample P6-LAF

Conversely, P5-LAF and P6-LAF recorded silty sandy soil due to the more dominant of the silty component as the second most abundant fraction after the sand fraction (Figures 5 and 6). The silt components are 14% and 16% respectively compared to the clay fraction of 2% and 4% recorded in both samples (Table 3). Lastly, P7-LAF sample (Table 3) recorded Silty-Clayey-Sandy soil due to the same quantity of silt and clay fraction in the sample ie 8% and its termed Silty-Clayey Sandy soil. This sample is not desirable for the BWS area, but can be excavated for a more stable geologic material like laterite with low amount of clay in the soil matrix as pioneered by previous notable workers (Shahid et al., 2018; Ukut et al., 2014).

Free swell test

Free swell index of selected samples of the study area has revealed a wide variation values that showed sample P3-LAF to be the lowest in terms of the capacity to swell with minimum addition of moisture (water) to the samples with a swelling capacity of 5.49% (Table 4). The BWS lithological profile cannot be affected with swelling properties due to more sandy soil inference that are contained in the soil profile of the area with less amount of clay and silt content (Figures 2-5 and Table 3). But more importantly, the BWS which is more of the pipeline areas will equally not experience rupture of the pipelines due to more sandy soil facies contained in the area with less swelling minerals like smectite. P8-LAF recorded the highest FSI with 14% (Table 4).

Table 4 Free swell test result of evaluated samples in the study area

S/N	SAMPLE ID	Vd (m3)	Vk (m3)	FSI (%)	Inference
1	P1-LAF	0.00042	0.000395	6.33	Good for BWS
2	P2-LAF	0.00046	0.00043	6.05	
3	P3-LAF	0.00048	0.000455	5.49	
4	P4-LAF	0.00034	0.000305	11.48	
5	P5-LAF	0.00044	0.00041	7.32	
6	P6-LAF	0.00049	0.00042	16.67	
7	P7-LAF	0.00055	0.00049	12.24	
8	P8-LAF	0.00057	0.0005	14.00	

$$\text{Free swell index} = \frac{[Vd - Vk] \times 100\%}{Vk}$$

Vd= Volume of soil specimen read from the graduated cylinder containing distilled water

Vk = Volume of soil specimen read from the graduated cylinder containing kerosene

P3-LAF recorded a swelling Index of 5.49% (Table 4) this was interpreted as one of the lowest in the area. This reflects the absence of swelling minerals like Smectite, Kaolinite and Montmorillonite in the void spaces of lattice layering of either 1:1 or 2:1 layers. This was similarly advanced Becker, (1997) in the development for the national building code of Canada There is a marked trend of decreasing value from the P6-LAF down to the bottommost part of established data ie BWS. In summary, the free swelling index of the assessed samples have all reflected the variability of the assessed samples that showed varying content of clay content in the evaluated area that is low and will not cause severe problem to the BWS area.

Direct shear box test

All collected samples were evaluated for shear box test to know the angle of internal friction, shear strength and soil cohesion from the area. Selected 5 samples of the area were subjected to shear box test. Most investigated soils investigated are cohesive while some few others are not. Angle of internal friction ranged from a value of 18°-31° with shear strength (C) varied between 2-18KN/m² (Table 7). Internal friction ranged from a value of 15°-26° in soils of Kamrej taluka Jangir et al., (2020) in Surat district, Gujarat. P2-LAF revealed 4.91 to 14.2KN/m² Normal stress (Table 5). ϕ of 29° and C is 2KN/m² (Figure 6).

Table 5 Shear strength of sample P2-LAF at different time intervals

TIME	Kg/div	Kg/div	Kg/div	KN	KN	KN	KN/m ²	KN/m ²	KN/m ²
	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg
0	0	0	0	0	0	0	0	0	0
5sec	2	6	10	0.024	0.071	0.119	2.374	7.122	11.870
10sec	5	10	21	0.059	0.119	0.249	5.935	11.870	24.927
15sec	7	13	26	0.083	0.154	0.309	8.309	15.431	30.862
30sec	10	17	29	0.119	0.202	0.344	11.870	20.179	34.423
1min	12	20	34	0.142	0.237	0.404	14.244	23.740	40.358
2min	14	23	39	0.166	0.273	0.463	16.618	27.301	46.293
3min	15	27	41	0.178	0.320	0.487	17.805	32.049	48.667
Load	Kg		5	10		15	-		
Shear Stress	KN/m ²			27.30		51.63	77.16		
Normal Stress	KN/m ²			4.91		9.81	14.72		

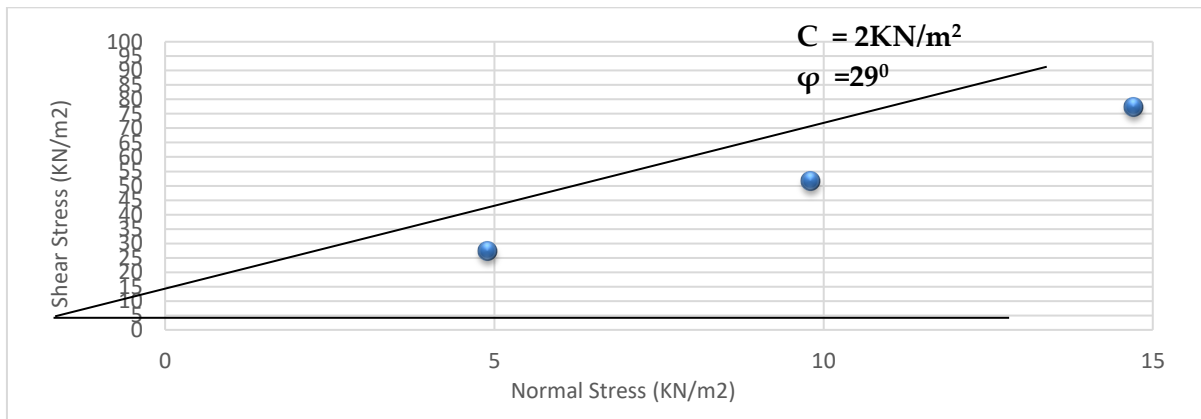


Figure 6 Graph of Shear stress against Normal stress of P2-LAF

P3-LAF revealed 4.91 to 14.72KN/m² Normal stress (Table 6). ϕ ie Angle of internal friction of 31° and C is 4KN/m² (Table 7 & Figure 7). In a similar way, P4-LAF revealed 4.91 to 14.72 KN/m² Normal stress (Table 8). ϕ ie Angle of internal friction of 30 and C is

6KN/m² (Figure 8). P5-LAF revealed a similar trend of 4.91 to 14.72 KN/m² Normal stress (Table 9). ϕ ie Angle of internal friction of 24 and C is 18KN/m² (Figure 9).

Table 6 Shear strength of sample P3-LAF at different time intervals

TIME	Kg/div	Kg/div	Kg/div	KN	KN	KN	KN/m ²	KN/m ²	KN/m ²
	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg
0	0	0	0	0	0	0	0	0	0
5sec	3	8	9	0.036	0.095	0.107	3.561	9.496	10.683
10sec	5	12	12	0.059	0.142	0.142	5.935	14.244	14.244
15sec	6	14	14	0.071	0.166	0.166	7.122	16.618	16.618
30sec	8	17	21	0.095	0.202	0.249	9.496	20.179	24.927
1min	10	20	22	0.119	0.237	0.261	11.870	23.740	26.114
2min	11	22	24	0.131	0.261	0.285	13.057	26.114	28.488
3min	14	25	25	0.166	0.297	0.297	16.618	29.675	29.675
Load	Kg	5	10	15					
Shear Stress KN/m ²		28.49	49.85	71.22					
Normal Stress KN/m ²		4.91	9.81	14.72					

Specific Gravity

The specific gravity of the collected sample refers to the ratio of the soil particles to the unit weight of water. This was done to elucidate the Bulk water supply (BWS) suitability of the area as vast network of pipeline will need deliver irrigable water to all the irrigation rooms for adequate nourishment of the proposed sugarcane plantation. The summary of results (Table 10) obtained during the assessment has revealed a good area for such purpose.

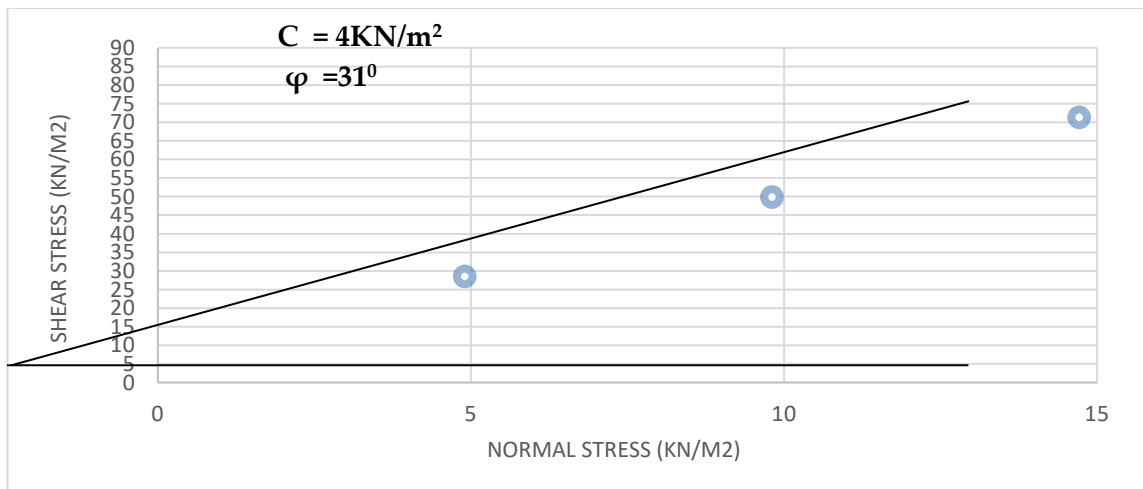


Figure 7 Graph of Shear stress against Normal stress of P3-LAF

Table 7 Angle of internal friction and shear strength of studied samples

S/N	Sample codes	Angle of internal friction(ϕ)	Shear strength (KN/m ²)	Inference
1	P1-LAF	29	2	Averagely Good for Bulk Water Supply in the studied area
2	P2-LAF	29	2	
3	P3-LAF	31	4	
4	P4-LAF	30	6	

5	P5-LAF	24	18
6	P6-LAF	26	22

Table 8 Shear strength of sample P4-LAF at different time intervals

TIME	Kg/div	Kg/div	Kg/div	KN	KN	KN	KN/m2	KN/m2	KN/m2
	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg
0	0	0	0	0	0	0	0	0	0
5sec	1	2	3	0.012	0.024	0.036	1.187	2.374	3.561
10sec	5	5	8	0.059	0.059	0.095	5.935	5.935	9.496
15sec	8	7	11	0.095	0.083	0.131	9.496	8.309	13.057
30sec	11	9	15	0.131	0.107	0.178	13.057	10.683	17.805
1min	13	11	19	0.154	0.131	0.226	15.431	13.057	22.553
2min	15	17	23	0.178	0.202	0.273	17.805	20.179	27.301
3min	16	21	25	0.190	0.249	0.297	18.992	24.927	29.675
Load	Kg		5	10		15	-		
Shear Stress	KN/m2		29.68	47.48		67.66	-		
Normal Stress	KN/m2		4.91	9.81		14.72	-		

The studied area has shown that P6 with a specific gravity (Ga) recorded 2.79 Ga and the highest recorded across the evaluated samples and the lowest from sample P4 with 2.46 Ga (Table 10). The analyzed samples have all shown that the area of investigation has a relatively good specific gravity. In essence, the displayed result has indicated that the area in question will be good for Bulk water supply using the proposed vast network of pipeline in the area, but there will be need for more detailed design for environmental condition most especially rainfall precipitation and flooding condition in the area. Specific Gravity values of the tested soil samples vary from 2.63 to 2.66 in the foundation Shahid et al., (2018) investigation of Bhaunrat dam site.

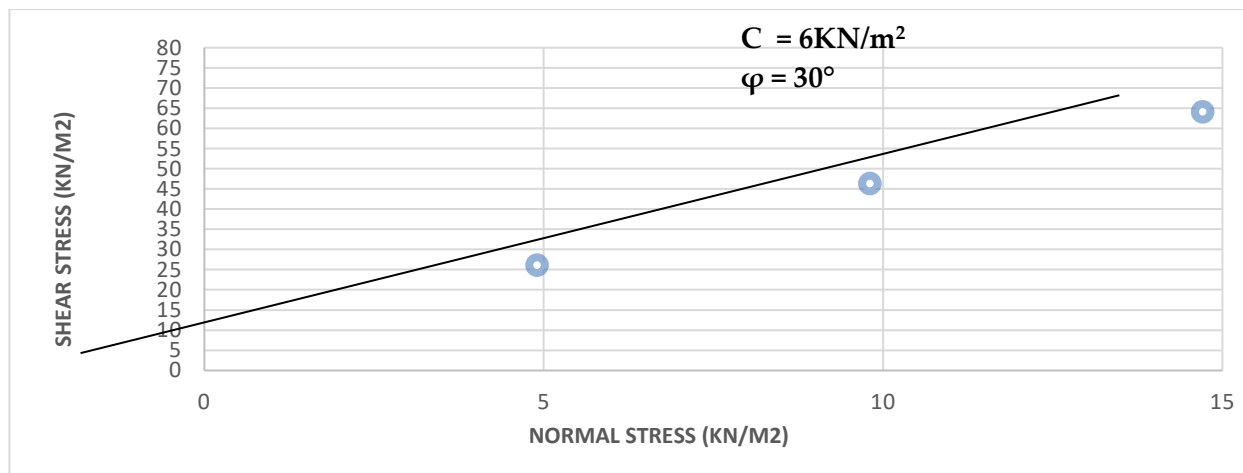


Figure 8 Graph of Shear stress against Normal stress of P4-LAF

Table 9 Shear strength of sample P5-LAF at different time intervals

TIME	Kg/div	Kg/div	Kg/div	KN	KN	KN	KN/m2	KN/m2	KN/m2
	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg	5Kg	10Kg	15Kg
0	0	0	0	0	0	0	0	0	0
5sec	2	3	6	0.024	0.036	0.071	2.374	3.561	7.122
10sec	6	4	7	0.071	0.047	0.083	7.122	4.748	8.309

15sec	7	6	12	0.083	0.071	0.142	8.309	7.122	14.244
30sec	12	7	18	0.142	0.083	0.214	14.244	8.309	21.366
1min	13	11	18	0.154	0.131	0.214	15.431	13.057	21.366
2min	14	13	20	0.166	0.154	0.237	16.618	15.431	23.740
3min	15	15	21	0.178	0.178	0.249	17.805	17.805	24.927
Load	Kg		5	10		15	-		
Shear Stress	KN/m ²		20.18	29.68		42.73	-		
Normal Stress	KN/m ²		4.91	9.81		14.72	-		

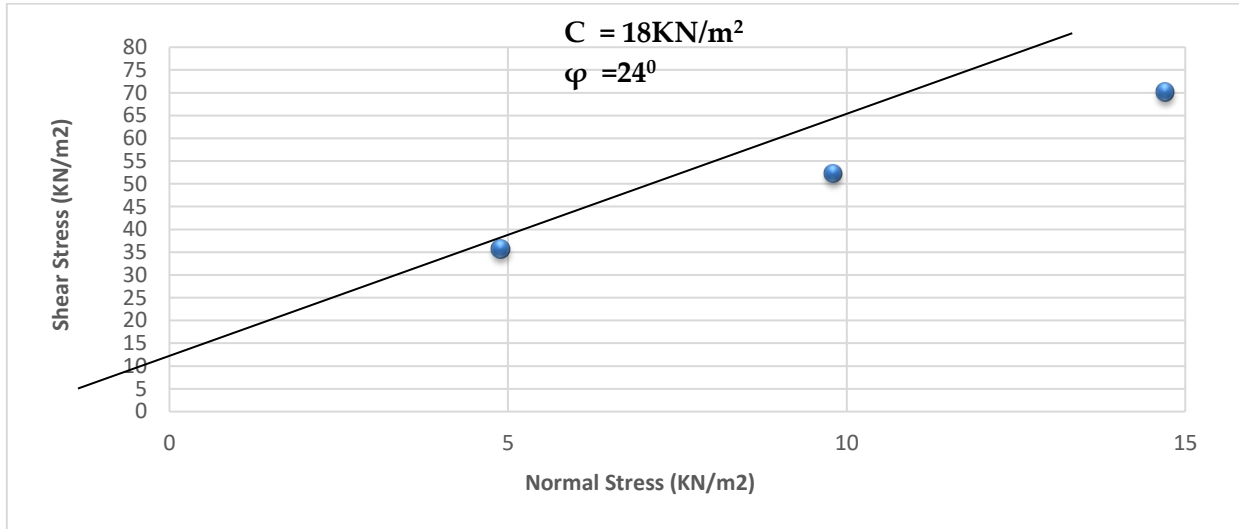


Figure 9 Graph of Shear stress against Normal stress of P5-LAF

Table 10 Specific weight result of evaluated samples of the area

SAMPLES ID	WEIGHT OF EMPTY PYCONMETER (g)	WEIGHT OF PYCONMETER+SOIL (g)	WEIGHT OF PYCONMETER+SOIL+WATER (g)	WEIGHT OF PYCONMETER+WATER (g)	SPECIFIC GRAVITY (GS)
P1-LAF	15.0	37.0	90.0	76.0	2.75
P2-LAF	15.0	38.5	91.0	76.0	2.76
P3-LAF	15.0	33.0	87.5	76.0	2.77
P4-LAF	15.0	31.0	85.5	76.0	2.46
P5-LAF	15.0	34.0	88.0	76.0	2.71
P6-LAF	15.0	34.5	88.5	76.0	2.79
P7-LAF	15.0	35.0	88.5	76.0	2.67
P8-LAF	15.0	33.0	87.3	76.0	2.69

Compaction strength test

Compaction strength test was conducted on the study samples with a value that ranges from about 3-14% moisture content (Table 11 and 12). The curves were plotted for each sample as dry density (g/cm³) against moisture content (%) of each sample and were further interpreted as soil with high tendency to have their bearing capacity and stability increased after all void spaces are closed ie compacted (Figures 10-12) and (Table 13).

Table 11 P3-LAF and P4-LAF compaction strength data

P3-LAF. MDD = 1.95, OMC = 8.80.				
Dry Density (g/cm ³)	1.76	1.90	1.95	1.67
Moisture Content (%)	4.92	6.81	8.80	10.54
P4-LAF MDD = 2.00, OMC = 7.8				
Dry Density (g/cm ³)	1.83	1.96	2.00	1.90
Moisture Content (%)	3.21	5.11	7.80	9.6

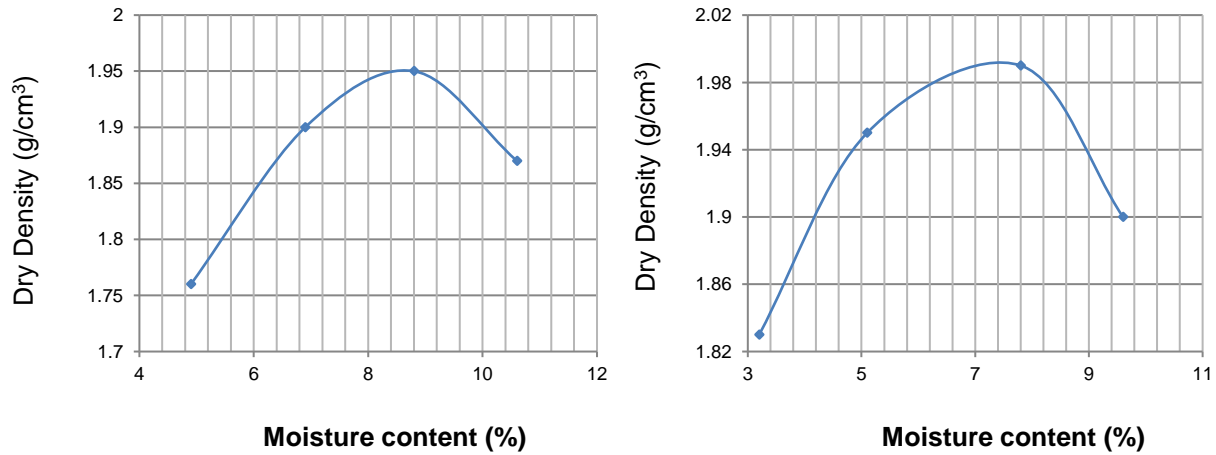


Figure 10 Compaction curve of sample P3-LAF and P4-LAF in the studied area

Table 12 P5-LAF and P6-LAF compaction strength data

P5-LAF MDD = 1.95, OMC = 8.80.				
Dry Density (g/cm ³)	1.66	1.90	1.95	1.77
Moisture Content (%)	4.98	6.81	8.80	10.55
P6-LAF MDD = 2.00, OMC = 7.8				
Dry Density (g/cm ³)	1.83	1.96	2.00	1.90
Moisture Content (%)	3.21	5.11	7.80	9.6

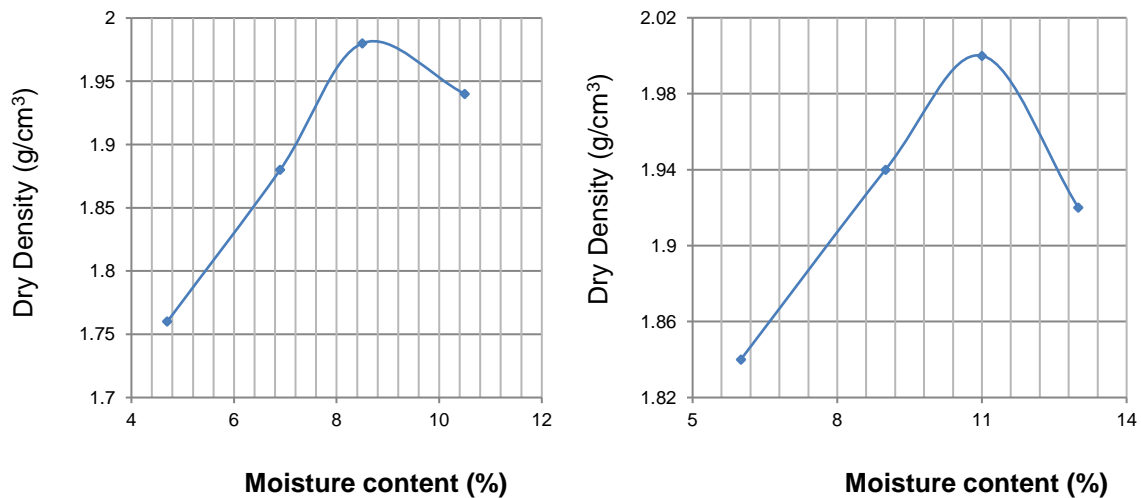


Figure 11 Compaction curve of sample P5-LAF and P6-LAF in the studied area

Permeability of the soil samples have all reduced with ability to control erosion in the area. Unit weights of investigated soil samples increased with higher moisture contents of study samples. The curves of the study area ie zero void space curve represents the soil density against the moisture content of the area increased (Table 13).

Table 13 P7-LAF and P8-LAF compaction strength data

P7-LAF MDD = 2.02, OMC = 9.20.				
Dry Density (g/cm ³)	1.66	1.90	1.95	1.87
Moisture Content (%)	4.90	6.83	8.80	10.6
P8-LAF MDD = 1.99, OMC = 7.80				
Dry Density (g/cm ³)	1.83	1.96	1.99	1.90
Moisture Content (%)	3.16	5.18	7.80	9.60

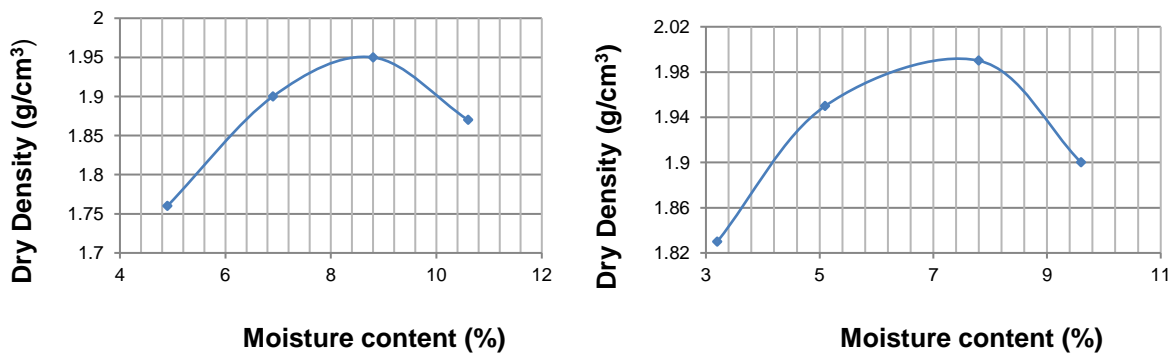


Figure 12 Compaction curve of sample P7-LAF and P8-LAF

Triaxial strength test

Triaxial strength test of selected representative samples were done using the Mohr circle for better interpretation of the failure plane. Selected samples of the drilled pits were subjected to appropriate confining overburden pressure using the triaxial cell. The hydraulic pressure was kept constant for the 3 cycles of each test and the deviator stress increased until coulomb’s failure occurred for the samples. When the soil samples finally failed, the shear stress on the failure plane that defines the shear strength of the soil was measured against the normal stress for each investigated sample (Figures 13 and 14) and was found to vary from 5-15KN/m². The triaxial test result of 55 KN/m² for clay layers was advanced Amu et al., (2011) in the Geotechnical properties of lateritic soil stabilized with sugarcane straw ash. This is quite higher than the 5-15KN/m² obtained in this study which has reflected more sandy soil than clayey soil.

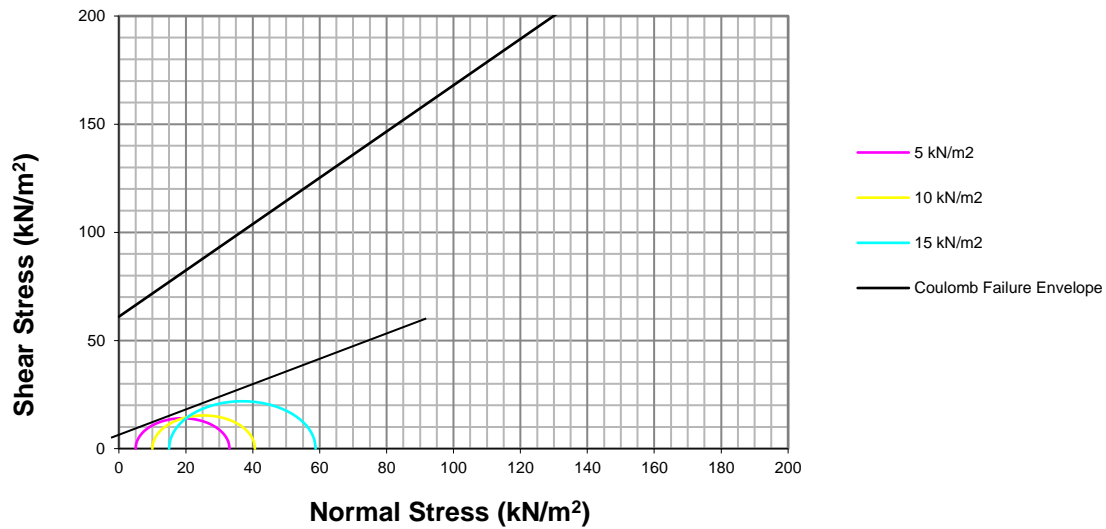


Figure 13 Mohr's circle curve of shear stress against Normal stress of P3-LAF.

It is worthy of note that the geometry of the shearing made all evaluated samples shorter while bulging out at the sides and as they grow taller again, they form the cycle series of short-tall samples episodes allowed the measurement of the stress and strain of tested samples in the area.

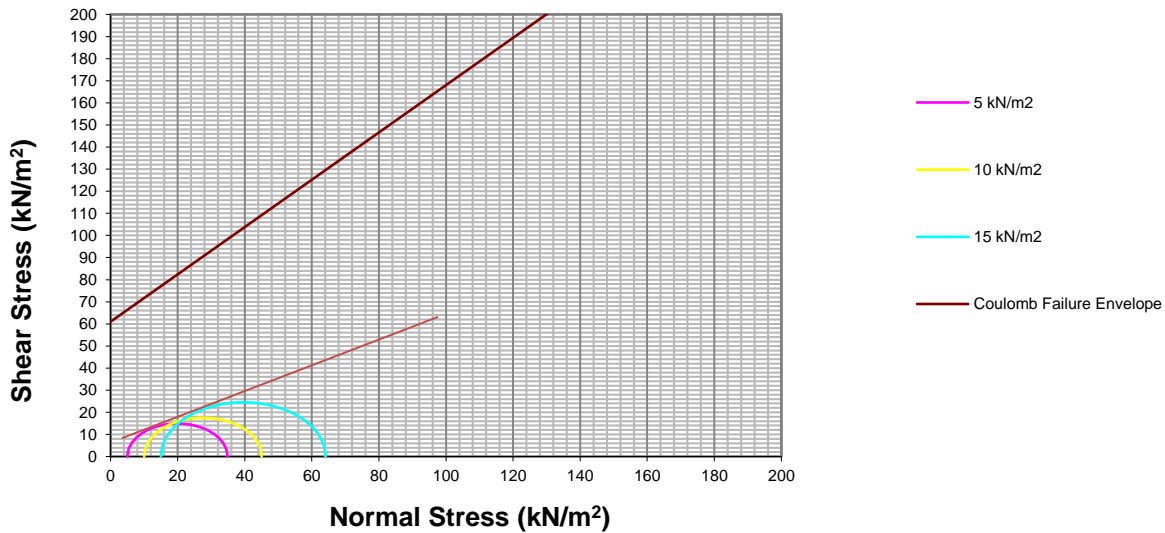


Figure 14 Mohr's circle curve of shear stress against Normal stress of P5-LAF

Atterbergs limit test

Atterberg's test was carried out on some of the study pit samples with low clay/silt content in their matrix (Table 14). As such, P1-P6 LAF samples were subjected to Atterberg's consistency limit test to determine their moisture content. The liquid limit, plastic limit and plasticity index were determined for the samples to know if they will need be excavated and replaced with a suitable geologic material

that will be crucial for the Bulk Water Supply (BWS) material in the area. P1-LAF had a plastic limit of 17.1% and a liquid limit value of 23.6% and a Plasticity index of 6.5% (Table 13) was also recorded. P2-LAF sample recorded a liquid limit value of 17.14%, plastic limit of 21.4% and Plasticity index of 4.96%. P3-LAF and P4-LAF recorded plastic limit of 0% and Liquid limit of 23.1 and 30.8% respectively.

Plasticity index of 23.1% and 30.8% respectively were also recorded. P5-LAF recorded a plastic limit of 1% and liquid limit value of 28.9% and Plasticity index of 27.9% (Table 13). P6-LAF recorded a Plastic limit of 2%, liquid limit of 33.7% and Plasticity Index of 31.7% (Figures 15, 16, 17 and 18). This is in wide variance with what was obtained in Ibrahim et al., (2024) the Geoscientific assessment of Kemanji Dam site using Kemanji and Semon river, Kaiama area, Kwara state, North-Central Nigeria.

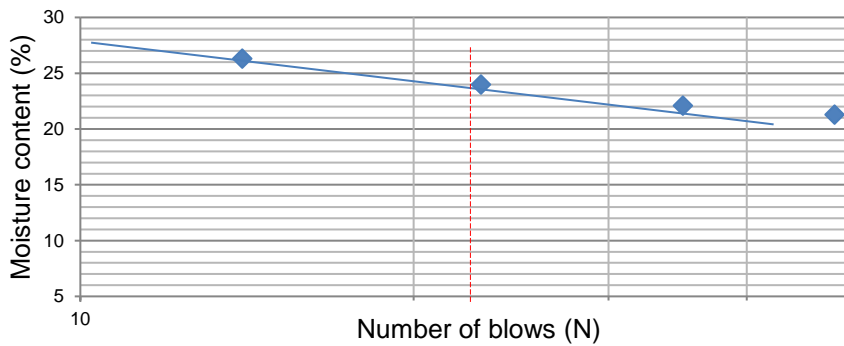


Figure 15 Atterbergs limit graph of the studied area

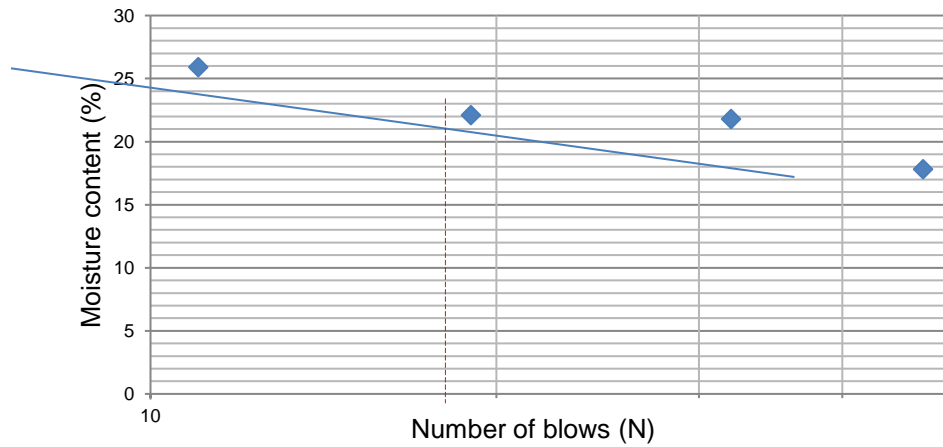


Figure 16 Atterbergs limit graph of the studied area

Table 14 Summary of Atterbergs content of studied samples in the area

S/N	PIT AND SAMPLE I.D	PLASTIC LIMIT (%)	LIQUID LIMIT (%)	PLASTICITY INDEX (%)
1	P1-LAF	17.1	23.6	6.5
2	P2-LAF	17.14	21.4	4.96
3	P3-LAF	0	23.1	23.1
4	P4-LAF	0	30.8	30.8
5	P5-LAF	1	28.9	27.9
6	P6-LAF	2	33.7	31.7

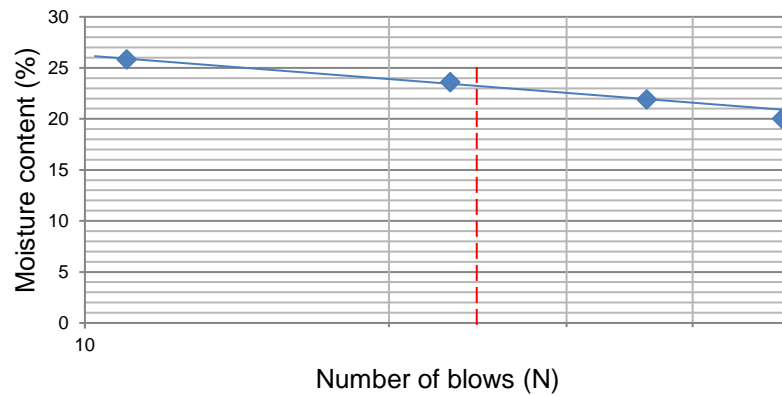


Figure 17 Atterbergs limit graph of the studied area

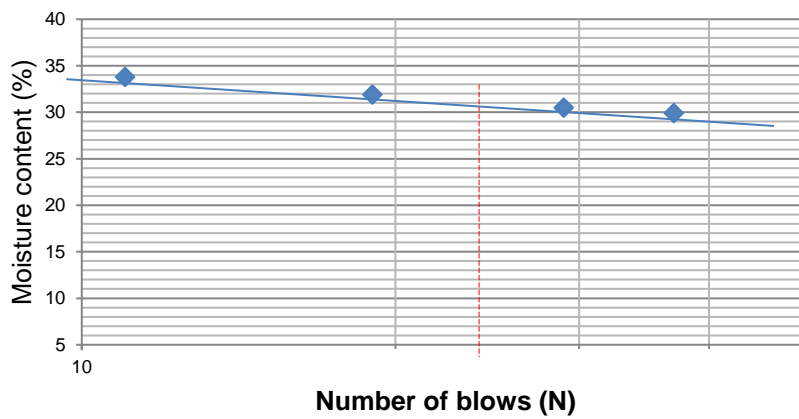


Figure 18 Atterbergs limit graph of the studied area

Load Bearing Capacities

Strip, Pad ie square and Circular foundational footings of the study area were assessed, calculated and computed for the load bearing capacities using Terzaghi equation (Terzaghi 1940). The load bearing capacity of the area for strip (Table 15) will be desirable for the anticipated load in the area. More importantly, Pad and circular foundational footing of the area (Tables 16 and 17) have all shown the stability and less settlement potential of the area. In essence strip is strongly recommended than the pad and circular footings.

$Q_u = c N_c + q D N_q + 0.5 \gamma B N_\gamma$equation 1 ie Strip footing

$Q_u = 1.3 c N_c + q D N_q + 0.4 \gamma B N_\gamma$equation 2 is square ie Pad footing

$Q_u = 1.3 c N_c + q D N_q + 0.3 \gamma B N_\gamma$equation 3 ie circular footing

The following equations were thus utilized for the computation of footings in the area with strip decided to be more desirable.

Table 15 Load bearing capacity for strip foundational footing of the study area

SN	Nc	Nq	Ny	c	γ	D	B	QU	Qa	Qs
P1S1	25.1	12.7	9.7	2	1194.1	3.0	2.5	588.64	196.21	87.21
P1S2	37.2	22.5	19.7	4	1305.9	3.0	2.5	1181.24	393.75	175.00
P2S1	25.1	12.7	9.7	5	1426.5	3.0	2.5	703.82	234.61	104.27

P2S2	17.7	7.4	9.5	22	997.1	3.0	2.5	337.00	112.33	49.93
P2S3	37.2	22.5	19.7	6	1405.9	3.0	2.5	1272.31	424.10	188.49
P3S1	37.2	22.5	19.7	22	911.8	3.0	2.5	831.74	277.25	123.22
P3S2	25.1	12.7	9.7	18	947.1	3.0	2.5	470.89	156.96	69.76
P3S3	37.2	22.5	19.7	17	958.8	3.0	2.5	872.44	290.81	129.25
P4S1	37.2	22.5	19.7	16	1002.9	3.0	2.5	911.93	303.98	135.10
P5S1	25.1	12.7	9.7	12	958.8	3.0	2.5	475.21	158.40	70.40
P5S2	17.7	7.4	5	15	923.5	3.0	2.5	260.27	86.76	38.56
P6S1	37.2	22.5	19.7	12	1041.2	3.0	2.5	945.02	315.01	140.00
P7S1	25.1	12.7	9.7	24	982.4	3.0	2.5	489.75	163.25	72.56
P9S1	17.7	7.4	5	26	1044.1	3.0	2.5	295.82	98.61	43.83

Qu - Ultimate Bearing Capacity, Qa - Allowable Bearing Capacity, Qs - Safe Bearing Capacity

Table 16 Load bearing capacity for square ie Pad foundational footing of the study area

SN	Nc	Nq	Nr	c	γ	D	B	QU	Qa	Qs
P1S1	25.1	12.7	9.7	2	1194.1	3.0	2.5	560.39	186.80	83.02
P1S2	37.2	22.5	19.7	4	1305.9	3.0	2.5	1118.61	372.87	165.72
P2S1	25.1	12.7	9.7	5	1426.5	3.0	2.5	670.27	223.42	99.30
P2S2	17.7	7.4	9.5	22	997.1	3.0	2.5	314.92	104.97	46.65
P2S3	37.2	22.5	19.7	6	1405.9	3.0	2.5	1205.07	401.69	178.53
P3S1	37.2	22.5	19.7	22	911.8	3.0	2.5	790.12	263.37	117.05
P3S2	25.1	12.7	9.7	18	947.1	3.0	2.5	449.70	149.90	66.62
P3S3	37.2	22.5	19.7	17	958.8	3.0	2.5	827.99	276.00	122.66
P4S1	37.2	22.5	19.7	16	1002.9	3.0	2.5	865.24	288.41	128.18
P5S1	25.1	12.7	9.7	12	958.8	3.0	2.5	453.29	151.10	67.15
P5S2	17.7	7.4	5	15	923.5	3.0	2.5	249.73	83.24	37.00
P6S1	37.2	22.5	19.7	12	1041.2	3.0	2.5	896.05	298.68	132.75
P7S1	25.1	12.7	9.7	24	982.4	3.0	2.5	468.16	156.05	69.36
P9S1	17.7	7.4	5	26	1044.1	3.0	2.5	284.38	94.79	42.13

Qu - Ultimate Bearing Capacity, Qa - Allowable Bearing Capacity, Qs - Safe Bearing Capacity

Table 17 Load bearing capacity for circular foundational footing of the study area

SN	Nc	Nq	Nr	c	γ	D	B	QU	Qa	Qs
P1S1	25.1	12.7	9.7	2	1194.1	3.0	2.5	815.82	271.94	120.86

P1S2	37.2	22.5	19.7	4	1305.9	3.0	2.5	1685.81	561.94	249.75
P2S1	25.1	12.7	9.7	5	1426.5	3.0	2.5	975.21	325.07	144.48
P2S2	17.7	7.4	9.5	22	997.1	3.0	2.5	522.78	174.26	77.45
P2S3	37.2	22.5	19.7	6	1405.9	3.0	2.5	1815.52	605.17	268.97
P3S1	37.2	22.5	19.7	22	911.8	3.0	2.5	1184.03	394.68	175.41
P3S2	25.1	12.7	9.7	18	947.1	3.0	2.5	651.07	217.02	96.46
P3S3	37.2	22.5	19.7	17	958.8	3.0	2.5	1242.91	414.30	184.13
P4S1	37.2	22.5	19.7	16	1002.9	3.0	2.5	1299.45	433.15	192.51
P5S1	25.1	12.7	9.7	12	958.8	3.0	2.5	657.62	219.21	97.43
P5S2	17.7	7.4	5	15	923.5	3.0	2.5	350.84	116.95	51.98
P6S1	37.2	22.5	19.7	12	1041.2	3.0	2.5	1347.31	449.10	199.60
P7S1	25.1	12.7	9.7	24	982.4	3.0	2.5	676.64	225.55	100.24
P9S1	17.7	7.4	5	26	1044.1	3.0	2.5	398.21	132.74	58.99

Ph, EC and SAR

The recorded Ph of the investigated samples varied significantly. P1S1 sample has a value of 4.60, P2S1, P3S1 and P4S1 all recorded 4.15, 2.35 and 1.80 respectively. More importantly, P5S1, P6S1, P7S1 and P9S1 all recorded 2.05, 4.08, 3.85 and 3.45 respectively (Table 18). pH of assessed samples were acidic ranging from 1.80-4.14, while Electrical conductivity ranged from 18.50 to 66.0 $\mu\text{S}/\text{cm}$ (Table 18). Sodium Adsorption Ratio gave a value that ranged from 0.004 to 1.56. These are values that are desirable for the soil to be used for sugarcane plantation. The Ph is in slight variance with what was obtainable Ibrahim et al., (2024) in the Oshin River area.

Table 18 Summary Inference of Ph, EC and SAR of collected samples in the area

S/N	SAMPLE CODES	Ph (H ₂ O)	EC ($\mu\text{S}/\text{cm}$)	SAR	Inferences
1	P1S1	4.60	24.00	1.56	Geochemical assessment showed no soil toxicity on BWS of the area, as such, no contamination of the soil was recorded, in essence, the soil is good for BWS
2	P2S1	4.15	23.00	1.12	
3	P3S1	2.35	53.50	0.004	
4	P4S1	1.80	41.00	0.04	
5	P6S1	2.05	18.50	1.54	
6	P6S1	4.08	74.00	0.005	
7	P7S1	3.85	66.00	0.77	
8	P8S1	3.45	19.00	1.53	

Ph is Hydrogen ion concentration, Electrical conductivity and SAR is the Sodium Adsorption Ratio.

The pH of surface soil samples were acidic to slightly alkaline while sub-surface soil samples were slightly acidic to strongly alkaline in Gandevi taluka. More importantly, the electrical conductivity of the surface soil samples ranged from 0.011 dS m⁻¹ observed in Kolva village of Gandevi taluka to 1.580 dS m⁻¹ observed in Natvad village of Vansda taluka Keniya et al., (2024) with an average of 0.483 dS m⁻¹.

Percentage Porosity, Organic carbon and Water Holding Capacity

Determination of these soil factors is to further evaluate the soil suitability for the sugarcane plantation. The mean porosity of the medium was established to reveal the movement of nutrient capacity in the soil and ranged from 22.05 to 34.08%. Organic carbon measurement ranged from 18.50% to 66.00% while the maximum water holding capacity of the area is said to be moderate with recorded values ranging from 21.1% to 31.5% Keniya et al., (2024) (Table 19) recorded a mean porosity of 48.39 in Sugarcane Cultivation Areas of Navsari District, Gujarat. Similarly, the Maximum water holding capacity of 36.81 was recorded in the area.

The percentage porosity ranged between 31.60-55.47 at the Khergam sugarcane plantation area. Water holding capacity measured in this area has shown a value that varied between 22.77% - 46.06 which is at variance with that of the Khergam proposed sugarcane plantation area. Variability of the groundwater condition in the area and climatic condition traced to climate change are critical factors that have the potential to alter the geochemical condition of the soil Ibrahim et al., (2024a), Ibrahim et al., (2024b) and Ibrahim et al., (2024c) which is replicable in the study area. More importantly, groundwater seepages in the excavated pit samples were not analyzed in the laboratory for further detail environmental condition. No contaminant of the soil that will warrant bioregulation.

Table 19 Summary inference of mean porosity, organic carbon and water holding capacity

S/N	SAMPLE CODES	Mean porosity (%)	OC (%)	MWHC (%)	Inferences
1	P1S1	24.60	24.00	21.5	Estimated Mean Porosity, Organic carbon and Maximum water holding capacity have all shown good environmental factors that will enhance BWS of the area for sugarcane plantation.
2	P2S1	24.15	23.00	21.1	
3	P3S1	22.35	53.50	26.8	
4	P4S1	31.80	41.00	23.8	
5	P6S1	22.05	18.50	31.5	
6	P6S1	34.08	74.00	27.5	
7	P7S1	23.85	66.00	28.7	
8	P8S1	23.45	19.00	29.9	

OC is Organic Matter content. MWHC is Maximum Water Holding Capacity

4. DISCUSSION

Evaluation of the study area for the purpose of design and Construction of bulk water supply that will serve a sugarcane plantation was concluded with Geo-technical and chemical evidences revealing the dominant silty-sandy soil in the area with minor clayey-sandy soil. The transformative properties of the soil shows the absence of swelling minerals like Smectite, Kaolinite and Montmorillonite in the void spaces and lattice layering of the 1:1 or 2:1 layers. There is a marked trend of decreasing value in analyzed samples, in essence, the free swelling index of the assessed samples have all reflected the variability of the clay content that showed is low and will not cause severe problem to the BWS area and pipeline.

Shear box test of the investigated soils are more cohesive with angle of internal friction that ranged from a value of 18°-31° with shear strength (C) varied between 2-18KN/m². Compaction test has shown the soil void spaces will be closed further as all air and water spaces closed with the soil getting to 1.66 g/cm³. Shear stress on the failure plane that defines the shear strength of the soil was measured against the normal stress to vary from 5-15KN/m².

5. CONCLUSIONS

P1-LAF had a plastic limit of 17.1% and a liquid limit value of 23.6%. Plasticity index of 6.5% was recorded. P2-LAF sample recorded a liquid limit value of 17.14%, plastic limit of 21.4% and Plasticity index of 4.96%. P3-LAF and P4-LAF recorded plastic limit of 0% and Liquid limit of 23.1 and 30.8% respectively. Plasticity index of 23.1% and 30.8% respectively were also recorded. P5-LAF recorded a plastic limit of 1% and liquid limit value of 28.9% and Plasticity index of 27.9%. P6-LAF recorded a Plastic limit of 2%, liquid limit of 33.7% and Plasticity Index of 31.7% with adequate load bearing capacities for strip, pad and circular types.

More importantly, Geochemical assessment of the area revealed pH of assessed samples were slightly acidic ranging from 1.80-4.14, while Electrical conductivity ranged from 18.50 µS/cm to 66.0 µS/cm Sodium Adsorption Ratio gave a value that ranged from 0.004 to

1.56. The mean porosity of the medium was established to reveal the movement of nutrient capacity in the soil and ranged from 22.05% to 34.08%. Organic carbon measurement that ranged from 18.50% to 66.00% revealed the soil is fertile, while the maximum water holding capacity of the area is said to be moderate with recorded values ranging from 21.1% to 31.5%. All obtained results have revealed good area for BWS for sugarcane plantation that will enhance economic prosperity and feasibility of a sugar factory and refinery construction in the area.

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Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Informed consent

Not applicable.

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Data and materials availability

All data associated with this study are present in the paper.

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