

Characterization of Density and Porosity of Rocks Samples from Ogun State of Nigeria

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Abstract

Knowledge of densities of rocks is essential in petrological and geological studies, interpretation of gravity anomalies and ground water exploration. Fifty samples were collected from Abeokuta, Sagamu, Odeda, Ewekoro, Ibese Yewa North Local Government, Ijebu East Local Government and Obafemi Owode in Ogun State and dry bulk density, saturated density, porosity and particle density were determined. Results showed that Ewekoro shale has the lowest mean density of 1.35g/cm³ while Ibese, Yewa North Local Government limestone has the highest mean density of 3.9g/cm³. Porosity ranges from 0.030 to 0.640 with the granite in Odeda local government having the highest porosity and the shale in Ewekoro local government having the lowest porosity. Mean porosity for all the rocks samples in the seven Local Government Areas was 0.34. Test of significance revealed that there is significant relationship in the values of density of rock samples within the state.

Keywords: dry bulk density, saturated density, particle density, porosity, groundwater exploration

1. Introduction

In geology, rock density has particular value as a theme that connects the properties of minerals and rocks to topics such as seismic velocity, isostasy and porosity (Robert and Robert, 2000). According to Caravaca et al. (2001) and Shrestha et al. (2007) study of bulk density, particle density, saturated density, porosity, organic matter content and size distribution of soil samples from an area reveal some vital soil physical properties of the area. Knowledge of densities of rocks is essential in petrological and geological studies and more so for a meaningful structural interpretation of gravity anomalies Ajakaiye (1975). It was also stated by Horgan (1996) that the gravity reduction is computed by taking the density as a constant (2.67g/cm³) which represents the topographical density.

The effect of density on porosity follows a mixing law. The porosity, ϕ , is the fractional pore volume of a rock. The total mass of a volume of rock V_T is made up of the mass of the pore fluid, of density ρ_f , plus the mass of the matrix minerals of density ρ_{ma} the density measured is the bulk density ρ_h .

The total mass then becomes:

$$Total\ Mass = V_T \rho_h = \phi V_T \rho_f + (1 - \phi) V_T \rho_{ma} \quad (1)$$

which gives a formula for the bulk density in terms of the porosity, pore fluid density and the matrix density. The mixing law for density is given as follows:

$$\rho_h = \phi \rho_f + (1 - \phi) \rho_{ma} \quad (2)$$

From the mixing law we can then find the porosity via:

$$\phi = \frac{\rho_{ma} - \rho_h}{\rho_{ma} - \rho_f} \quad (3)$$

2. Geology of Study Area

Ogun State is entirely in the tropics, located in the Southwest Zone of Nigeria with a total land area of 16,409.26 square kilometers. It is bounded on the West by the Benin Republic, on the South by Lagos State and the Atlantic Ocean, on the East by Ondo State, and on the North by Oyo and Osun States. It is situated between

Latitude 6.2°N and 7.8°N, and Longitude 3.0°E and 5.0°E. The geology of Ogun state comprises of sedimentary rocks and basement complex rocks, which underlay the remaining surface area of the state. It also consists of intercalations at argillaceous sediment. The rock is soft and friable but in some places cement by ferruginous on silicious material. It lies uncomfortably on the crystalline basement. The extensive Precambrian rocks are classified into three major groups: In Ogun state, the basement complex rock extends North western part to Ijebu-Igbo. They consist of rocks types like coarse – porphyroblastec – biotite – grained granite, biotite granite, gneiss, pegmatite porphyroblastic granite amphibolite schist quartzite, quartz – schist and banded gneiss (Iloje (1979).

The sedimentary rock unit of Ogun state consists of Abeokuta formation lying directly above the basement complex. This is in turn overlain by Ewekoro, Oshosun and Ilaro formations, which are themselves overlain by the coastal plain sands (Benin formation). The flood plains of the major rivers and streams are covered by the alluvial sands (Kehinde, 1992).

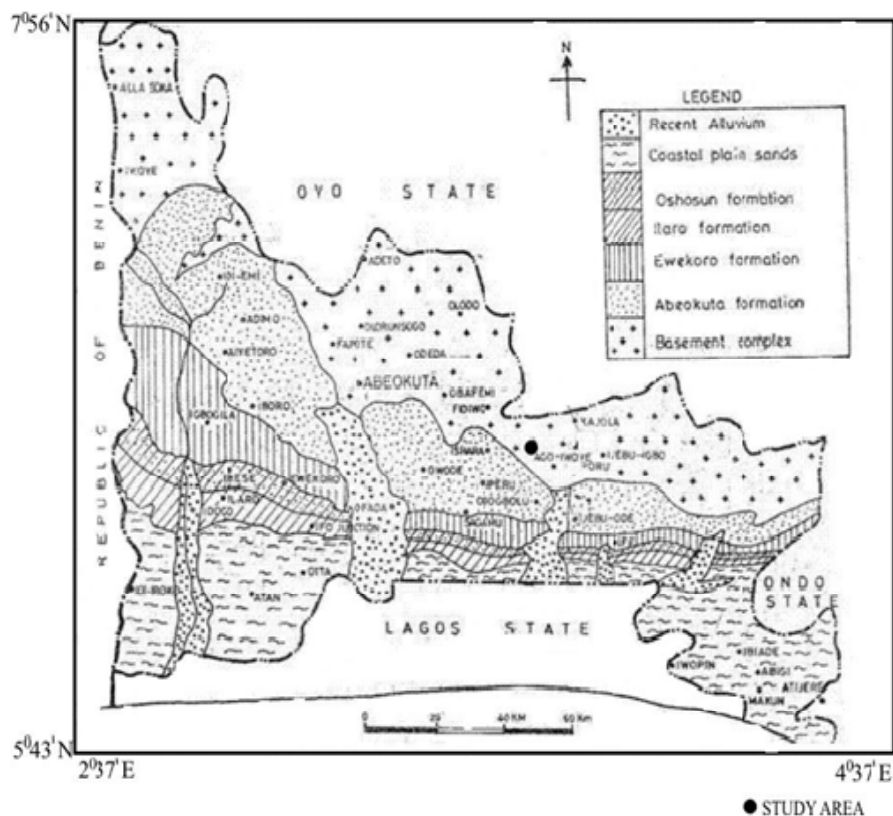


Figure 1. Geological Map of Ogun State

3. Methodology

Fifty rock samples were collected from Abeokuta North Local government and six other locations namely, Sagamu, Odeda, Ewekoro, Ibese/Yewa North Local Governments, Ijebu East Local Government and Obafemi-Owode in Ogun State. Samples were crushed into small grain size and later taken to the laboratory for analysis. Using an electronic weighing balance, 20g of rock samples were collected in 50 different crucibles and each crucible was labeled according to the sample description. The rock samples were heated in an oven at a temperature of 100°C for 18 hours and later weighed separately in air (w_d) and in water (w_w) (after adding 40ml of water to the samples). The samples were then saturated in water for 24 hours and weighed again in water (w_s) and in air (w_t). The weight in air after saturation (w_t) was measured by draining off the water remaining in the crucible and then weighing, using an electronic balance.

From the results obtained, that is, the value of W_d , W_w , W_t and W_s , the dry bulk density (ρ_d), saturated density (ρ_s) and particle or grain density (ρ_g) for the fifty rock samples was calculated using the following mathematical expression (Ajakaiye, 1975).

$$\text{Dry Bulk Density, } \rho_d = \frac{W_d}{W_t - W_s} \quad (4)$$

$$\text{Saturated Density, } \rho_s = \frac{W_t}{W_t - W_s} \quad (5)$$

$$\text{Particle or Grain Density, } \rho_d = \frac{W_d}{W_t - W_s} \quad (6)$$

$$\text{Porosity, } \emptyset = \frac{W_s - W_w}{W_d - W_w} \quad (7)$$

4. Results and Discussion

4.1 Results

Table 1 shows the densities of the fifty rock samples collected from the different locations of the study areas. Table 2 is the Analysis of variance of studied parameters while Table 3 shows the mean densities and porosity of the rock samples.

The map of Ogun State within which the study areas located is shown in Figure 1. Figure 2 is the bar chart of the dry bulk density, saturated density, particle density and porosity of the rock samples taken from Odeda Local government area. The samples collected from Odeda local government area are pegmatite, granite and quartzite. Figure 3 is the bar chart of saturated density, dry bulk density, particle density and porosity of limestone being the only rock samples collected from Sagamu LGA. Figures 4, 5, 6, 7 and 8 are the bar charts showing the dry bulk density, saturated densities, particle density as well as porosity of rock samples respectively from Abeokuta North, Ewekoro, Yewa North, Ijebu East and Obafemi-Owode local government area. Rock samples from Abeokuta North are quartzite, kaolin, feldspar and granite while limestone and granite were taken from Yewa North and Ijebu East Local Government Area. Also granite and kaolin were collected from Obafemi-Owode local government area and limestone and shale from Ewekoro Local Government Area.

Table 1. The densities of the fifty rock samples collected from the selected locations are given below

S/N	Sample Name	Sample Location	Dry bulk density (g/cm ³)	Saturated density (g/cm ³)	Particle density (g/cm ³)	Porosity
1	Pegmatite	OLG	1.83	2.2	3.66	0.309
2	Pegmatite	OLG	1.7	1.54	3.4	0.358
3	Pegmatite	OLG	1.71	1.22	3.42	0.355
4	Granite	OLG	1.74	3.5	3.48	0.343
5	Granite	OLG	1.72	2.07	3.44	0.351
6	Granite	OLG	1.55	1.9	3.1	0.415
7	Granite	OLG	1.86	2.25	3.72	0.298
8	Granite	OLG	1.82	2.26	3.64	0.313
9	Granite	OLG	1.99	2.4	3.98	0.249
10	Quartzite	OLG	1.88	2.43	3.76	0.291
11	Granite	OLG	7.6	7.61	7.63	0.64
12	Granite	OLG	3.08	3.09	3.09	0.4
13	Granite	OLG	2.82	2.95	3.24	0.08
14	Granite	OLG	2.22	2.22	2.22	0.12
15	Granite	OLG	3.12	3.12	3.12	0.44
16	Granite	OLG	1.99	2	2.02	0.09
17	Granite	OLG	1.85	1.85	1.85	0.08
18	Limestone	SLG	1.45	1.82	2.9	0.453
19	Limestone	SLG	1.96	2.31	3.92	0.261
20	Limestone	SLG	1.52	2.11	3.04	0.426
21	Limestone	SLG	1.58	2.02	3.16	0.404
22	Limestone	SLG	2.77	2.76	3.54	0.06
23	Quartzite	ANLG	1.61	1.93	3.22	0.392
24	Kaolitic clay	ANLG	1.3	1.94	2.6	0.509
25	Feldspar	ANLG	1.24	1.78	2.48	0.532
26	Granite	ANLG	1.76	2.17	3.52	0.336
27	Granite	ANLG	1.9	2.37	3.8	0.268
28	Limestone	ELG	1.72	3.4	3.44	0.351
29	Shale	ELG	1	1.61	4.96	0.623
30	Shale	ELG	1.23	2.19	2.46	0.536
31	Limestone	ELG	1.67	2.06	3.34	0.37
32	Limestone	ELG	1.56	2.02	3.12	0.41
33	Limestone	ELG	1.45	1.95	2	0.453
34	Shale	ELG	1.65	1.75	1.83	0.06
35	Shale	ELG	1.5	1.63	1.72	0.03
36	Limestone	YNLG	1.87	2.26	3.74	0.294
37	Limestone	YNLG	1.93	2.35	3.86	0.272
38	Limestone	YNLG	2.05	2.38	4.1	0.224
39	Granite	IELG	1.46	1.76	2.92	0.449
40	Granite	IELG	1.59	1.94	3.18	0.4
41	Granite	IELG	1.15	1.45	2.3	0.566
42	Granite	OOLG	1.59	3.13	3.18	0.4
43	Granite	OOLG	1.95	2.36	3.9	0.264
44	Granite	OOLG	1.89	2.3	3.78	0.287
45	Granite	OOLG	1.72	2.05	3.44	0.351
46	Granite	OOLG	1.85	2.26	3.7	0.302
47	Kaolin	OOLG	1.48	2.16	2.96	0.442
48	Granite	OOLG	1.69	2.07	3.38	0.362
49	Granite	OOLG	1.89	2.13	3.78	0.287
50	Granite	OOLG	1.93	2.23	3.86	0.272

OLG: Odeda Local government area

SLG: Sagamu Local government area

ANLG: Abeokuta North Local Government area

ELG: Ewekoro Local Government area

YNLG: Yewa North Local Government area

IELG: Ijebu East Local Government area

OOLG: Obafemi-Owode Local Government area

Table 2. Table of the analysis of variance of studied parameters

	Sum of Squares	df	Mean Square	F	Sig.
Saturated density Between Groups	3.598	6	0.6		
Within Groups	35.893	43	0.835	0.718	0.637
Total	39.491	49			
Dry bulk density Between Groups	6.87	6	1.145		
Within Groups	34.96	43	0.813	1.408	0.234
Total	41.831	49			
Particle density Between Groups	4.524	6	0.754		
Within Groups	36.183	43	0.841	0.896	0.506
Total	40.707	49			
Porosity Between Groups	0.12	6	0.02		
Within Groups	0.861	43	0.02	1.002	0.436
Total	0.982	49			

Table 3. The table below shows the mean densities of the rock samples

S/N	SAMPLE	Dry bulk density	Saturated density	Particle density	Porosity
1	Odeda granite	2.57	2.86	3.43	0.294
2	Odeda Pegmatite	1.75	1.65	3.49	0.341
3	Sagamu limestone	1.86	2.2	3.31	0.321
4	Ewekoro shale	1.35	1.8	2	0.312
5	Ewekoro limestone	1.6	2.36	2.98	0.396
6	Yewa North L.G limestone	1.95	2.33	3.9	0.253
7	Ijebu granite	1.4	1.72	2.8	0.472
8	Obafemi-Owode granite	1.81	2.32	3.63	0.316

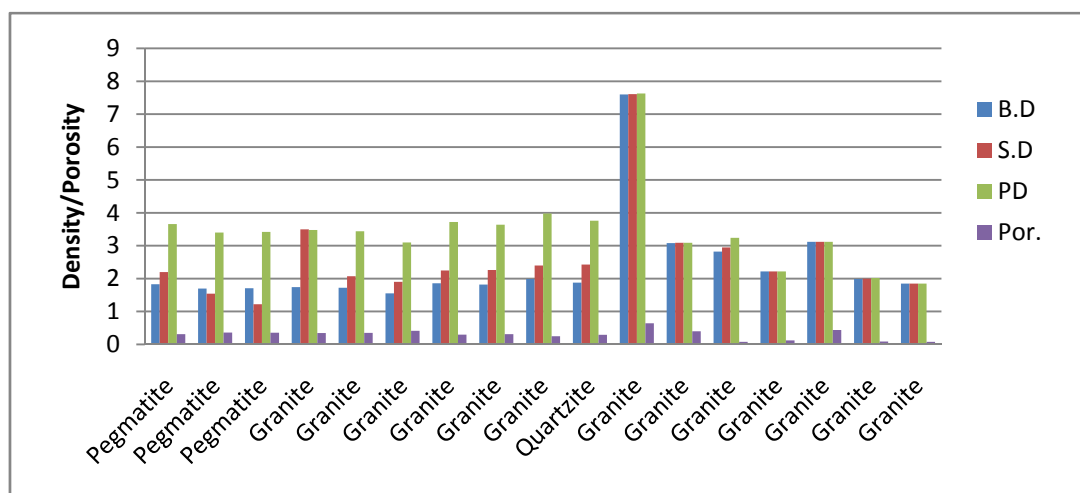


Figure 2. Bar chart of densities and porosity of samples from Odeda LG

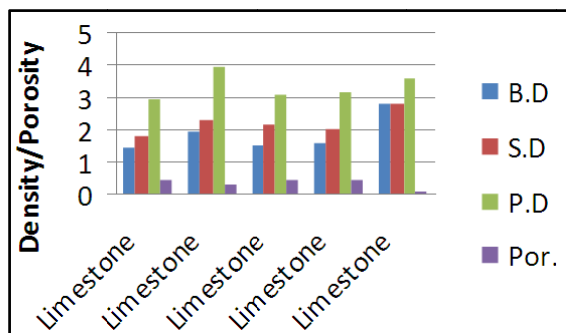


Figure 3. Bar chart of densities and porosity of samples from Sagamu LG

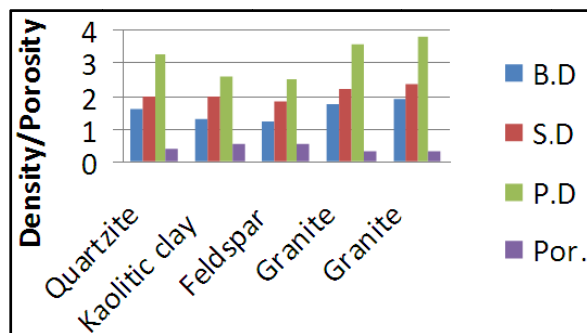


Figure 4. Bar chart of densities and porosity of samples from Abeokuta North LG

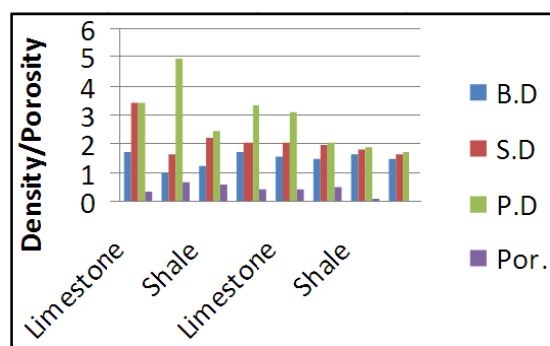


Figure 5. Bar chart of densities and porosity of samples from Ewekoro LG

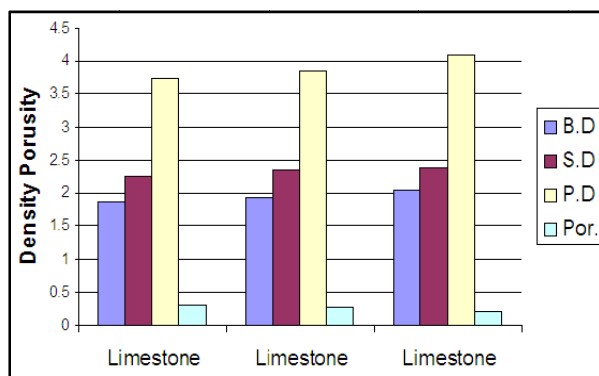


Figure 6. Bar chart of densities and porosity of samples from Yewa LG

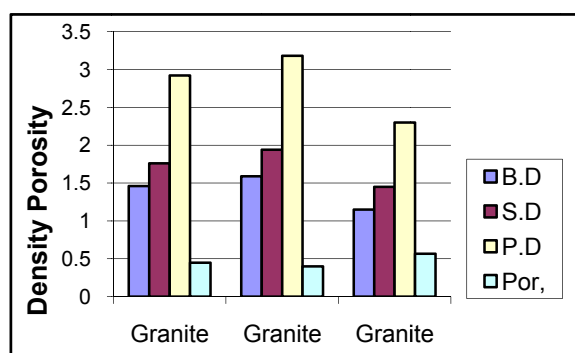


Figure 7. Bar chart of densities and porosity of samples from Ijebu East LG

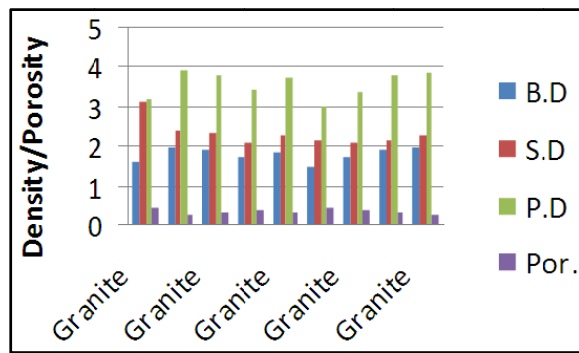


Figure 8. Bar chart of densities and porosity of samples from Obafemi-owode LG

4.2 Discussions

4.2.1 Dry Bulk Density

The only sample of quartzite from Odeda LGA has dry bulk density of 1.88g/cm³. The dry bulk densities of granite and pegmatite from the same LGA range from 1.55g/cm³ to 7.60g/cm³ and from 1.70g/cm³ to 1.83g/cm³ respectively. The dry bulk density of the limestone from Sagamu LGA ranges from 1.45g/cm³ to 2.77g/cm³. Two rock types collected from Ewekoro LGA were limestone and shale and their dry bulk density range from 1.45g/cm³ to 1.72g/cm³, and from 1.00g/cm³ to 1.65g/cm³ respectively. Dry bulk density of limestone from Yewa North LGA ranges from 1.87g/cm³ to 2.05g/cm³ while bulk density of granite from Ijebu East LGA ranges from 1.25g/cm³ to 1.46g/cm³. Two rock types samples were collected In Obafemi-Owode LGA, granite and kaolin. Dry bulk density of granites ranges from 1.48g/cm³ to 1.95g/cm³, while dry bulk density of kaolin in

Obafemi-Owode was 1.48g/cm^3 . From Figures 2 and 3, granite in Odeda LGA has the highest dry bulk density (3.12 g/cm^3) among rocks samples while shale in Ewekoro LGA has the lowest dry bulk density (1.00 g/cm^3).

4.2.2 Saturated Density

Saturated density of granite from Odeda LGA ranges from 1.85g/cm^3 to 7.61g/cm^3 while the saturated density of pegmatite ranges from 1.22g/cm^3 to 2.20g/cm^3 . Quartzite from Odeda has its saturated density determined to be 2.43g/cm^3 , while the saturated density of the limestone from Sagamu ranges from 1.82g/cm^3 to 2.76g/cm^3 . The saturated densities of limestone and shale in Ewekoro LGA range from 1.95g/cm^3 to 3.40g/cm^3 , and from 1.61g/cm^3 to 2.19g/cm^3 respectively. In Yewa North LGA saturated density of limestone ranges from 2.26g/cm^3 to 2.38g/cm^3 , while granites from Ijebu East LGA have saturated density ranging from 1.45g/cm^3 to 1.94g/cm^3 . Two rock types collected In Obafemi-Owode were granite and kaolin. The saturated density of granite in Obafemi-Owode ranges from 2.05g/cm^3 to 3.13g/cm^3 , while for kaolin in the same Local Government, saturated density was determined as 2.16g/cm^3 . Analysis of rock samples from Abeokuta North LGA shows that granite has the highest saturated density of 2.37g/cm^3 followed by quartzite, kaolitic clay and feldspar with 1.78g/cm^3 . Figures 1 to 8 revealed that granite has the highest and lowest saturated density among all rock samples considered. Granite with highest saturated density (3.5 g/cm^3) was in Odeda LGA while the one with least value (1.45 g/cm^3) was found in Ijebu East LGA.

4.2.3 Particle Density

Particle densities of granite and pegmatite in Odeda LGA range from 1.85g/cm^3 to 7.63g/cm^3 and from 3.40g/cm^3 to 3.66g/cm^3 respectively, while particle density for quartzite in the same LGA was 3.76g/cm^3 . The particle density of the limestone in Sagamu LGA ranges from 2.90g/cm^3 to 3.92g/cm^3 , while the particle density of limestone In Ewekoro LGA ranges from 2.00g/cm^3 to 3.44g/cm^3 . The particle density of shale from Ewekoro LGA ranges from 1.72g/cm^3 to 4.96g/cm^3 , while particle density of limestone from Yewa North LGA ranges from 3.74g/cm^3 to 4.10g/cm^3 . Particle density of granites from Ijebu East ranges from 2.30g/cm^3 to 3.18g/cm^3 , while the particle density of granite from Obafemi-Owode ranges from 3.18g/cm^3 to 3.90g/cm^3 . The particle density of kaolin for Obafemi-Owode was 2.96g/cm^3 . In Abeokuta North LGA, granite has the highest particle density of 3.80g/cm^3 followed by quartzite, kaolitic clay and feldspar with 2.48g/cm^3 . Figures 1 to 8 revealed that particle density was consistently high for all rocks from the state. It also shows that granite from Obafemi-Owode LGA has the highest particle density (3.9g/cm^3) among all rock samples, while shale from Ewekoro LGA has the least particle density (1.72 g/cm^3).

4.2.4 Porosity

Mean porosity of granite from Odeda LGA was determined to be 0.341. For the pegmatite rock samples, the mean porosity was 0.302 while the mean porosity of all the rock samples in Odeda LGA was found to be 0.302. In Odeda LGA granite rock samples has the highest (0.640) and the lowest (0.088) porosity. The porosity of five samples of limestone rock from Sagamu LGA ranges from 0.060 – 0.453, while mean porosity was 0.321. The four different rock samples from Abeokuta North LGA are; Quartzite, kaolitic clay, feldspar and two granite rock samples with porosity of 0.392, 0.509, 0.532, 0.336 and 0.268 respectively. It is clearly seen that the granite samples have lowest porosity when compared to other rock samples for this area. The mean porosity for the local government area was 0.407. Mean porosity of limestone and shale from Ewekoro LGA was 0.354 while the mean porosity of limestone and shale rock samples was 0.396 and 0.312 respectively. The porosity of limestone rock samples ranges from 0.351 – 0.453 while that of shale ranges from 0.030 – 0.623. The highest and lowest porosity was recorded by shale in this local government area. The porosity of granite from Obafemi-Owode LGA ranges from 0.264 – 0.316. The mean porosity for the granite was 0.316; the porosity for the Kaolin rock sample was 0.442. The mean porosity of all the rock samples collected in this area was 0.330.

Considering the mean porosity of all the seven local government areas, the mean porosity ranges from 0.302 - 0.472. The lowest mean porosity (0.302) was in Odeda local government area while the highest porosity (0.472) was in Ijebu-East local government area. Figures 1 to 8 compared the porosity of the samples and place of origin, it can be deduced that granite from Odeda LGA has the highest porosity (0.64) while shale from Ewekoro LGA has the least porosity (0.03).

4.3 Test of Significance

To test the trend of the densities and porosity in seven selected local government areas, null hypothesis, H_0 and alternative hypothesis, H_1 were set for saturated density as follows:

H_0 : There is no significant trend between saturated densities obtained from seven Local Government Areas

H_1 : There is significant trend between saturated densities obtained from seven Local Government Areas

From Table 2, F_{RATIO} (0.718) calculated for saturated density is greater than $F_{\text{TABULATED}}$ (0.637) at 5%, therefore suggesting that there is significant relationship between saturated densities obtained within the state.

Similarly for dry bulk density and particle density significant relationships exist between the dry bulk densities and also between the particle densities within the state. This is because F_{RATIO} (1.408) of dry bulk density is greater than $F_{\text{TABULATED}}$ (0.637) and also F_{RATIO} (0.896) of particle density is greater than $F_{\text{TABULATED}}$ (0.506).

Figure 2 also revealed that F_{RATIO} (1.002) calculated for Porosity is greater than $F_{\text{TABULATED}}$ (0.436) at 5% which suggests that there is significant relationship between porosity within the state.

5 Conclusion

The Limestone rock sample from Ibese, Yewa North Local Government area has the highest mean density value of 3.9g/cm^3 while the shale rock sample from Ewekoro has the lowest mean density of 1.35g/cm^3 . The highest porosity was from granite in Odeda local government area with a value of 0.640 and the lowest porosity was from Shale in Ewekoro Local Government Area. The mean porosity of all the rock samples is 0.34 which shows that all the location does not have the same mean porosity when one location is compared with the other locations. It was observed that significant relationship exists between densities within the state, as well as between porosity within the state.

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