GEOTECHNICAL INVESTIGATION OF GULLY EROSION SITES IN ANKPA METROPOLIS, KOGI STATE, CENTRAL NIGERIA.

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ABSTRACT

The study area covers Ankpa metropolis in Ankpa Local Government Area of Kogi State. It is underlain by rocks of Anambra Sedimentary basin consisting of Ajali Formation and Mamu Formation. Geotechnical investigations of soils from gully sites on the basis of Atterberg limit, particle size and compaction tests were carried out to assess the geopedologic and hydrologic causes of the gully erosion in the area and proffer solutions to the menace. Plasticity index of the soils ranges from 1.2% to 5.2% which shows that the soils are non-cohesive and non plastic. Sieve analysis revealed that the soils from the gully sites are within the medium to coarse grain range with low percentage of silt/clay, hence an indication that the soil is non-plastic. The compaction test shows that the optimum moisture content ranges from 13.50% to 15.20% while the maximum dry density ranges from 1.75mg/m^3 to 1.98mg/m^3. The maximum dry density values are generally low which indicates that the soil is not compact but loose. A proper and concrete drainage should be constructed along highways and areas suffering the menace of gully erosion. Concrete terracing of gully affected areas is recommended to reduce the impact or the force of rain-drop. This will reduce widening of incipient gullies. A holistic development program of monitoring the pedosphere is recommended to ensure a safe environment.

Key Words: Ankpa, Gully Erosion, Non-plastic soil, concrete terracing

INTRODUCTION

Gullies are steep-sided ravines, cut into susceptible, often shallow slope materials by the surface water from heavy rainfalls. Once initiated, they offer avenues for easy down-slope movement of water from later storms, Hudec, Peter P. (2002). The flowing water erodes soil from the sides and floor of each gully, making it wider and deeper. Unchecked progress of gullies results in 'badland' topography, and destroys the ecology and economy of the affected areas.

Vast area of Nigeria is underlain by thick, extensive sand and sandstone deposits. Though these geologic units enhance the groundwater resources potential of the areas, their good hydrologic properties often produce negative geotechnical impacts on the environment. Notable among these has been an increase in erodibility potential, accounting for the widespread development of deep extensive gullies, under the prevailing human influences incipient gullies develop with deep incisions around Ankpa & environs (Figure1). These have produced badland topography and created fears among the dwellers in the area.

Figure 1: An erosion gully site in Ankpa

Okogbue (2006) studied the factors that govern the development of gully erosion and landslides in southeastern Nigeria and summarized that gully erosion is controlled by physiography, geology, hydrogeology and engineering properties of the soil materials.

Akudinobi (1999) studied the hydrogeotechnical anthropogenic factors and its implications on soil/gully erosion in Nigeria. On the basis of his findings, high permeability and transmissivity values of the formations in addition to poor engineering practices contribute to gully developments. Egboka et al, (1993) in his contribution to gully erosion studies, said that the classical explanation of erosion is the ability of the agents of the environment (wind, water, man etc) to loosen, wear away, dislodge, transport and deposit particulate soil materials from one location to another. He further explained the loads of soil materials are carted off by floods, streams, rivers and sometimes man, down gradient to form alluvial deposits, fans, deltas, channels, bars e.t.c.

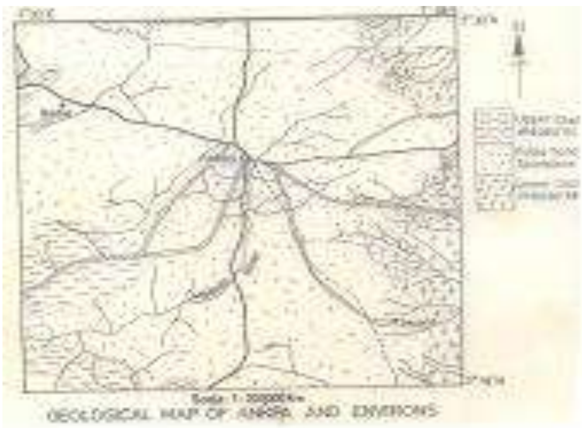
Ankpa falls within the Nigerian meteorological zone characterized by warm temperature days and moderately cool nights. Two distinct climatic divisions are demarcated. These are the dry and rainy seasons representing two broad periods of significant but contrasting variations in weather parameters, and hence geopedologic stability. The rainfall regime is very high resulting in significant reduction of average intergranular friction and shear resistance apparently due to reduced intergranular contact. Particle disaggregation rate of the soil zone thus increases, especially in the sandy formation. This study employs Atterberg limit determination, particle size analysis and compaction tests to determine the causes of gully erosion in the area.

MATERIALS AND METHOD OF STUDY

Traverse method of survey was employed to gain access to sample locations.Soil samples were obtained from incipient gullies at depths of 0.5m and 3.0m, wrapped in polythene bags and taken to the laboratory for Atterberg limits determination. In addition, particle size analysis for the soil samples was carried out using the American type of standard sieve(Half-phi ASTM stand) and a digital weighing balance. Furthermore, compaction test was employed with the aid of a BS 1377 mould and a 2.5 Rammer.

Geology of the Study Area

Ankpa falls within the Anambra basin whose genesis has been linked with the development of the Niger–Delta miogeosyncline and the opening of the Benue Trough (Murat, 1972). The stratigraphy comprises cyclic sedimentary sequence that started in the Early Cretaceous time (Reyment, 1965). Marine and fluviatile sediments comprising friable to poorly cemented sands, shales, clays and limestone were deposited, with occasional coal, peat and thin discontinuous seams of lignite (due Preez, 1945). These sediments have been affected by the major Santonian folding, and a minor Cenomanian folding and uplift (Murat, 1972).The study area is typical of Ajali Formation or the False bedded sandstone and the Mamu Formation .The Ajali consists of thick friable poorly sorted sandstone, typically white in colour but sometimes iron-stained. Ajali sand is often overlain by a considerable thickness of red earthly sands, formed by weathering and ferruginization of the Formation. The Mamu consist mainly of sandstone, carbonaceous shales, sandy shales and some coalseams (Figure 2).



Scale: 1:200,000km
Figure 2: GEOLOGICAL MAP OF ANKPA AND ENVIRONS

Dynamics of Gully Erosion

Gully development and spread involve disaggregation and removal of earth materials along a defined path downslope, in a course of running flood. Under satisfactory soil condition, flow velocity and volume constitute the major hydrologic factors controlling the potential for gully development.

The hydrologic components of eroding force (Fh) thus depend on the flow velocity (L/T) and the rate of increase of flow volume (V/T), given as:

$Fh = VL/T^2$ -- (1)

Where: L is distance parameter (M), V is average flow Volume (m^3) and T is time parameter (S). Thus,

$Fh = KVL/T^2$ --- (2)

Where: K represents a constant factor corresponding to an index property of the running flood specifically the density (P) substituting PV = M (mass of flowing water).

$Fh = ML/T$

$= (M/T.L/T)$ -- (3)

For flood force during erosion, M/T depends on the amount and intensity of rainfall, while L/T is slope – controlled. The effectiveness of the force further depends on the strength properties, particulate nature (lithology) and density of the bedrock or soil.

DISCUSSION OF RESULTS

Eight soil samples from four gully sites in the study area at depths of 0.5m and 3.0m were analyzed using Atterberg limits, sieve and compaction methods.

Table 1: Summary of Atterberg Limits of Soil Samples From Gully Sites in Ankpa metropolis.

LOCATION	DEPTH (m)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTIC INDEX (%)
Ankpa 1	0.5 3.0	28.60 26.90	24.80 23.50	3.80 3.40
Ankpa 2	0.5 3.0	29.50 28.00	24.30 25.00	5.00 3.00
Ankpa 3	0.5 3.0	28.90 27.00	24.50 23.00	4.40 4.00
Ankpa 4	0.5 3.0	30.80 28.20	26.80 27.00	4.00 1.20

Table 2: Standard Range of Plastic Limits of Soils (Clayton and Juckes, 1978).

PLASTIC LIMIT OF SOILS (%)	PLASTICITY
Below 35%	Low Plasticity
Between 35 – 50%	Intermediate Plasticity
Above 50%	High Plasticity

Table 3: Plasticity Indices and Corresponding States of Plasticity (Burmister, 1997)

S/N	PLASTICITY INDEX %	STATE OF PLASTIC
1	0	Non Plastic
2	1-5	Slight
3	5-10	Low
4	10-20	Medium
5	20-40	High
6	>40	Very High

Table 4: Graphic mean data interpretation for the study locations

Location	Depth (m)	Calculated Mean	Soil Description
Ankpa 1	0.5	1.33	Medium sand
	3.0	0.96	Coarse sand
Ankpa 2	0.5	2.00	Medium sand
	3.0	1.00	Coarse sand
Ankpa 3	0.5	1.33	Medium sand
	3.0	0.70	Coarse sand
Ankpa 4	0.5	1.32	Medium sand
	3.0	0.73	Coarse sand

Table 5: Standard table for mean grain size distribution (Wentworth, 1922)

Phi (∅) range	Descriptive terms
-1.00 – 0.00	Very coarse sand
0.00 – 1.00	Coarse sand
1.00 – 2.00	Medium sand
2.00 – 3.00	Fine sand
3.00 – 4.00	Very fine sand
4.00 – 5.00	Slit

Table 6: Summary of Compaction Test on soils in the study area

LOCATION	DEPTH (M)	OPTIMUM MOISTURE CONTENT	MAXIMUM DRY DENSITY (MMD) mg/m^3
Ankpa 1	3.0	13.50	1.98
Ankpa 2	3.0	15.20	1.78
Ankpa 3	3.0	13.50	1.98
Ankpa 4	3.0	14.80	1.75

Compaction Test Data For The Study Area

Ankpa 1

COMPACTION TEST NO	1	2	3	4	5
WT OF MOULD + WET SOIL (g)	3690	3807	3898	3860	3805
WT OF MOULD (g)	1821	1821	1821	1821	1821
WT OF WET SOIL (g)	1869	1986	2077	2039	1984
DENSITY OF WET SOIL (mg/m^3)	1.87	1.99	2.07	2.04	1.98

MOISTURE CONTENT										
TIN NO.	21b	32b	40b	33b	37b	20b	28b	44b	12b	8b
WT OF WET SOIL + TIN (g)	20.4	22.3	23.1	19.4	17.8	19.9	24.6	24.6	28.6	25.4
WT OF DRY SOIL + TIN (g)	19.5	21.2	21.7	17.9	16.3	18.5	22.3	22.3	25.3	22.6
WT OF TIN (g)	9.7	10.0	10.1	10.0	6.6	9.6	9.8	9.8	9.9	10.2
WT OF DRY SOIL (g)	9.8	11.2	11.6	7.9	9.7	8.9	12.5	12.5	15.4	12.4
WT OF WATER (g)	0.9	1.1	1.4	1.5	1.5	1.4	2.3	2.3	3.3	2.8
MOISTURE CONTENT(%)	9.2	9.8	12.1	18.9	15.5	15.7	18.4	18.4	21.4	22.6

Mean moisture content (%)	9.5	15.5	15.6	18.4	22.0
Dry Density (mg/m^3)	1.71	1.76	1.8	1.72	1.63

Ankpa 2

COMPACTION TEST NO	1	2	3	4	5
WT OF MOULD + WET SOIL (g)	3689	3834	3893	3859	3804
WT OF MOULD (g)	1821	1821	1821	1821	1821
WT OF WET SOIL (g)	1868	2013	2072	2038	1983
DENSITY OF WET SOIL (mg/m^3)	1.87	2.01	2.07	2.04	1.98

MOISTURE CONTENT										
TIN NO.	16a	11a	4a	8a	13a	15a	1a	6a	3a	12a
WT OF WET SOIL + TIN (g)	20.2	22.1	23.0	19.4	19.8	24.5	30.0	28.6	25.4	27.0
WT OF DRY SOIL + TIN(g)	19.3	21.0	21.6	17.8	18.4	22.2	26.8	25.3	22.6	24.9
WT OF TIN(g)	9.5	9.8	10.0	10.2	9.5	9.7	10.0	9.9	10.2	9.2
WT OF DRY SOIL (g)	9.8	11.2	11.6	7.6	8.9	12.5	16.8	15.4	12.4	15.7
WT OF WATER (g)	0.9	1.1	1.4	1.6	1.4	2.3	3.2	3.3	2.8	2.1
MOISTURE CONTENT (%)	9.2	9.8	12.1	21.1	15.7	18.4	19.0	21.4	22.6	13.4

Mean moisture content (%)	9.5	16.6	17.1	20.2	18.0
Dry Density (mg/m^3)	1.70	1.72	1.76	1.69	1.60

Ankpa 3

COMPACTION TEST NO	1	2	3	4	5
WT OF MOULD + WET SOIL (g)	3432	3779	4073	4010	3880
WT OF MOULD (g)	1821	1821	1821	1821	1821
WT OF WET SOIL (g)	1611	1958	2252	2189	2059
DENSITY OF WET SOIL (mg/m^3)	1.61	1.96	2.25	2.19	2.06

MOISTURE CONTENT										
TIN NO.	44b	51b	22b	31b	47b	20b	12b	34b	27b	41b
WT OF WET SOIL + TIN (g)	33.0	32.5	29.5	35.4	36.6	39.5	48.2	49.7	54.0	49.4
WT OF DRY SOIL + TIN(g)	32.1	31.5	28.0	33.5	33.7	36.2	42.3	44.4	47.9	42.9
WT OF TIN(g)	10.4	10.2	10.1	10.3	10.0	10.4	10.0	9.9	16.5	9.8
WT OF DRY SOIL (g)	21.7	21.3	17.9	23.2	23.7	25.8	32.3	34.5	31.4	33.1
WT OF WATER (g)	0.9	1.1	1.5	1.9	2.9	3.3	5.9	5.3	6.1	6.5
MOISTURE CONTENT (%)	4.15	4.69	8.38	8.19	12.24	12.79	18.27	15.36	19.43	19.64

Mean moisture content (%)	4.42	8.30	12.52	16.82	19.54
Dry Density (mg/m^3)	1.53	1.81	2.0	1.88	1.72

Ankpa 4

ACTION TEST NO	1	2	3	4	5
WT OF MOULD + WET SOIL (g)	3424	3779	4073	4073	4010
WT OF MOULD (g)	1821	1821	1821	1821	1821

WT OF WET SOIL (g)	1603	1958	2252	2252	2189
DENSITY OF WET SOIL (mg/m^3)	1.60	1.96	2.25	2.24	2.19

MOISTURE CONTENT										
TIN NO.	44b	51b	22b	31b	47b	20b	12b	34b	27b	41b
WT OF WET SOIL + TIN (g)	33.0	32.5	29.5	35.4	36.6	39.5	48.2	49.7	54.0	49.4
WT OF DRY SOIL + TIN (g)	32.1	31.5	28.0	33.5	33.7	36.2	42.3	44.4	47.9	42.9
WT OF TIN (g)	10.4	10.2	10.1	10.3	10.0	10.4	10.0	9.9	16.5	9.8
WT OF DRY SOIL (g)	21.7	21.3	17.9	23.2	23.7	25.8	32.3	34.5	31.4	33.1
WT OF WATER (g)	0.9	1.1	1.5	1.9	2.9	3.3	5.9	5.3	6.1	6.5
MOISTURE CONTENT (%)	4.15	4.69	8.38	8.19	12.24	12.79	18.27	15.36	19.43	19.64

Mean moisture content (%)	4.42	8.30	12.52	16.82	19.54
Dry Density (mg/m^3)	1.53	1.81	2.0	1.88	1.72

The liquid and plastic limits were used to obtain the Plasticity index, which is the measure of the plasticity of the soils (Onwemesi, 1990). A plasticity chart was plotted.

From the plasticity chart (Table 1), all the soil at the various gully sites have their plots clustered within the low plastic range (Figure 3), hence they are cohesionless. The values of the plastic index obtained ranged from 1.2% to 5.2% which is very low. Therefore, the noncohesive or the friable nature of the soils in the areas account for the gully erosion problem because water flows through the soils with ease and move the soil particles downslope with increase in velocity of motion of the water.

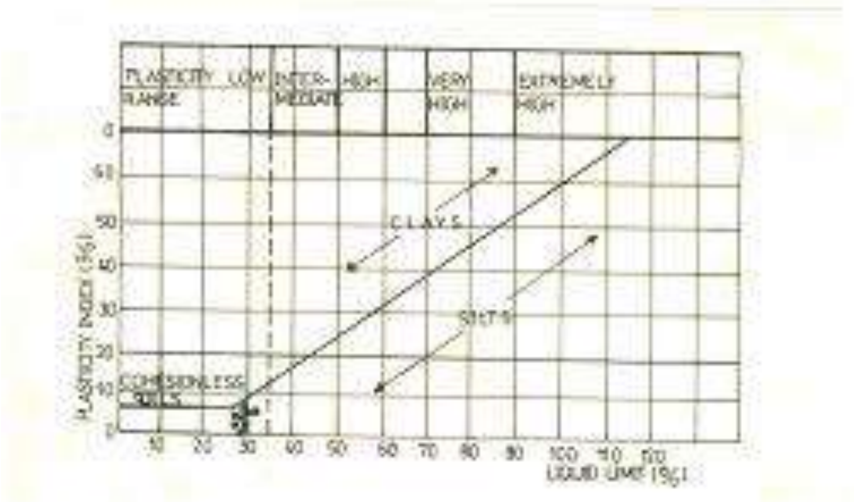


Fig2s. Plot of Atterberg Limits of Soil Samples on the Plasticity Chart

Sieve or particle size analysis involves the division of rock samples by sieving into sized fractions. The result can be used to distinguish between sediments of different environment and to classify soils. Cumulative curves of the various soils from gully sites were plotted. From the curves the graphic mean was calculated using the relation:

$$\text{Mean} = \frac{\varnothing 16 + \varnothing 50 + \varnothing 84}{3}$$

The graphic mean is used to calculate the average diameter of the grain interpreted using Wentworth scale (1922) for sand. The values of the parameters in the relation above were traced from the curves as summarized in table 4 above. A typical area is shown in figure 4.

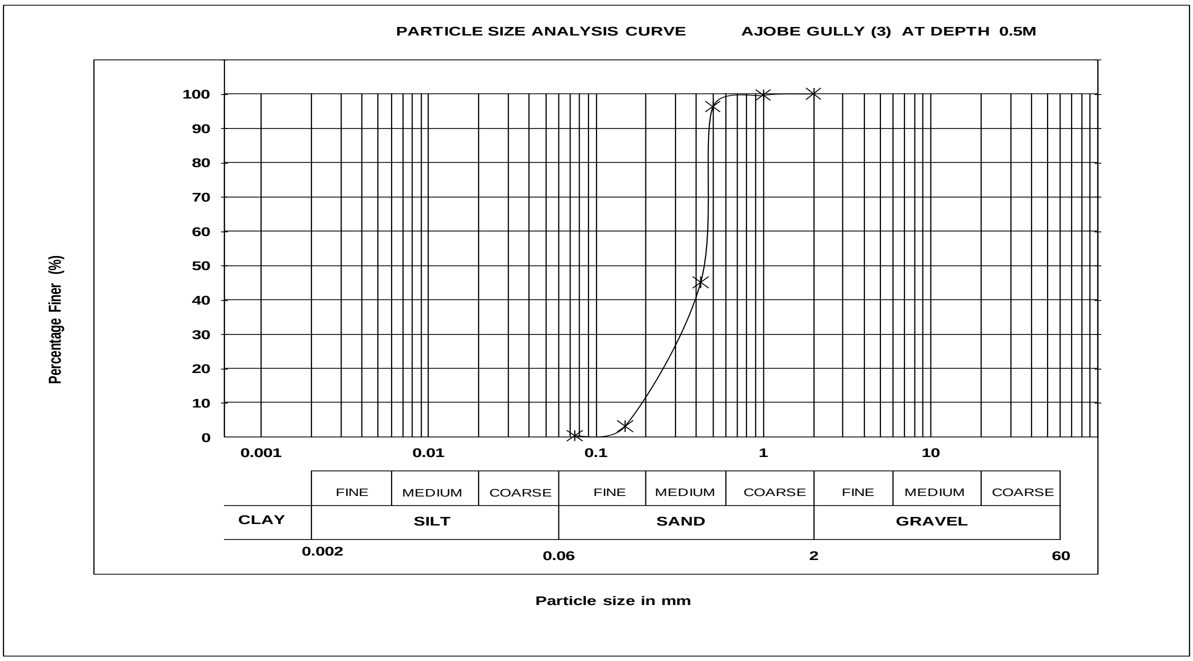


Figure 4: A typical sieve analysis curve for Ankpa

The result of sieve analysis shows a grain size distribution ranging from medium to coarse grain with strongly unimodal curves. The absence of "fines" or silt/clay content indicates that the soils are non-plastic. These areas correspond with outcropping locations of the aquiferous Ajali sandstone characterized by good transmissivity (T) and conductivity (K) values. Such severe gully erosion menace also exist in Nanka sands and the sandy members of the Ameki Formation in Anambra state where soil unit with similar hydrogeotechnical properties exist.

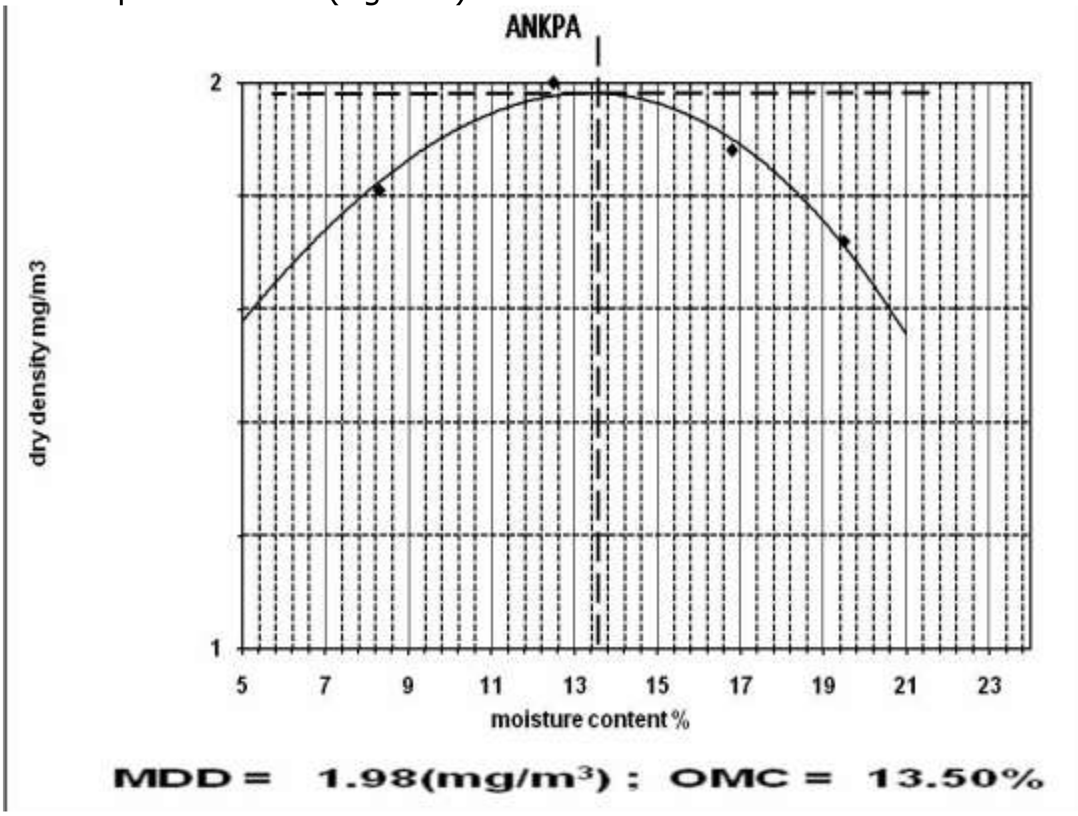
Compaction Test:

Compaction test shows the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) of the soils. However, due to seasonal changes, it is difficult to assign a standard value for the maximum dry density and optimum moisture content of a soil, because the minimum dry density and the optimum moisture content for a particular soil in the dry season differs from that in the rainy season. One of the major reasons for carrying out compaction test on soils is to increase the soil strength and to prevent seepage of water through the soil. Thus, the soil water content and the bulk density (dry density) both affect soil strength, which will increase when the soil is compacted to a higher density, and when the soil looses water, dries and hardens.

Though compaction test indicates the maximum dry density to which the soil may be compacted by a given force and it indicates when the soil is either drier or wetter than its optimum moisture content, compaction will be more difficult (Nyle C. Brady and Ray R. Weil, 1999).

The porosity and water content of a rock also governs its compressive strength which decreases with an increase in porosity, since the water present in the rock will reduce the magnitude of internal friction of the rock, consequently decreasing its strength; the moisture content thus reduces the soil strength (Garg, 2003).

The compaction test in table 6 shows that the optimum moisture content ranges from 12.5% to 17.7% while the maximum dry density ranges from 1.76mg/m^3 to 2.0mg/m^3 (Figure 5). The maximum dry density values are generally low signifying that the soil is not compact but loose (Figure 6).



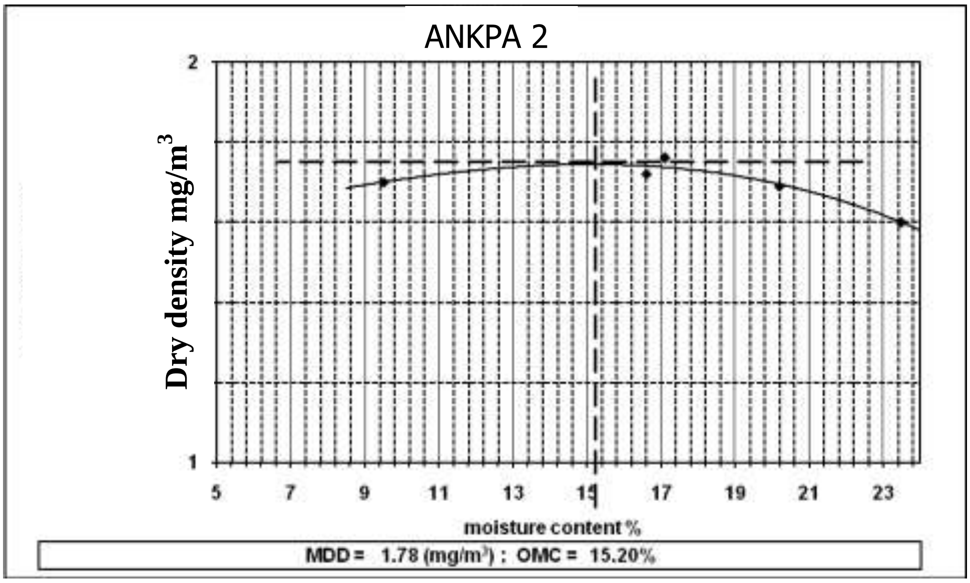


Figure 6: Dry density versus Moisture curve

CONCLUSION AND RECOMMENDATIONS

The result of the Atterberg, sieve and compaction tests shows that the soil in the study area are cohesionless, not compact, and non-plastic, hence the menace of gully erosion has a geopedologic and hydrologic influence. An integrated use of agronomic and engineering practices that will protect the soil and reduce run-off is required. This will involve afforestation and tillage practice that will ensure optimum absorption of rainfall. A proper and concrete drainage should be constructed along highways and areas suffering the menace of erosion. Concrete terracing of gully affected areas is necessary to reduce the impact or the force of raindrop. This will reduce widening of incipient gullies. Erodibility potential maps need to be prepared, using geological and geotechnical properties of the soil zones. Areas with high potentials for gully erosion hazards should be delineated for closer monitoring on regular basis.

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