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Original Research Article

Interaction of Chemical, Physicochemical, and Geotechnical Soil Properties of Anambra State Gully Erosion Sites

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Abstract

Disturbed subgrade soil samples were collected from five (5) different erosion sites in Anambra State, Nigeria. In-situ and laboratory tests were conducted to ascertain the biochemical, physicochemical, and geotechnical properties of these samples. The topsoil characteristics were studied differently from the subsoil characteristics. All the samples considered were non plastic (from Atterberg limit tests). The result of relative size of soil particles in Anambra state reveals a higher mean values of sand when compared to silt and clay. The maximum dry density of the soil averaged (1858.19 ± 52.257) kg/m^3 and (1866.986 ± 50.298) kg/m^3 for the topsoil and subsoil respectively indicating high compaction values. The sodicity (Sodium Absorption Ratio and Exchangeable Sodium Percentage) of the soil was used to measure the dispersiveness of the soil, and the results show that Anambra state soils are highly dispersive, especially the topsoil. Hence, it is highly related to the erodibility of the soils in the zone considered. Furthermore, correlation analysis showed that there is a considerable correlation between geotechnical, physicochemical and biochemical properties of the soils in the state with the presence of sodium playing a major role in determining the influential properties.

Keywords: Gully erosion, Anambra State, sodicity, dispersiveness, biochemical properties.

1.0 INTRODUCTION

Soil erosion is amongst the main environmental hazards in the world. Soil erosion is responsible for loss of farmlands, displacement of people from their homes, disruption of movement along major highways and general economic recession in south-Eastern Nigeria. According to Osadebe *et al.*, (2014), 70% of the land belonging to Anambra State has been threatened by erosion at various levels of development. Although efforts have been made towards arresting this menace, it continues to increase in its severity.

In 2009, the World Bank report on countries listed gully erosion as one of the major hazards that threatens the Nigerian environment. Since then there has been an emergence of several gullies and the old ones have attained disaster levels (Akpokodje *et al.*, 2010). Past researchers disclosed that only the Agulu-Nanka gully accounts for loss of agricultural land to the tune of 930 hectares (Ofomata, 1981). Similarly, the united nation development program cited Nanka erosion gullies in Anambra State as the most comples erosion site in the world (UNDP, 1997). This calls for Emergency in the issue of erosion ravaging the state.

According to Igwe (2012), numerous factors either acting concurrently or individually detach, transport and deposit soil particles in other places other than their origin leading to soil erosion. Several researchers have proposed various causative factors that cause intense gullies in the south eastern part of Nigeria. Although these proposed factors are distinctive, they are related. Some of these findings have been summarised by Oraefo (2005) and is presented here as Table 1.

Table 1.0: Summary of opinion of various researchers on the causes of gullying (Oraefo, 2005)

Author(s)	Causes of gullying
Floyd (1965)	Soil Characteristics and human activities
Ofomata (1965)	Mainly soil characteristics, less of human activities
Ogbukagu (1976)	Mostly geological formation and soil characteristics

Author(s)	Causes of gullying
Nwajide and Hoque (1979)	Topography, climate, and soil characteristics
Egboka and Nwankwo (1985)	Mostly groundwater conditions and soil characteristics
Uma and Onuoha (1986)	Groundwater flow conditions

The aim of this research therefore is to thoroughly investigate the relationship between the biochemical, physicochemical, and geotechnical properties of the major erosion sites in Anambra State. A good knowledge of this interaction is crucial to effectively tackle the menace of erosion in Anambra state.

2.0 STUDY AREA

The study area lies within latitudes 5° 45N to 6° 45N and 7° 15E to 7° 45E in the Anambra basin. The Anambra State is widely covered by geological units of Nanka Sand (Ecocene), overlain by paralic Ogwashi-Asaba formation (Oligocene) and underlain by the marine Imo Shale (Paleocene) (Okoro *et al*., 2010). Ancient Cretaceous deltas make up the sedimentary rocks while Imo shale is dominant on the surface, occasionally clay iron stones and sandstone beds. A geological map of Anambra state is shown in Figure 1.

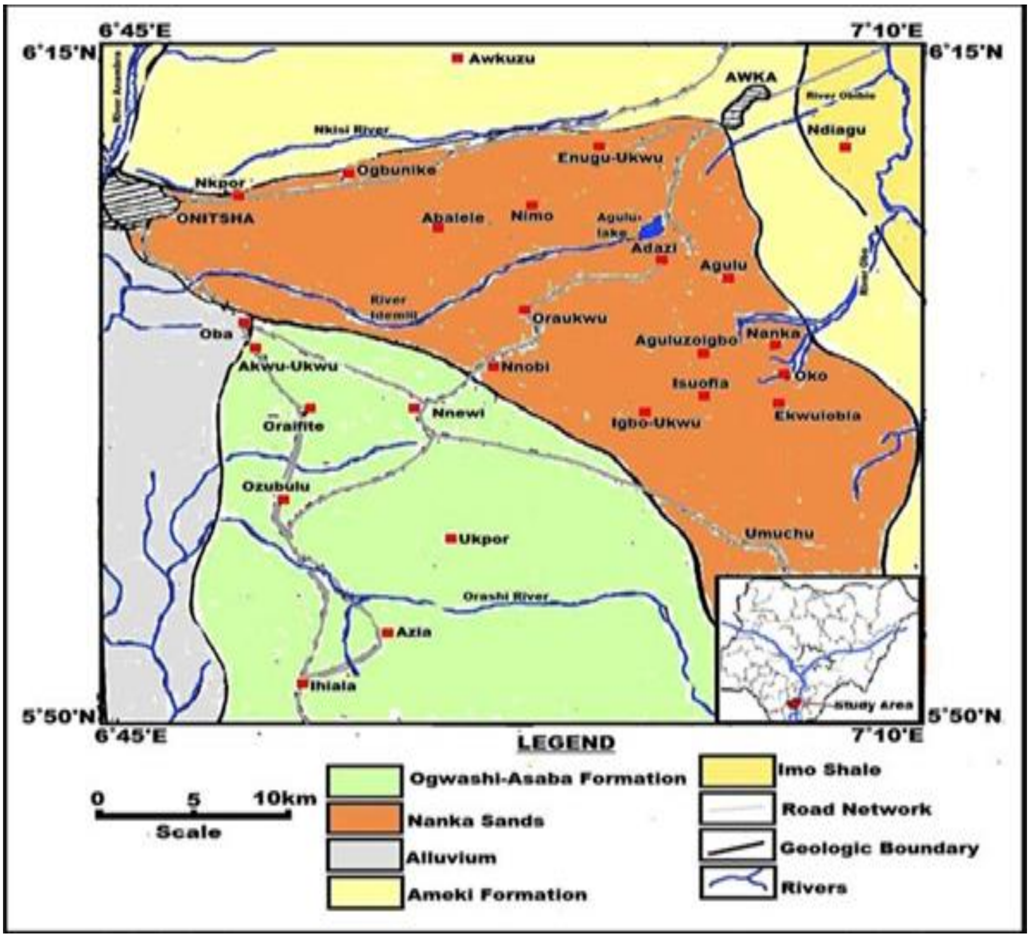

Figure 1: Geologic Map of Anambra State

Anambra State lies within the tropical rainforests which are very fragile habitats. Frequently, they are "wet deserts" which grow on soils poor in nutrients.in tropical regions; the bedrock is weathered and old hence, depleted in minerals and nutrients. The mineral release is also inhibited by the acidic nature of many tropical soils. The soil types derived from the bedrock underlying tropical forests are mainly soils called oxisols and ultisols (Richter and Babbar, 1991). Oxisols have high aluminium and iron oxide content and low silica content. Ultisols are described as highly-weathered acidic soils. However ultisols are less usually found than oxisols. These two types of soils, generally of low fertility, comprise about 43% of the soils under tropical rainforests (Hoffman and Carroll, 1995). Oxisols are acidic soils and contain considerable quantities of iron and aluminium. Under dry conditions and, particularly in soils with high iron contents and low silicate content, the oxides in oxisols form impermeable layers, known as laterite, below the surface. Thus, when the forests overlying such oxisols are cut down, the logged area becomes much drier and eroded, and this often leads to lateralization. This will not happen if the surface is covered with trees and vegetation. Because laterite is impermeable, the rain will run off quickly, leading to erosion and flooding. Lateralization is not reversible. Many essential elements such as calcium and potassium are easily leached out by the heavy tropical rainfall, further reducing soil nutrient levels. There are few nutrients more than 5cm (2 inches) below the surface of the soil in tropical rainforests (Rainforest Conservation Fund, 2013).

3.0 METHODOLOGY

Disturbed soil samples were collected from different areas in Anambra state for the purpose of testing and analysis as shown in Tables 2.0 and 3.0 below. Also some in-situ tests were also carried out at the sites. Table 2.0 shows the GPS location and elevation above ground level (G.E) of the selected erosion sites, while Table 3.0 shows the erosion status and gully profile of the selected sites.

Table 2.0: GPS Location and Ground Elevation (G.E) above sea level of the selected sites

S/No	Gully Profiles	GPS Location	G.E.
1	Agu-Awka	N06^{O} 13.159/E007^{O} 05.258’	140m
2	Agulu	N06^{O} 06.895/E07^{O} 02.434’	193m
3	Nanka	N06^{O} 02.654’/E007^{O} 04.922’	259m
4	Ekwulobia	N06^{O} 01.761’/E007^{O} 05.198’	283m
5	Ogidi	N06^{O} 09.448’/E006^{O} 51.062’	138m

Table 3.0: Erosion status and gully profiles of the selected sites

S/No	Gully Profiles	Erosion Status (m)	Top Soil (m)	Sub Soil (m)	Underlying Rocks/Stones (m)	Total Depth (m)
1	Agu-Awka	Moderately gullied	0.96	13.63	3.96	18.55
2	Agulu	Most Severely gullied	0.87	29.93	2.90	33.70
3	Nanka	Most Severely gullied	0.40	11.90	47.77	60.07
4	Ekwulobia	Most Severely gullied	0.94	23.80	13.97	38.71
5	Ogidi	Severely gullied	0.20	10.48	12.53	23.21

All geotechnical tests conducted were in conformity with AASHTO sampling and testing protocols and also as recommended by the Federal Ministry of Works (F.M.W) specifications for Roads and Bridges (1997). Heavy metal analysis was conducted using Varian AA240FS Atomic Absorption Spectrophotometer according to the method of APHA (American Public Health Association) 1995. Other tests were carried out using specified and recommended laboratory procedures. The results obtained were subjected statistical analysis using statistical software package. Values are taken to be significant at $P < 0.05$.

4.0 RESULTS AND ANALYSIS

The laboratory results from analysis carried out on the soil samples are presented in the subsections below. The different erosion sites considered were Agu-Awka, Agulu, Nanka, Ekwulobia, and Ogidi.

4.1 Geotechnical/physical parameters

In this section, the geotechnical parameters reported are the particle size distribution, consistency limits, soil sedimentation, water content, CBR, compaction test results, soil densities, and porosity.

4.1.1 Particle Size Distribution

The results from the particle size distribution analysis are as shown in Table 4.0. For the top soil at the various sites, the (Mean ± SEM) of sand, clay and silt, are (80.288 ± 5.22) %, (10.816 ± 3.72) %, and (8.896±3.30) % respectively. Also for the sub soil, the (Mean ± SEM) of sand, clay and silt, are (77.148 ± 4.129) %, (19.156 ± 3.35) %, and (5.19 ± 1.474) % respectively.

Table 4.0: Particle size distribution of the selected sites

Site	Sand (%)		Clay (%)		Silt (%)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	80.51	74.23	6.19	24.33	13.3	9.0
Agulu	84.01	70.99	10.43	23.36	5.56	5.56
Nanka	69.31	72.01	24.27	23.49	6.42	4.50
Ekwulobia	69.91	75.11	10.99	18.11	19.1	6.78
Ogidi	97.70	93.40	2.2	6.49	0.10	0.11

4.1.2 Soil Sedimentation

The results from the soil sedimentation are as shown in Table 5.0. For the top soil at the various sites, the (Mean ± SEM) of 5 seconds, 10 seconds and 20 seconds sedimentation values, are (0.647 ± 0.536) secs, (0.68 ± 0.539) secs, and (0.7376 ± 0.544) secs respectively. Also for the sub soil, the (Mean ± SEM) of 5 seconds, 10 seconds and 20 seconds sedimentation values, are (0.558 ± 0.234) secs, (0.7044 ± 0.228) secs, and (0.772 ± 0.240) secs respectively

Table 5.0: Soil sedimentation value of the selected sites

Site	5sec Sedimentation		10sec Sedimentation		20sec Sedimentation	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	0.092	0.87	0.112	0.93	0.2	0.98
Agulu	0.22	1.32	0.31	1.42	0.42	1.52
Nanka	0.061	0.32	0.066	0.42	0.078	0.5
Ekwulobia	0.072	0.063	0.082	0.072	0.09	0.081
Ogidi	2.79	0.22	2.83	0.68	2.9	0.78

4.1.3 Natural moisture content and CBR

The results from the laboratory determination of the natural moisture content and the California Bearing Ratio (CBR) are as shown in Table 6.0. The Mean ± SEM of the water content (%) and CBR (%) of the top soil are (9.14 ± 1.10) % and (45.3 ± 7.68) % respectively. For the sub soil, the Mean ± SEM of the water content (%) and CBR (%) are (8.896 ± 1.377) % and (46.2 ± 5.56) % respectively.

Table 6.0: Natural Moisture Content and CBR of the selected sites

Site	Water content (%)		CBR (%)	
	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	7.84	3.72	73	62
Agulu	8.12	9.13	45	57
Nanka	9.34	10.27	30	39
Ekwulobia	7.10	11.87	47	39
Ogidi	13.30	9.49	32	34

4.1.4 Soil densities and porosity

The results from the laboratory determination of the soil densities (pore density and bulk density) and porosity are shown in Table 7.0. The Mean ± SEM of the pore density (g/cm^3), bulk density (g/cm^3) and porosity (%) for the top soil in the various sites are (1.182 ± 0.066) g/cm^3, (1.152 ± 0.047) g/cm^3 and (0.176 ± 0.012) % respectively. For the sub soil, the Mean ± SEM of the pore density (g/cm^3), bulk density (g/cm^3) and porosity (%) at the various sites are (1.156 ± 0.026) g/cm^3, (1.19 ± 0.037) g/cm^3 and (0.174 ± 0.012) % respectively.

Table 7.0: Soil densities and porosity results of the selected sites

Site	Pore Density (g/cm^3)		Bulk Density (g/cm^3)		Porosity (%)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	1.30	1.13	1.25	1.09	0.17	0.21
Agulu	1.35	1.20	1.06	1.32	0.18	0.16
Nanka	0.99	1.16	1.11	1.19	0.16	0.14
Ekwulobia	1.18	1.07	1.06	1.16	0.15	0.18
Ogidi	1.09	1.22	1.28	1.19	0.22	0.18

4.1.5 Soil compaction

The results from the soil compaction tests are as shown in Table 8.0. The Mean ± SEM of the optimum moisture content (%) and maximum dry density (kg/m^3) of the top soil are (13.026 ± 1.579) % and (1858.19 ± 52.257) kg/m^3 respectively. For the sub soil, the Mean ± SEM of the optimum water content (%) and MDD (%) are (11.548 ± 1.622) % and (1866.986 ± 50.298) kg/m^3 respectively.

Table 8.0: Soil compaction properties of the selected sites

Site	Optimum Moisture Content (%)		Maximum Dry Density (kg/m^3)	
	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	11.70	5.70	1859.42	2023.55
Agulu	9.30	13.08	2004.07	1890.66
Nanka	13.19	13.03	1843.76	1905.68
Ekwulobia	12.13	15.19	1902.13	1763.14
Ogidi	18.81	10.74	1681.57	1751.90

4.2 Soil Physicochemical Properties

The physicochemical properties observed in-situ and in the laboratory which are discussed in this section are the soil percolation, base saturation, rheology, soil temperature, pH, soil resistivity, organic matter content, cation exchange capacity, and loss on ignition. The results obtained are presented in the subsections below.

4.2.1 Soil percolation, base saturation, and rheology

Table 9.0 shows the Mean ± SEM value of the soil percolation (seconds), base saturation (%), and rheoogy of all the zones under consideration. The Mean ± SEM of the percolation (seconds), base saturation (%) and rheology (pa/sec) for the top soil in the various sites are (429.732 ± 200.12) secs, (102.236 ± 1.355) % and (0.0866 ± 0.0032) pa/sec respectively. For the subsoil, the Mean ± SEM of the percolation (seconds), base saturation (%) and rheology (pascals/second) at the various sites are (347.134 ± 100.449) secs, (102.04 ± 0.4088) % and (0.085 ± 0.00268) pa/sec respectively.

Table 9.0: Soil percolation, base saturation, and rheology properties of the selected sites

Site	Percolation (secs)		Base Saturation (%)		Rheology (pa/sec)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	36.33	381	106.79	102.09	0.081	0.079
Agulu	207.33	322.33	100.12	102.19	0.090	0.085
Nanka	111	708.67	100.27	103.38	0.078	0.091
Ekwulobia	1068	143.67	103.94	100.86	0.088	0.091
Ogidi	726	180	100.06	101.68	0.096	0.079

4.2.2 Soil pH values, resistivity, organic matter content, loss on ignition, cation exchange capacity

Table 10.0 shows the Mean ± SEM value of the pH values, resistivity, organic matter, loss on ignition and cation exchange capacity for the topsoil which are (6.466 ± 0.161), (0.01245± 0.0061) cm/μs, (1.818 ± 0.243)%, (47.4 ± 3.411)%, and (1.524 ± 0.377) cmol$_c$/kg respectively. While the Mean ± SEM values of pH values, resistivity, organic matter, loss on ignition and cation exchange capacity for the subsoil are (6.578 ± 0.141), (0.0191 ± 0.0096) cm/μs, (1.556 ± 0.105)%, (35.2 ± 4.0391)%, and (0.36 ± 0.029) cmol$_c$/kg respectively.

Table 10.0: Results of other physicochemical properties of the selected sites

Site	pH		SR (cm/μs)		SOMC (%)		LOI (%)		CEC (cmol$_c$/kg)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	6.48	6.56	0.00065	0.00030	2.25	1.83	39	34.5	0.20	0.44
Agulu	6.72	6.43	0.0357	0.00357	2.30	1.64	42	25	2.08	0.34
Nanka	5.87	7.13	0.0133	0.033	1.16	1.67	58.5	42.5	2.08	0.29
Ekwulobia	6.78	6.38	0.0074	0.0087	1.30	1.23	47/.0	46	1.15	0.31
Ogidi	6.48	6.39	0.0052	0.0500	2.08	1.41	50.5	28	2.11	0.42

SR – Soil Resistivity; **SOMC** – Soil organic matter content; **LOI** – Loss on ignition; **CEC** – Cation Exchange Capacity

4.3 Soil minerals

Soil minerals that were tested in the laboratory are the essential elements, trace elements, heavy metals, and metalloids.

4.3.1Essential Elements

Table 11.0 shows the Mean ± SEM value of the soil essential elements which are sodium, calcium, magnesium, and potassium. The Mean ± SEM (in ppm) of the sodium, calcium, magnesium and potassium for the top soil in the various sites are (360.72 ± 96.62) ppm, (2.737 ± 1.648) ppm, (1.506 ± 0.979) ppm and (6.037 ± 1.347) ppm respectively. For the sub soil, the Mean ± SEM (in ppm) of the sodium, calcium, magnesium and potassium are (79.766 ± 5.75) ppm, (1.357 ± 0.271) ppm, (0.952 ± 0.738) ppm and (1.560 ± 0.371) ppm respectively.

Table 11.0: Results of the Essential Elements Content of the sites

Site	Sodium (ppm)		Calcium (ppm)		Magnesium (ppm)		Pottasium (ppm)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	31.462	92.158	2.716	1.822	5.040	3.860	8.298	1.073
Agulu	475.654	76.077	0.495	1.471	0.160	0.130	2.281	1.743
Nanka	475.654	66.136	1.125	1.992	0.000	0.000	6.423	2.885
Ekwulobia	263.192	70.038	9.100	0.525	0.070	0.050	3.735	0.727
Ogidi	475.654	94.423	0.249	0.975	2.260	0.720	9.449	1.373

4.3.2 Trace elements

Table 12.0 shows the Mean ± SEM value of the tested soil trace elements which are copper, zinc, manganese, and cobalt. The Mean ± SEM (in ppm) of the copper, zinc, manganese and cobalt for the top soil in the various sites are (4.798 ± 1.217) ppm, (118.63 ± 11.417) ppm, (2.00 ± 1.549) ppm and (0.1522 ± 0.0389) ppm respectively. For the sub soil, the Mean ± SEM (in ppm) of the copper, zinc, manganese and cobalt are (10.798 ± 3.745) ppm, (127.076 ± 21.857) ppm, (1.6 ± 1.166) ppm and (0.1584 ± 0.0207) ppm respectively.

Table 12.0: Results of the Trace Elements Content of the Various Sites

Site	Copper (ppm)		Zinc (ppm)		Manganese (ppm)		Cobalt (ppm)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	5.330	24.670	163.100	117.410	8.000	0	0.198	0.215
Agulu	2.670	11.330	102.940	159.590	0	0	0.188	0.197
Nanka	3.330	3.330	117.110	173.300	2.000	0	0.213	0.149
Ekwulobia	3.330	9.330	102.790	48.480	0	2.000	0.162	0.123
Ogidi	9.330	5.330	107.210	136.600	0	6.000	0	0.108

4.3.3 Heavy metals

Table 13.0 shows the Mean ± SEM value of the soil essential elements which are cadmium, nickel, chromium, and lead. The Mean ± SEM (in ppm) of the cadmium, nickel, chromium, and lead for the top soil in the various sites are (0.00 ± 0.00) ppm, (0.1336 ± 0.065) ppm, (91.2 ± 9.499) ppm and (0.358 ± 0.212) ppm respectively. For the sub soil, the Mean ± SEM (in ppm) of the cadmium, nickel, chromium, and lead are (0.0014 ± 0.0014) ppm, (0.1908 ± 0.107) ppm, (96.8 ± 8.616) ppm and (0.0794 ± 0.0354) ppm respectively.

Table 13.0: Results of the Heavy Metal Content of the Various Sites

Site	Cadmium (ppm)		Nickel (ppm)		Chromium (ppm)		Lead (ppm)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil
Agu-Awka	0	0	0.034	0.020	116.000	104.000	0.200	0.050
Agulu	0	0	0.050	0.029	72.000	88.000	0.200	0.050
Nanka	0	0.007	0.268	0.420	108.000	124.000	1.200	0.050
Ekwulobia	0	0	0.316	0.484	68.000	72.000	0.110	0.270
Ogidi	0	0	0	0.001	92.000	96.000	0.080	0.220

4.3.4 Other metals and metalloids

Table 14.0 shows the Mean ± SEM value of other metals and metalloids which are silver, iron, aluminuim, and metalloid (silicate). The Mean ± SEM (in ppm) of the silver, iron, aluminium, and silicate for the top soil in the various sites are (0.7704 ± 0.0505) ppm, (8.982 ± 2.936) ppm, (9.978 ± 3.230) ppm and (7.518 ± 0.585) ppm respectively. For the sub soil, the Mean ± SEM (in ppm) of the silver, iron, aluminium, and metalloid are (0.8174 ± 0.116) ppm, (11.712 ± 2.122) ppm, (10.286 ± 4.76) ppm and (6.822 ± 1.00) ppm respectively.

Table 14.0: Results of Other Metals and Metalloid Content of the Various Sites

Site	Silver (ppm)		Iron (ppm)		Aluminium (ppm)		Metalloid (Silicate) (ppm)	
	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Sub Soil	Top Soil	Subsoil
Agu-Awka	0.711	0.886	2.160	5.140	4.900	0	7.140	9.820
Agulu	0.699	0.551	17.790	15.450	7.660	9.610	9.310	5.450
Nanka	0.922	0.716	13.920	11.350	13.120	6.470	8.190	4.200
Ekwulobia	0.662	1.231	5.500	9.590	3.200	7.110	7.140	8.320
Ogidi	0.858	0.703	5.540	17.030	21.010	28.240	5.810	6.320

5.0 DISCUSSION OF RESULTS

The discussion of the results is grouped into geotechnical parameters, degree of dispersiveness, and correlation of the analysis results.

5.1 Discuss on geotechnical parameters

The results of soil particle size distribution of erosion sites in Anambra state reveal a higher mean values of sand at (80.288 ± 5.22 and 77.148 ± 4.129) at the top soil and sub soil respectively. This agrees with earlier observation of Obasi (2013) in his works from southern Nigeria who stated that percentage of sand composition ranges from 71% to 85%. Though sand is believed to enhance drainage (infiltration) and so does not allow overland flowing of water yet these areas are still susceptible to soil erosion. Onwuka *et al*., (2012) stated that high sand composition implies low binding factor with the soils which explains unconsolidated, friable and loose nature of the rocks which enhances erodibility. Soil texture within Anambra State shows that the soils in the state is predominantly sandy which is in conformity with the characteristics of tropical rainforest; it gets saturated easily and becomes vulnerable to runoff and concentrated runoff leads to erosion (Egboka, 1993., Mirsal, 2008., Obasi, 2013., Rainforest Conservation Fund, 2013).

The erodibility of soil increases with increased compaction because it reduces water infiltration (affects soil available water) by closing pore spaces thereby increasing surface runoff. According to Ekeocha and Akpokodje (2014), in their work, maximum dry density (MDD) range of 1760 to 2030 kg/m3 was obtained from subgrade soils in Benue trough of southeastern Nigeria while our average result was (1858.19 ± 52.257) kg/m3 for topsoil and (1866.986 ± 50.298) kg/m3 for subsoil. This shows that Anambra state soils are following Federal Government specifications for non-weak soils (Onwuka *et al*., 2012). High compaction values for Anambra State soils depict high susceptibility to erosion. Erodibility increases with increasing compaction value which results in an increase in bulk density but the decrease in atterberg limit against (Onwuka *et al*., 2012) submission that low bulk density increases susceptibility to erosion. This is dependent on soil texture as fine-textured surface soils such as silt loams, clays, and clay loams generally have lower bulk densities than sandy soils which our soil samples are predominantly made of.

The pH of the eroded sites is slightly acidic at (6.466 ± 0.161) for topsoil and (6.578 ± 0.141) for subsoil, and this acidic nature could enhance chemical reactions with certain minerals thereby weakening the structure of the soil and making it more susceptible to erosion. Onwuka *et al*., (2012) observed a lower pH of between 5.2 and 5.4 in Nanka and Ekwulobia axis which made the soils easily detachable and could be transported from one location to another by agents of erosion.

The results of base saturation were low and it agrees with Nwachokor *et al*., (2009) that high precipitation which is predominant with tropical rainforest can lead to leaching of basic cations from the soils and this enhances erodibilty. Onweremadu (2007) added that high rainfall amount, duration and intensity may have increased leaching of these basic cations even in clayed soils. He noted a significant relationship between exchange basic cations and sand, silt contents. This study also recorded the same relationship.

5.2 Evaluation of the degree of dispersiveness

The presence of high sodium concentration makes the soil more dispersive (Batool *et al*., 2015). The two parameters which are often used to check the chemical compatibility are Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP). This is often referred to as the ‘sodicity’ of soils.
Sodium Absorption Ratio (SAR) is given by;

$$SAR = \frac{Na^+}{\sqrt{0.5(Ca^+ + Mg^+)}} \quad \text{------------------------ (1)}$$

Where, Sodium, Calcium and Magnesium are in units of milliequivalent per litre (meq/l) The exchangeable sodium percentage (ESP) is given by;

$$ESP = \frac{Na^+ \times 100}{\sum Cations} \quad \text{------------------------------ (2)}$$

At the topsoil for the sites considered, the average sodium, calcium, magnesium, and potassium in meq/l are, (14.970 ± 3.842), (0.1368 ± 0.082), (0.1254 ± 0.0816), and (0.1545 ± 0.0344), respectively.

$$\text{Hence } SAR = \frac{14.970}{\sqrt{0.5(0.1368 + 0.1254)}} = 41.344$$

$$ESP = \frac{14.970 \times 100}{14.970 + 0.1368 + 0.1254 + 0.1545} = 97.291\ \%$$

Since SAR (41.344) > 10, soils are highly dispersive (Harmse and Gerber, 1988) and since ESP (97.291%) > 15%, soil is strongly sodic, hence highly dispersive and erodible (Wikipedia, 2016). Hence high sodium content strongly contributes to the problem of erosion in Anambra State.

For the subsoil samples considered, the average sodium, calcium, magnesium, and potassium content in meq/l are, (3.4659 ± 0.251), (0.06785 ± 0.0125), (0.0792 ± 0.0615), and (0.039935 ± 0.0095), respectively.

$$\text{Hence } SAR = \frac{3.4659}{\sqrt{0.5(0.0678 + 0.0792)}} = 12.784$$

$$ESP = \frac{3.4659 \times 100}{3.4659 + 0.06785 + 0.0792 + 0.0399} = 94.88\%$$

Since SAR (12.784) > 10, the subsoils are highly dispersive and since ESP (94.88%) > 15%, they are also strongly ‘sodic’, hence highly dispersive and erodible.

This result suggests that the top soils in those areas are highly more erodible than the sub soils. It also suggests that high sodium content strongly contributes to the problem of erosion in Anambra State.

On considering the sites individually, the SAR and ESP are as shown in Table 15.0.

Table 15.0: Evaluation of the 'sodicity' of the various erosion sites

Site	SAR		ESP	
	Top Soil	**Sub soil**	**Top Soil (%)**	**Sub Soil (%)**
Agu-Awka	2.595	8.822	64.040	90.105
Agulu	149.882	16.088	99.535	96.243
Nanka	123.318	12.859	98.944	94.300
Ekwulobia	23.839	24.681	95.363	98.415
Ogidi	65.283	17.608	97.904	96.614

We can verify from Table 15.0 that soil from Agu-Awka erosion site was less 'sodic' than soils from the other sites. Also the same Agu-Awka erosion site was less gullied than the rest from physical observation. However, a lot of other factors can be related to this including anthropogenic factors, groundwater conditions, geologic structure, and age of erosion. However, soil chemistry has offered an insight on what might be a contributing factor.

5.3 Significant Correlation analysis for the subsoil parameters

In the subsoil of the sites tested, pH of the soil correlated positively with the percolation and base saturation of the soils in the eroded zone. This suggests that pH plays an important role in the erodibility of the subsoils of Anambra state. (See APPENDIX 1).

Among the essential elements, sodium correlated positively with the CBR of the tested soils (correlation coefficient of 0.9191) and also correlated positively with the maximum dry density (correlation coefficient of 0.8172) of the soils. It however correlated negatively with the optimum moisture content. This is consistent with the results from the work of (Amu and Salamu, 2010) where the addition of common salt (Sodium Chloride) improved the CBR and compaction characteristics of lateritic soils. Also (Dubey and Jain, 2015) have discovered in their research that the addition of Sodium Chloride (NaCl) improved the maximum dry density, and soaked CBR of black cotton soils from 1.64 g/cm3 to 1.79g/cm3 and 1.43% to 3.10% respectively. This suggests that sodium content at a certain percentage has a direct positive relationship with the strength of soils at lower water content (sodium correlated negatively with natural moisture content). The results also suggest that calcium, magnesium, and potassium have a positive relationship with the strength of soils (using CBR and maximum dry density as Adhoc references). Calcium correlated positively with Maximum Dry Density, Base Saturation, Organic Matter Content, pH, clay, and silt content. It is pertinent to note that other elements that correlated positively with sodium are magnesium, copper, cobalt, and silicate at correlation coefficients of 0.8617, 0.9824, 0.8734, and 0.6996 respectively. It will be logical to believe that these elements are contributing to the dispersiveness of the subsoils in Anambra state.

However, Ding *et al*., (1996) found that the addition of only sodium silicates to hydrated clay may actually negatively affect soil stabilization. Clay particles typically have a net negative charge on their face and a positive charge along their edges due to broken bonds. upon addition of sodium silicates to ad hydrated clay, the silicate ions that are negatively charged from the sodium silicates are attracted towards clay particle edges causing the clay particles to become negatively charged. When the clay particles become negatively charged, the repel one another, hence the structure becomes weak and dispersed. . Although sodium silicates may weaken clay when added alone, Ruff and Davidson (1961) affirm that sodium silicates may strengthen clay if lime (Calcium Carbonate) is added along with the sodium silicates.

Among the trace metals, copper correlated positively with CBR and MDD, while manganese correlated negatively with CBR and MDD but correlated positively with sand content in the areas tested. Cobalt correlated positively with CBR and MDD but correlated negatively with sand content.

5.4 Significant Correlation analysis for the topsoil parameters

It was however interesting to realize that for the topsoil, sodium content correlated negatively with the CBR values of the soil (correlation co-efficient of 0.92757) (see APPENDIX 2). The hypothesis is that this is happening because of the relatively high content of sodium in the topsoil. For instance, you can verify that we recorded the highest CBR value (72%) at the topsoil of Agu-Awka which has the lowest sodium content at 31.462 ppm. While this may not be a piece of concluding evidence, the average sodium content of the topsoil is (360.72 ± 96.62) ppm as opposed to the sodium content of the subsoil at (79.766 ± 5.75) ppm. This is about a 77.88% difference. Research by Madurwar *et al*., (2013) on black cotton soils has shown that the stabilization of soil by addition of sodium silicate showed about 15.5% reduction in the 7 days soaked CBR value when the dosage of sodium silicate was increased from 4.5% to 6%. Also in the work of

Amu and Salamu (2010) on lateritic soils, the maximum dry density of three samples was achieved at around 6-8% of addition of common salt (NaCl). All increases to 10% in the various samples saw the maximum dry density reduced. However, in his CBR test, he did not go beyond 8% addition of common salt so the optimum dosage cannot be properly determined. Dubey and Jain (2015) did not also go beyond the 8% addition of NaCl in their study. The two works of literature considered above however indicate that sodium-based additives should not be used alone for improving soils. Including calcium-based additives gives better results. So the hypothesis is that there is a certain percentage at which sodium content weakens the stability of sandy soils using CBR as a reference. This is a recommendation for further study

6.0 CONCLUSION

It can be concluded that there exist differences in the chemical characteristics of the topsoils and subsoils in the erosion sites of Anambra state. By implication, the results suggest that the topsoils of Anambra state are more susceptible to erosion mainly due to higher sodicity levels (dispersivity). Tackling erosion requires in-depth knowledge of all the parameters of the soil so that the best decision can be reached most economically. All related anthropogenic factors should be put in check, and erosion control structures should be put in place to stop the propagation of already existing gullies. Since gullies are well recognized environmental hazard that renders people homeless, cripples economic activities, and endangers lives and properties, serious measures should be adopted to find lasting solutions to the problem.

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APPENDIX 1

Correlation of Subsoil Parameters

	SW	CBR	PD	BD	Porosity	OMC	MDD	PCLTN	pH	SR	SOMC	LOI	CEC	BS	RHLGY	SDM	CLAY	SILT	SAND
pH	0.0298	-0.1356	0.0154	-0.1089	-0.5949	0.0337	0.4016	0.9638	1										
resistivity	0.427	-0.5103	0.852	0.6369	-0.5893	0.3141	-0.4872	0.0505	0.0695	1									
organic matter	-0.7907	0.7278	0.2803	-0.0851	0.0804	-0.6906	0.9416	0.6563	0.46	-0.1704	1								
LOI	0.3515	-0.3643	-0.8344	-0.5246	-0.1157	0.3413	-0.089	0.231	0.4165	-0.5264	-0.3151	1							
CEC	-0.7643	0.3555	0.3091	-0.4091	0.8048	-0.8626	0.2542	-0.366	-0.4554	-0.0796	0.3145	-0.5539	1						
Base Saturation	-0.187	0.1242	0.4101	0.1637	-0.5779	-0.1518	0.5525	0.953	0.8787	0.2847	0.7143	-0.0586	-0.2271	1					
Rheology	0.725	-0.3618	-0.5049	0.2099	-0.6711	0.814	-0.237	0.3243	0.4419	-0.105	-0.3602	0.7197	-0.9744	0.1285	1				
Sedimentation	-0.8287	0.461	0.3686	-0.3412	0.7564	-0.8989	0.3691	-0.268	-0.3918	-0.07	0.4431	-0.6178	0.9881	-0.1151	-0.9822	1			
CLAY	-0.3301	0.6918	-0.3665	0.0242	-0.1307	-0.0987	0.7839	0.5891	0.449	-0.5663	0.6297	0.2402	-0.3406	0.4557	0.3595	-0.2304	1		
SILT	-0.4648	0.7298	-0.6988	-0.3462	0.3912	-0.2688	0.673	0.1337	0.0326	-0.9205	0.392	0.3549	-0.0439	-0.0602	0.1646	0.003	0.8191	1	
SAND	0.0896	-0.5642	0.4555	-0.1454	0.2503	-0.1549	-0.5922	-0.495	-0.3866	0.5348	-0.4143	-0.3347	0.5383	-0.3376	-0.5552	0.444	-0.9642	-0.7856	1
Sodium	-0.8745	0.9191	-0.2677	-0.3775	0.6827	-0.736	0.8172	0.0219	-0.1588	-0.7295	0.6568	-0.1489	0.5126	-0.0238	-0.4373	0.5767	0.5924	0.8072	-0.4354
calcium	-0.5635	0.4859	0.2954	-0.0332	-0.2171	-0.4872	0.8448	0.8731	0.7312	-0.0236	0.9372	-0.141	0.0566	0.9068	-0.1154	0.1834	0.6241	0.2493	-0.4391
Magnesium	-0.9525	0.6482	-0.1347	-0.6731	0.8231	-0.9509	0.6991	-0.002	-0.1118	-0.5865	0.6077	-0.1454	0.7873	-0.0175	-0.6859	0.8101	0.2292	0.5134	-0.0076
Potassium	0.1757	-0.169	0.4344	0.3522	-0.8232	0.1886	0.234	0.8834	0.8683	0.4926	0.4236	0.0166	-0.4739	0.9322	0.3512	-0.3853	0.2906	-0.2811	-0.2562
Zinc	0.7168	-0.3767	0.1326	0.6392	-0.9812	0.7862	-0.231	0.5054	0.5504	0.4556	-0.1418	0.2199	-0.8985	0.4877	0.7857	-0.8539	0.225	-0.2541	-0.3759
Copper	-0.8681	0.8544	-0.2969	-0.4562	0.8062	-0.7614	0.7106	-0.137	-0.2951	-0.7426	0.5403	-0.1525	0.6118	-0.1807	-0.5176	0.6511	0.4478	0.7575	-0.295
Manganese	0.2961	-0.6752	0.3421	-0.069	0.1765	0.0622	-0.7656	-0.602	-0.4612	0.5293	-0.6208	-0.2293	0.3737	-0.474	-0.3835	0.261	-0.9987	-0.794	0.97
Cobalt	-0.7576	0.9761	0.0007	0.0272	0.2696	-0.5565	0.9068	0.317	0.0778	-0.4596	0.837	-0.3117	0.2558	0.3304	-0.2754	0.3791	0.785	0.7144	-0.644
Cadmium	0.2494	-0.3236	0.0376	-3E-16	-0.7289	0.2342	0.1923	0.8998	0.974	0.2036	0.2701	0.4518	-0.5866	0.8194	0.559	-0.5402	0.3232	-0.117	-0.311
Nickel	0.6503	-0.494	-0.6867	-0.1595	-0.4421	0.6668	-0.281	0.2468	0.4318	-0.2649	-0.4514	0.921	-0.821	-0.0038	0.9208	-0.8728	0.2124	0.1777	-0.38
Chromium	-0.321	0.0117	0.3529	-0.1743	-0.3463	-0.3699	0.5352	0.894	0.8703	0.209	0.6894	0.0305	0.0078	0.9232	-0.0519	0.0841	0.267	-0.1179	-0.097
Lead	0.5664	-0.6792	-0.3125	-0.1828	0.2072	0.4195	-0.8708	-0.752	-0.5505	0.0511	-0.9448	0.2945	-0.0277	-0.8104	0.1155	-0.1752	-0.7342	-0.3599	0.5788
Silver	0.1891	-0.2046	-0.9198	-0.622	0.4221	0.1679	-0.2504	-0.397	-0.2374	-0.7026	-0.5434	0.769	-0.1389	-0.6517	0.3444	-0.2483	-0.0241	0.4295	-0.0772
Iron	0.5345	-0.4679	0.7597	0.7626	-0.5201	0.4579	-0.6305	-0.212	-0.2019	0.9439	-0.36	-0.568	-0.1185	0.0194	-0.0648	-0.1224	-0.5974	-0.8598	0.5064
Aluminium	0.3741	-0.6392	0.6501	0.2919	-0.1283	0.1758	-0.733	-0.425	-0.3386	0.8221	-0.4873	-0.4611	0.2443	-0.217	-0.3443	0.1771	-0.9296	-0.948	0.8953
Silicon	-0.5516	0.4179	-0.5794	-0.6973	0.9472	-0.5441	0.2348	-0.511	-0.5264	-0.7959	-0.0037	0.1544	0.5761	-0.6269	-0.4023	0.5213	0.047	0.5953	0.0236

APPENDIX 2

Correlation of Topsoil Parameters

	SW	CBR	PD	BD	Porosity	OMC	MDD	PCLTN	pH	SR	SOMC	LOI	CEC	BS	RHLGY	SDM	CLAY	SILT	SAND
pH	-0.276	0.395	0.736	-0.158	0.075	-0.248	0.339	0.516	1										
Resistivity	-0.207	-0.274	0.372	-0.652	-0.025	-0.556	0.687	-0.25	0.179	1									
Organic matter	0.179	0.468	0.729	0.463	0.592	-0.065	0.044	-0.328	0.461	0.209	1								
LOI	0.431	-0.845	-0.956	-0.111	-0.002	0.477	-0.427	0.119	-0.745	-0.089	-0.752	1							
CEC	0.537	-0.926	-0.446	-0.266	0.403	0.293	-0.123	0.102	-0.261	0.573	-0.175	0.631	1						
Base Saturation	-0.559	0.906	0.422	0.225	-0.441	-0.294	0.13	-0.046	0.276	-0.584	0.119	-0.607	-0.997	1					
Rheology	0.541	-0.298	0.163	0.189	0.723	0.457	-0.293	0.611	0.625	0.158	0.422	-0.174	0.391	-0.388	1				
Sedimentation	0.936	-0.413	-0.261	0.662	0.947	0.865	-0.788	0.33	0.075	-0.209	0.358	0.158	0.408	-0.426	0.772	1			
CLAY	-0.331	-0.383	-0.488	-0.598	-0.637	-0.342	0.327	-0.324	-0.688	0.259	-0.738	0.644	0.294	-0.274	-0.718	-0.618	1		
SILT	-0.828	0.582	0.28	-0.391	-0.818	-0.516	0.451	0.28	0.354	-0.293	-0.352	-0.345	-0.723	0.765	-0.391	-0.704	0.102	1	
SAND	0.76	-0.095	0.171	0.673	0.971	0.57	-0.519	0.054	0.266	0.001	0.748	-0.241	0.247	-0.289	0.759	0.885	-0.777	-0.705	1
Sodium	0.52	-0.928	-0.445	-0.287	0.383	0.279	-0.107	0.111	-0.256	0.58	-0.19	0.633	1	-0.996	0.385	0.391	0.307	-0.707	0.228
calcium	-0.588	0.271	0.067	-0.406	-0.648	-0.23	0.241	0.659	0.444	-0.332	-0.495	-0.141	-0.478	0.539	-0.077	-0.43	0.015	0.902	-0.581
Magnesium	0.118	0.723	0.319	0.823	0.287	0.185	-0.358	-0.333	0.052	-0.601	0.588	-0.542	-0.714	0.671	-0.1	0.195	-0.588	0.039	0.394
Potassium	0.669	0.041	-0.419	0.942	0.538	0.772	-0.891	-0.118	-0.421	-0.764	0.152	0.186	-0.197	0.168	0.001	0.586	-0.335	-0.359	0.466
Zinc	-0.228	0.789	0.264	0.543	-0.143	-0.146	-0.075	-0.591	-0.206	-0.518	0.321	-0.43	-0.802	0.765	-0.57	-0.26	-0.147	0.253	-0.056
Copper	0.859	-0.133	-0.265	0.89	0.847	0.897	-0.906	0.233	-0.014	-0.55	0.357	0.065	0.054	-0.077	0.548	0.914	-0.67	-0.519	0.806
Manganese	-0.293	0.798	0.273	0.478	-0.214	-0.21	-0.012	-0.61	-0.216	-0.486	0.283	-0.426	-0.81	0.774	-0.622	-0.333	-0.088	0.296	-0.125
Cobalt	-0.285	0.128	-0.088	-0.106	-0.382	-0.429	0.295	-0.9	-0.72	0.18	-0.112	0.18	-0.064	0.032	-0.853	-0.56	0.682	-0.082	-0.434
Cadmium	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####	#####
Nickel	-0.475	-0.268	-0.457	-0.671	-0.789	-0.227	0.253	0.349	-0.224	-0.075	-0.942	0.512	0.027	0.034	-0.446	-0.582	0.714	0.587	-0.88
Chromium	0.198	0.264	-0.283	0.638	0.063	0.223	-0.42	-0.668	-0.713	-0.524	0.057	0.144	-0.349	0.308	-0.611	-0.015	0.152	-0.179	0.004
Lead	-0.025	-0.428	-0.645	-0.245	-0.37	-0.067	0.013	-0.486	-0.917	0.083	-0.622	0.745	0.324	-0.324	-0.723	-0.373	0.918	-0.167	-0.548
Silver	0.689	-0.682	-0.837	0.326	0.354	0.61	-0.623	-0.259	-0.874	-0.148	-0.328	0.836	0.564	-0.579	-0.167	0.39	0.417	-0.682	0.134
Iron	-0.098	-0.504	0.013	-0.651	-0.09	-0.428	0.541	-0.348	-0.205	0.918	-0.073	0.276	0.719	-0.727	-0.061	-0.237	0.566	-0.396	-0.152
Aluminium	0.975	-0.697	-0.607	0.53	0.81	0.84	-0.781	0.035	-0.433	-0.093	0.065	0.576	0.663	-0.685	0.422	0.843	-0.123	-0.884	0.647
Silicon	-0.584	0.009	0.368	-0.747	-0.471	-0.843	0.876	-0.517	-0.049	0.845	0.002	-0.105	0.228	-0.237	-0.375	-0.668	0.568	0.048	-0.435

SW = Soil water; **CBR** = California Bearing Ratio; **PD** = Pore Density; **BD** = Bulk Density; **OMC** = Optimum Moisture Content; **MDD** = Maximum Dry Density; **PCLTN** = Percolation; **SR** = Soil Resistivity; **SOMC** = Soil organic matter content; **LOI** = Loss on ignition; **CEC** = Cation Exchange Capacity; **BS** = Base Saturation; **RHLGY** = Rheology; **SDM** = 20 sec Sedimentation.

All correlation coefficients with significance < 0.05 are highlighted in red.