JJEES

JJEES (2020) 11 (3): 211-224
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Susceptibility of Agricultural Land to Soil Degradation by Rainfall Using Aggregates' Stability Indices in Parts of Abia State, South Eastern Nigeria

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Received 22 December 2019; Accepted 17 April 2020

Abstract

This study determines the dynamics in soil aggregate stability within agricultural land in Abia State, Nigeria at three physiographic positions: Upper, middle and lower slopes. The soil samples were collected at 0–25cm and 25-50cm of soil depths along the slopes. The parameters assessed were aggregate stability (AS) and mean- weight diameter (MWD), size distribution of water stable aggregates (WSA): >2.00mm, 2-1mm, 1-0.50mm, 0.50-0.25 mm and <0.25mm. Class and severity indices were used as critical limits for soil aggregate stability. The results of the physical parameters indicate significant differences ($p \leq 0.05$), but there was no significant difference among the chemical parameters ($p \leq 0.05$) in the gully sites respectively. MC correlated with hydraulic conductivity ($r = -0.490$). Clay correlated positively with sand, aggregate stability and MWS ($r=-0.957$, $r=0.412$, $r=0.432$) respectively. Silt correlated negatively with sand ($r=-0.608$), sand was negatively correlated (MWD) ($r=-0.552$) and aggregate stability correlated positively with MWD ($r=0.938$). The recorded aggregate stability status based on 2mm, 1mm, 0.5mm and 0.25mm in USL was as follows: stable 17%, moderate 41.7%, unstable 66%, MWD 44.05%, MSL: very unstable 8%, stable 17%, medium 25% and unstable 50%, MWD 54.4% and LSL: severe moderate 33%, very severe 67% and MWD 59.04% respectively. The soil aggregate stability status along the slope gradients was the same at the $p \geq 0.05$ significant level. Soil aggregate structural deformation is influenced by soil moisture, hydraulic conductivity, textural characteristics and soil organic matter. It is recommended that the soil surface coverage must be improved on slopes which could lead to the stabilization of soil aggregates to avert soil erosion problems in the area.

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Keywords: Gully Erosion, Soil Aggregate Stability, Runoff, Land degradation

1. Introduction

The stability of soil aggregates describes their resistance to breakdown under disruptive forces. It is a key soil characteristic affecting ecosystem processes, such as carbon storage (Quanchao et al., 2018), nutrient availability (Wang et al., 2001), and the resistance of soils to erosion (Barthès and Roose 2002; Frei et al., 2003). In severely- eroded ecosystems, such as Badlands characterized by many active gullies and high level of disturbance, aggregate stability of soil is an emerging indicator of their ecological restoration status (Burri et al., 2009). The plant community composition dynamics through succession change, occurring on the eroded ecosystems, is a major factor of restoration (Walker and Del Moral, 2009), and thus can potentially provide aggregate stability to various soils. Studies showed that soil aggregate stability generally increases as succession proceeds (Cheng et al., 2015; Qui et al., 2015); however, the factors leading to these modifications along succession gradients are hardly known. Soil aggregate stability is an effective way of increasing soil quality and also preventing soil erosion and other environmental problems caused by soil degradation (Zhu et al., 2017), associated with the amount and intensity of precipitation and human activities (Ubuoh and Ogbonna, 2018). Higher amounts of precipitation and irregular rainfall events can decrease aggregate stability and increase erosion (Dimoyiannis, 1998). According to Six et al. (2004), it has also been suggested that the dynamics of aggregate formation are closely linked to SOM storage in soils (Golchin et al., 1998; Ubuoh et al., 2016). Soil aggregate stability is the most appropriate indicator in protecting slopes from erosion and shallow mass movements (Kalhoro et al., 2017). The micro aggregates are stabilized against disruption by several mechanisms wherein organo-mineral complexes and soil organic matter act as the main cementing agents in the soil aggregates' development (Denef and Six, 2005; Singh et al., 2017).When organic matter in soil reduces, aggregates breakdown, and the small particles of soils are transferred during soil erosion by water (Bronick and Lal, 2005).

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In Southeast Nigeria, the soils are naturally prone to erosion due to their fragile nature and ease of leaching being mainly ultisols and alfisols (Oguike and Mbagwu, 2009), especially gully erosion which is predominant in the region (Adekalu et al., 2007). Hence, erosion is a major cause of soil degradation leading to reduction in soil's productivity as the result of leaching out of the soil organic matter and other soil cementing agents which bind the soil particles together (Ubuoh and Ogbonna, 2018), especially in the Southeast Nigeria due to poor aggregation of soil (Onweremadu et al., 2010). Most studies have been carried out on agricultural soils (Idowu, 2003; Milne and Haynes, 2004), and far fewer on soils on steep slopes affected by erosion using indices (Gros et al., 2004 ;Canton et al., 2009). The soils in parts of Abia are particularly not fertile and are prone to leaching because of heavy rainfall, leading to the ecological problems such as sheet and gully erosion. Despite soil erosion on agricultural land, increasing demand for land as a result of population increase and food scarcity has made farmers to farm in marginal lands such as lands susceptible to erosion and flooding (Sanchez et al., 1997; Quansah, 1997; Ubuoh et al., 2017).

Therefore, the study aimed to investigate the relationships between the soil aggregate stability and rainfall along the slope gradient of agricultural land using aggregate stability indices in parts of Abia State, Southeastern Nigeria. The result of the study will reveal environmental conditions that would promote the stability of soil aggregate, which may lead to the development of the sustainable agricultural land to alleviate water erosion and ensure food security for the teeming population.

2. Research Methodology

2.1 Study Area

Abia state is located in the southeastern Nigeria and lies between latitude 5° 31' 59.99" N and Longitude 7° 28' 59.99" E. The state covers an area of about 5,243.7 square kilometres with a population of 2,833,999 (NPC, 2006). The area is dominated by flat and low lying land, but it is also characterized by undulating lands with many hills, generally less than120m above sea level. The mean annual rainfall is about 2200mm in average and the mean temperature is above 27^{0}C (Iheanyi, 2016). Relative humidity reaches about 90% throughout the year. The soils of the area fall within the broad group of ferallitic soils of the coastal plain sand and escarpment; other soil types includes alluvial soils found along the low terrace of Cross river and other rivers (Figure 1).

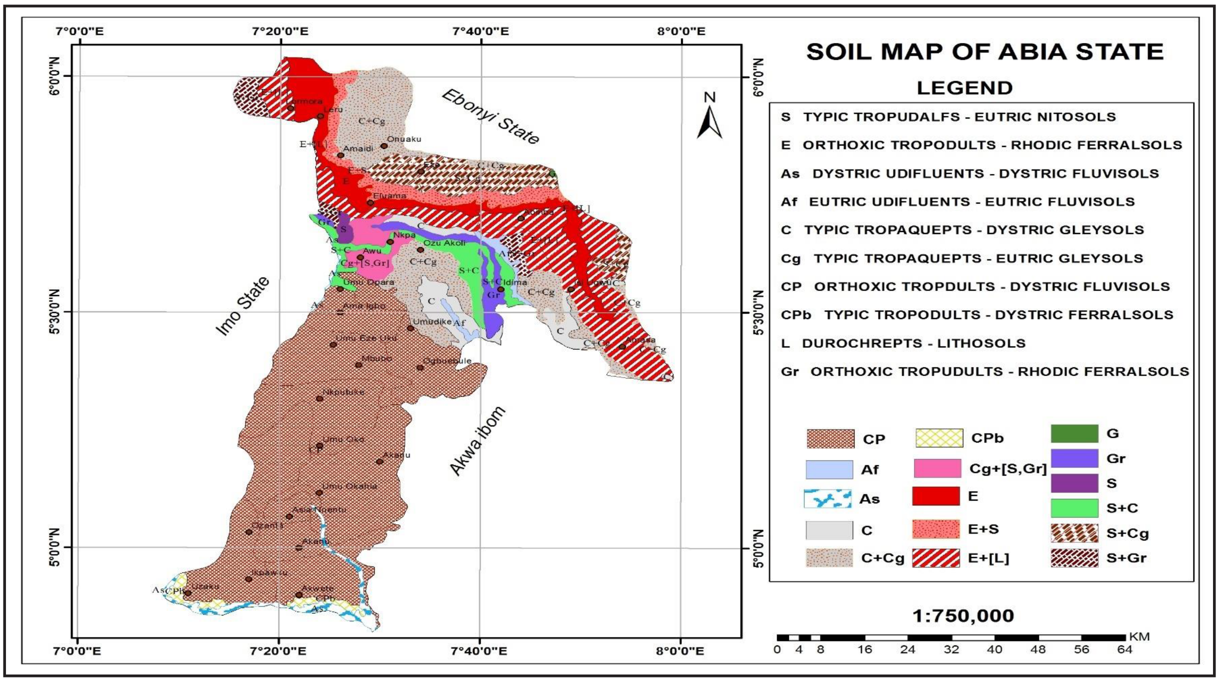

Figure 1. Soil Map of Abia State, Nigeria Source: Ogbonna, Abia State University, Uturu.

2.2 Soil Sample Locations

Soil samples were collected based on the chosen agro-ecological zones (Figure 2) in Abia State as follows:-

i: Bende: Two communities with pronounced gullies were selected to include: Ozuitem Ndiagho designated SSP_1 and OnuIbina-UkwuIgbere designated soil sample point (SSP_2)`

ii: Ohafia: Ohafia designated SSP_3 and Ebem- Ohafia designated SSP_4

iii: Umuneoche: Amuada designated SSP_5 and ObinaoluNgodo designated SSP_6

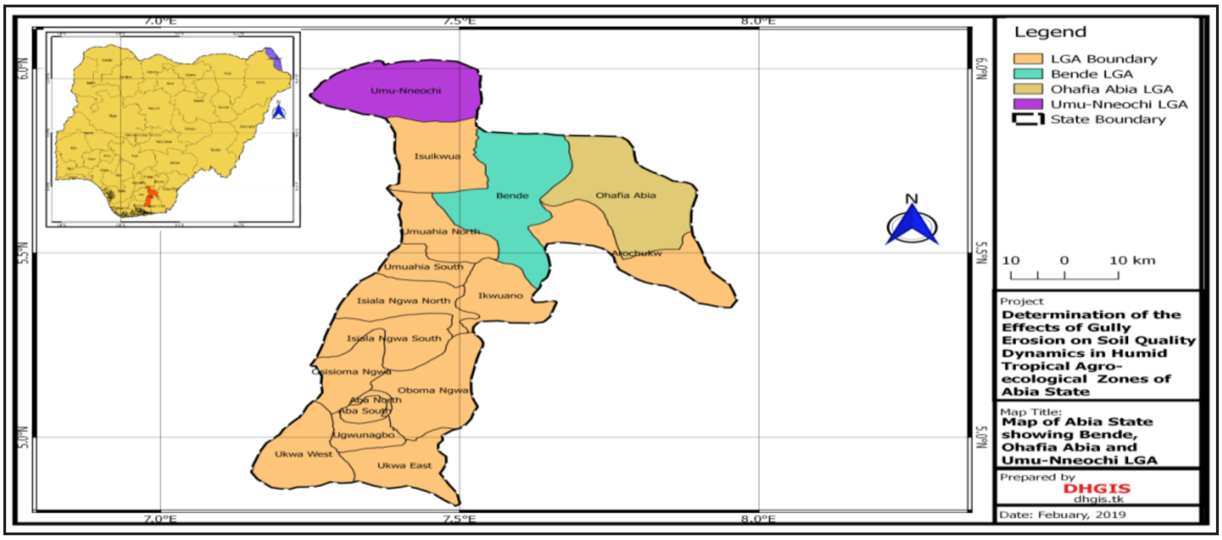

Figure 2. Map of Abia State Showing Sampling Locations

2.3 Soil Sampling Technique

Soil survey method was used to site points for soil sampling in each of the selected sites. Forty-eight soil samples were collected from each site at 0–25 cm, 25-50 cm of soil depths using an auger. From each of the study locations, soil samples were collected from the upper slope (USL), middle slope (MSL) and lower slope (LSL) of the gully and 100m away as controls. The samples were placed in polythene bags, labelled and were taken to the National Soil, Plant and Water Laboratory, Federal Department of Agricultural Land and Climate Change Management Services, Umudike for analysis. Handheld Global Positioning System receiver (Etrex Garmin Ltd. Kansas) was used for the geo-referencing of the sampling points (Table 1).

Table 1. Coordinates of the study Locations

S/No	Agroecological Zones	Coordinates of the study locations
1	BENDE	N 05^0 36.954 , E 07^0 36.423
	100 m away from erosion site	N 05^0 42.569, E 07^0 39.174
2	OHAFIA	N 05^0 38.421, , E 07^0 50.026
	100 m away	N 05^0 38.997, E 07^0 49.587
3	UMUNEOCHE	N 05^0 59.477, E 07^0 24.145
	100 m away	N 05^0 57.902, E 07^0 23.398

2.4 Soil Physical Properties and Analysis

The soil physical properties analysed were the factors presumed to be affecting soil quality. Particle-size distribution was determined by the hydrometer method (Gee and Or, 2002). Soil-bulk density was determined using the core method (Grossman and Reinsch, 2002). Saturated hydraulic conductivity was determined in the laboratory using a constant head permeameter (Young, 2000). The soil moisture content was calculated using the following formula:

$$\text{SMC} = \frac{\text{mass at saturation} - \text{oven dried mass}}{\textit{mass of dried soil}} x100 \quad \text{.......... Eq. 1}$$

2.5 Soil Chemical Properties and Analysis

Soil pH was determined with a pH electrode, extracted from 0.01M $CaCl_2$ with a ratio of 1:2.5 (Bao, 2000; Huang et al., 2015). Soil organic matter (SOM) was determined by wet digestion with a mixture of 5 mL of 0.8 mol/L potassium dichromate ($K_2Cr_2O_7$) and 5mL of concentrated sulfuric acid (H_2SO_4) (Kalembasa and Jenkinson, 1973). Organic C was determined by the oxidation of organic matter with a hot mixture of $K_2Cr_2O_7$ and H_2SO_4 using the Walkley and Black procedure (Walkley and Black, 1934). The amount of organic carbon was then determined by titration with 0.05N $FeSO_4$ following the procedure outlined by Nelson and Sommers (1982).

2.6 Soil Aggregate Stability Determinations

2.1.2. Percentage Aggregate Stability and Mean Weight Diameter (MWD)

The percentage of aggregate stability and Mean Weight Diameter (MWD) were computed from size distribution of water stable aggregates. The distribution of water stable aggregates was determined by the wet sieving technique described by Kemper and Rosenau (1986). To separate the water stable aggregate, 25gm of the >2mm air-dried aggregates were put on top of a nest of sieves measuring 1mm, 0.5mm, and 0.25mm, and was pre-soaked for ten minutes in water. The sieves and their contents were oscillated vertically once per second in water twenty times. The resistant aggregates on each sieve were oven-dried at 105°C for twenty-four hours and weighed. The mass of <0.25mm was obtained by calculating the difference between the initial sample weight and the sum of sample weight collected on the 2.00mm, 1.00mm, 0.50 mm, and 0.25mm sieve nests respectively. The percentage ratio of aggregates in each sieve represented the water stable aggregate of size >2.00mm, 2-1mm, 1-0.50mm, 0. 50-0.25 mm and <0.25mm and was computed as follows:

$$\mathrm{WSA} = \frac{\mathrm{Mr}}{\mathrm{Mt}} \mathrm{x}\ 100 \qquad \text{.. Eq. 2}$$

Where
WSA = Water stable aggregates
Mr = mass of resistant oven–dry aggregates in the size class fraction after wet sieving.
Mt = the total mass of the initial material (25gm)

Percentage of aggregate stability was calculated using this Formula:

$$\%\ \text{Aggregate stability} = \frac{\text{wt.of WSA>0.50}\ mm - wt.of\ sand x 100}{\text{wt.of sample} - \text{wt.of sand}} \qquad \text{.......... Eq. 3}$$

Where
Wt= weight

The mean weighted diameter (MWD) was calculated using the following equation (Oguike and Mbagwu, 2009).

$$\mathbf{MWD} = w_i x_i \qquad \text{.. Eq. 4}$$

Where
w_i *= weight of aggregate in the ith aggregate size range as fraction of dry weight of sample.*
w_i *= Mean diameter of any particular size range of aggregates separated by sieving.*

The larger MWD value is a manifestation of a higher distribution of macro-aggregates and, therefore, a higher stability to erosion by water. The aggregation stability index is the ratio between the mass of the total sample and the mass of the sample retained in the 0.212 mm sieve mesh, expressed as a percentage.

2.6.2. Soil Aggregate Stability Index (ASI)

Aggregate stability was determined using the method described by Le Bissonnais (1996). This method included three disruptive tests that correspond to various wetting conditions and energies. Five classes of the soil aggregate stability were identified according to the values of MWD (Table 2).

Table 2. Soil aggregate stability based on the values of MWD

S/N	Classes of MWD/mm	Stability
1	<0.4	Very unstable
2	0.4-0.8	Unstable
3	0. .8–1.3	Medium
4	1.3-2.0	Stable
5	>2.0	Very stable

Source: (Le Bissonnais, 1996).

2.6.3. Severity Index (SI).

Lal (1986) has classified the critical levels of aggregate stability based on the levels of MWD as follows:

a. 0.5<0.1-5 : designating very severe
b. 1- 2 : designating severe moderate
c. 2-2.5: designating low
d. 2.5< designating no limitation respectively.

2.7 Statistical Analysis

The interrelations between the wet and dry stable aggregate indices were determined through a correlation matrix using the SYSTAT9 statistical program (SPSS, 1999) computer package. Also the relationships between the macro-aggregates stability indices along the gully slopes: upper slope (USL), middle slope (MSL), and lower slope (LSL), and soil properties were determined in a correlation matrix.

3. Results and Discussion

Table 3 demonstrates the soil physical properties in the gully affecting the agricultural sites along the three slope profiles. The slope types exhibited significant differences in soil properties ($P<0.05$).

Table 3. Soil Physical Characteristics in Gully Erosion Prone Sites at the different Slope Gradients in the study area

Slope	Bulk density (%)	Moisture content (%)	Hydraulic conductivity (cm/hr)	Sand (%)	Silt (%)	Clay (%)
Upper slope(USL)	1.77±0.13	5.94±1.58	18.95±2.38	63.58±11.67	10.5±2.90	25.67±8.95
Middle slope(MSL)	1.66±0.04	6.39 ±1.58	10.63±16.2	78.5± 478	4.25±1.53	2.92±3.42
Lower slope (LSL)	1.68±0.06	7.70±3.46	22.36±10.20	81.83±4.0	4.58±0.82	12.5±3.56
Control (Ctrl)	1.94±0.05	13.05±3.36	6.28±1.67	75.08±7.54	6.67±3.07	19±6.13
F- $LSD_{0.05}$	0.1742	1.3117	11.7308	11.593	4.583	6.667
CV	10.49	81.61	93.20	18.16	70.74	61.26
Sig.	SD	SD	SD	SD	SD	SD

Data are expressed as Mean ± SD

From Table 3, the mean bulk density ranged between the mean value of 1.66±0.04 and 1.77±0.13 g/cm^3 with the upper slope being more compacted than the middle slope; the lower slope being the least compacted, but it was found less compacted than the control with 1.94±0.05, having 10.5% of CV more than the mean bulk density values of 1.14 and 1.26 g/cm^3 in the gully sites in Ideato, Imo State (Oyegun et al., 2016). The results of bulk density are also far above the value of 1.0-1.3 g/cm^3 considered for a well-aggregated forest (Ibitoye et al., 2008). The high bulk density suggests that soil erosion is very evident in the selected communities. Ubuoh et al. (2013) reported that dry bulk density and moisture content lead to gully formation in the southeastern part of Nigeria.

The mean moisture content ranged between 5.94±1.58 and 7.70±3.46% with the upper slope having the lowest mean value, followed by the middle slope and the lower slope recording the highest moisture content, but it was less than control with a 13.05±3.36 % moisture content, having 81.61% CV respectively. The present results of moisture content are greater than the results of soil moisture content at the field capacity that ranged from 0.23 to 0.31% in the gully site, Kano (Mallam et al., 2016). Robinson and Dean (1993) and Nyberg (1996) all found that moisture content is inversely proportional to relative elevation.

The mean hydraulic conductivity in the study area ranged between 10.63±16.2 and 22.36±10.20 with the lower slope recording the highest value and the middle slope being the lowest followed by the upper slope being greater than the control with a value of 6.28±1.67 having 93.20 % CV respectively. In soil, Hu (2008) reported that, along the slope, hydraulic conductivities generally decreased downwards, and the soil in this portion of the slope had a higher number of bio pores. Based on the soil particle analyses at the study area, sand ranged between 63.58±11.67 % to 81.83±4.0% with the lower slope having the highest mean value and the upper slope having the least values followed by the middle slope along with the control having 75.08±7.54% with18.16% of CV respectively; this is greater than the gully sand in Umueshi, Imo State with 62.44 -74.05% (Oyegun et al., 2016), within 74.1% reported by Ubuoh et al. (2013) in the Ukpor gully erosion site in Anambra State. Various authors (Ukaegbu et al., 2015; Nwite and Okolo, 2017) have previously reported predominance of sand fraction in soils of different land uses in southeast Nigeria. Accordingly, authors including Liu et al. (2013), Xu et al. (2016) reported that the southeastern part of Nigeria soils are predominantly sandy and is >70%, as a result, this region is more prone to erosion especially with the presence of high rainfall. There was significantly more sand in gully sites than non-gully site. This could be the result of the loss of organic binding agents under the effect of rain, leading to the loss of finer soil particles carried away by the force of erosion and flood water (Olusegun et al., 2011; Uwanuruochi and Nwachukwu, 2012). The clay content in the soil in the study area ranged between 2.92±3.42 and 25.67±8.95 percentage, with the middle slope recording the lowest value to be followed second by the lower slope. The upper slope has the highest clay content along with the control recording 19±6.13 percentage of clay. Silt and clay ranged between 4.25±1.53 to 10.5±2.90 and 2.92±3.42 to 25.67±8.95 respectively, with the middle slope recording the least mean values along with the control at 6.67±3.07, 19±6.13 showing CV70.74% and 61.26% respectively, which is suspected to be due to erosion processes down the slopes Soil physical parameters along the three slopes indicated significant differences at p>0.05 level. The result was in tandem with the finding of Hossein et al. (2015) who reported that textural classifications were significantly different among the slope positions and control site (p>0.05). This is different from the findings of Salako et al. (2006) who reported a high clay content down the slope of the gully.

Table 4. Correlation between soil physical properties and soil aggregate indicators in the study area.

Parameters	MC	BD	Clay	Silt	Sand	HC	AST.	MWD
Moisture Content	1							
Bulk Density	0.027	1						
Clay	-0.008	-0.386	1					
Silt	-0.352	-0.224	0.304	1				
Sand	0.214	0.368	0.957**	-0.608**	1			
Hydraulic C	-0.490*	-0.096	0.059	0.337	-0.195	1		
Aggregate Stab (AST).	0.255	0.140	0.412*	0.167	-0.441	0.124	1	
MWD	0.190	-0.001	0.432*	0.174	-0.552*	0.208	0.938**	1

***. 0.01 level (2-tailed). *. 0.05 level (2-tailed).*

Table 4 reveals that MC, correlated negatively, but also weakly, with hydraulic conductivity (r = -0.490) at the significant level p <0.05. This inverse relationship may be attributed to the low soil infiltration rates due to soil compaction. Accordingly, Infiltration rates decreased with an increase in the bulk density and with a reduction in the air-filled porosity. Clay correlated positively, but strongly, with sand fraction (r=-0.957) at the significant level p<0.01. The relationship may be attributed to the fact that sand soils of humid tropical southeastern Nigeria will effectively depend on reliability of determination of clay and coarse sand contents of the soils (Chinedu et al., 2012). Clay correlated positively, but weakly, with aggregate stability and MWD (r=0.412, 0.432) at the p<0.05 significant level respectively. This implies that clay content increased with the decrease in aggregate stability/MWD respectively. Since clay in the soil is weakly correlated with aggregate stability (MWD), hence aggregate stability is highly susceptible to erosion. Therefore, aggregate formation and stabilization are affected by different factors such as clay content (Denef and Six, 2005). The indication was that mean weight diameter increased as clay contents increased resulting in a better aggregation of the soil (Uzoma and Onwuka, 2018). Silt correlated negatively, but strongly, with sand (r=-0.608) at the significant level p<0.01, Sand correlated negatively, but moderately, with weight diameter (MWD) (r=-0.552) at the p< 0.05 significant level. This indicates that the increase in sand particles decreased the soil micro aggregation. Aggregate stability correlated positively with MWD (r=0.938) at the significant level p<0.01.

Table 5. Soil Chemical Characteristics in Gully Erosion Prone Sites at the study Area

Slope Profile	pH (H_2O)	E/C (ds/cm)	OM(%)	OC (%)
Upper Slope (USL)	5.43±0.25	0.97±0.23	4.25±1.02	3.65±0.14
Middle slope (MSL)	5.59±0.25	10.0±0.23	4.18±1.09	3.05±0.58
Lower slope (LSL)	5.60±0.23	1.08±0.28	4.28±1.33	3.04±0.50
control (Ctrl)	5.68±0.30	0.89±0.24	4.37±1.42	2.68±0.53
$F.LSD_{0.05}$	0.925	0.865	0.1935	0.3696
CV	4.804	29.167	25.293	20
Sig	NSD	NSD	NSD	NSD

From Table 5, the results of the soil pH ranged between 5.43±0.25 at the upper slope indicating strong acid conditions and 5.60±0.23; this is lesser than the control 5.68±0.30 which indicates moderate acid conditions (5.6-6.0) respectively (Shehu et al., 2015). Soil pH distribution in the study area was in the increasing order of: USL (5.43±0.25) ≤ MSL (5.59±0.25) ≤ LSL (5.60±0.23) ≤Ctrl: (5.68±0.30) indicating strong acid conditions (5.0-5.5), moderate acid conditions (5.6-6.0) for the middle slopes, the lower slopes, and the control respectively, and these values were similar to the overall mean values of soil pH (5.4) obtained from the three gully profiles in Kano State (Mallam et al., 2016). The mean value of soil electrical conductivity (EC) ranged from 0.97±0.23 to 10.0±0.23, which is greater than the control with 0.89±0.24 mm/S. However, the present results of EC are in tandem with the results of EC obtained by Ubuoh and Ogbonna (2018) from soils affected by human-induced environmental hazards in Imo State. The mean values of soil organic matter obtained in this study were between 4.18±1.09% for MSL and 4.28±1.33% for LSL which are less than control with the value of4.37±1.42%. The overall results of OM were at the decreasing order starting with the control with the values of 4.37±1.42≥ LSL: 4.28±1.33≥ USL: 4.25±1.02≥ and MSL: 4.18±1.09 with CV of about 25.3 indicating no significant difference in the level of OM along the three slopes and the control at the p>0.05 level. The significantly lower values of SOM along the slopes may have been caused by the removal of plant residues by water erosion (Shinjo et al., 2000). The ecreased aggregate stability in this study is suspected to be mainly driven by the lack of the soil organic-matter accumulation along the three slopes sequence as confirmed by Obalum et al. (2011). The soil Organic carbon ranged between 3.04±0.58 and 3.65±0.14 which is greater than the control value 2.68±0.53. The SOC was in the decreasing order of USL: 3.65±0.14≥MSL: 3.05±0.58≥ LSL: 3.04±0.50 ≥ and Ctrl: 2.68±0.53 showing a CV value of 20%, with no significant difference. The results are higher than the SOC values of (0.22% and 0.96%) in part of Imo State (Oyegun et al., 2016). The result from this study is different from the finding of Erktan et al. (2015), who observed that soil aggregate stability increased along the succession gradient, which is mainly driven by soil organic carbon accumulation. Thus, rainfall might have initiated the extent of the gully erosion (Ajaero and Mozie, 2011). Authors believed that the emphasis on high rainfall and topography can be attributed to the high rainfall in the humid tropics while the steep slopes in the area might have also aided the high speed of surface runoff leading to the rapid washing away of the soil surface and the weakening of soil strata.

Table 6. Correlation of the selected soil chemical properties with MWD and aggregate stability in the study area.

Variables	pH (H_2O)	E/C	Soil organic carbon	Soil organic matter	MWD	Agg. Stab.
pH (H_2O)	1					
E/C	0.233	1				
OC	-0.362	-0.134	1			
OM	-0.261	-0.295	0.022	1		
MWD	0.394	0.319	0. 757*	0.691**	1	
Agg. Stab.	0.555**	0.369	0.302	-.211	-0.938**	1

***. 0.01 level (2-tailed). *. 0.05 level (2-tailed).*

According to table 6, pH (H_2O) correlated positively, but moderately, with soil aggregate stability ((r= 0.56) at the significant level p<0.01. The weak positive association could be attributed to the moderate acidic pH level of the soil due to human activities such that accelerated soil erosion. Soil organic carbon correlated negatively, but strongly, with MWD (r= -0.76.). This implies that the decrease in soil organic carbon also led to the decrease in MWD leading to the susceptibility of the soil along with erosion by constant rainfall. This result is in line with the report by FAO (2019) which shows that most tropical soils are structurally fragile and are easily susceptible to many forms of erosion. Soil organic matter (SOM) correlated positively, but strongly, with MWD at r=0.69. This implies that reduction in soil organic matter leads to a decrease in the mean weighted diameter. MWD correlated negatively, but strongly, with aggregate stability (r= -0.94), signifying a low value of MWD. These low values of MWD could lead to quick dispersion of the soil during rainfall events leading to severe rill or inter-rill erosion and finally gully. In line with these results, it was suggested that wetting by rapid immersion for the measurement of dried aggregate stability had led to aggregate breakdown by slaking, while the slaking process may not occur in the measurement of wetting aggregate stability. As Ternan et al. (1996) and Unger (1997) suggested, the slaking process played a major role in the breakdown of surface soil aggregates in a semiarid region where intermittent rainfall causes rapid wetting of the relatively dry soil surface (Shinjo et al., 2000). However, Amezketa et al. (1996) showed that the combined use of MWD in various forms and the soil-slaking index could be useful in assessing soil erosive behavior. The results have further proven the important contributions of SOM and SOC in binding soil particles together into large macro aggregates to improve the aggregate stability of the soil (Yang, 2017). Oguike and Mbagwu (2009) observed that soils with low MWD have the potential to erode faster than those with higher MWD, and soils with good structures and high MWD resist aggregate breakdown during rainstorms (Ubuoh et al., 2013; Okon et al., 2016).

Table 7. MWD and Soil Aggregate Stability classes in Upper Slope in Gully Erosion Site regarding soil depth and particle size

LGA/ COMMUNITY	UPPER SLOPE (US)	Soil Depth (cm)	2mm	1mm	0.5mm	0.25mm	MWD (mm)	Class	Stability Status
BENDE: OZUITEM NDIAGHO	US	0-25	14.26	13.07	8.24	44.96	1.41	1.3-2.0	Stable
BENDE: OZUITEM NDIAGHO	US	25-50	4.3	10.19	16.2	54.83	0.61	0.4-0.8	Unstable
BENDE: ONUIBINA-UKWU IGBERE	US	0-25	3.23	8.72	10.04	55.34	0.51	0.4-0.8	Unstable
BENDE: ONUIBINA-UKWU IGBERE	US	25-50	3.74	16.1	16.66	52.55	0.68	0.4-0.8	Unstable
OHAFIA: ELU OHAFIA	US	0-25	2.85	11.1	15.84	58.36	0.53	0.4-0.8	Unstable
OHAFIA: ELU OHAFIA	US	25-50	1.34	10.63	19.74	57.82	0.56	0.4-0.8	Unstable
OHAFIA: EBEM OHAFIA	US	0-25	19.9	25.81	17.13	32.32	1.23	0. .8–1.3	Medium
OHAFIA: EBEMOHAFIA	US	25-50	26.86	35.82	16.41	18.37	1.53	1.3-2.0	Stable
UMUNEOCHE: AMUODA	US	0-25	2.92	14.2	16.14	50.66	0.61	0.4-0.8	Unstable
UMUNEOCHE: AMUODA	US	25-50	2.91	20.09	16.14	46.22	0.68	0.4-0.8	Unstable
UMUNEOCHE: OBINAOLU NGODO	US	0-25	12.04	31.22	19.37	31.19	1.09	0. .8–1.3	Medium
UMUNEOCHE: OBINAOLU NGODO	US	25-50	0.49	15.85	20.88	56.31	0.62	0.4-0.8	Unstable
F-$LSD_{0.05}$			21.29	20	7.91	32.75	0.84	-	
CV			106.96	50.84	22.71	27.44	44.05	-	
Sig.			NSD	NSD	NSD	NSD	NSD	-	

The summary of results and classes of soil aggregate stability in the upper slope in the gully erosion sites are presented in Table 7. At 2mm, aggregate stability ranged from 1.34 - 26.86 mm, at 1mm, aggregate stability ranged from 8.72 - 35.82 mm, at 0.5mm, aggregate stability ranged from 8.24 to 20.88 mm and at 0mm, aggregate stability ranged from 18.37 - 58.36mm respectively. The results imply that the smaller the particle size of the aggregate, the larger the specific surface area, and the greater the adsorption of organic matter. The results of this study demonstrated that the SOC contents of small-sized aggregate fractions were higher than those of coarse grain. This result also confirmed former reports by Arrouays et al. (1995). F-$LSD_{0.05}$ ranged between 7.91- 32.75, CV 22.71-106.96 with MWD 0.84±0.37, 0.84, 44.05 respectively. However, a non-significant ($p \leq 0.05$) effect was observed in the upper slope between 1mm – 0.25mm WSA alongside MWD mm. According to these results, land uses had little effect on dry aggregates in this study. Based on MWD, soil aggregate stability recorded stability constituting 17%, medium stability 17% and unstable 66% in the upper slope of the gully site. The result of unstable soil aggregates is explained by Hitoshi et al. (2012) that as the slope gradient increased, the amount of eroded soil assumed to increase, resulting in the relative increase of sand/ gravel in the soil surface coverage. The increase in the amount of eroded soil, in turn, would reduce the soil rooting depth, which is not suitable for the growth of shrub species whose tap root penetrates very deeply, sometimes 1 m or more, to exploit the limited amount of water (Thalen, 1979).

Table 8. MWD and Soil Aggregate Stability classes at the Middle Slope in the Gully Erosion Site regarding soil depth and particles size

LOCAL GOVERNMENT AREA/COMMUNITY	DISTANCE	Soil Depth (cm)	2mm	1mm	0.5mm	0.25mm	MWD (mm)	Stability status
BENDE: OZUITEM NDIAGHO	Middle Slope (MS)	0-25	14.26	13.07	8.24	44.96	1.41	Stable
OZUITEM NDIAGHO:	MS	25-50	1.26	2.73	3.63	61.28	0.13	Very unstable
ONU IBINA-UKWU IGBERE	MS	0-25	3.23	8.72	10.04	55.34	0.51	Unstable
ONU IBINA-UKWU IGBERE	MS	25-50	1.38	13.71	16.04	54.61	0.46	Unstable
OHAFIA: ELU OHAFIA	MS	0-25	2.85	11.1	15.84	58.36	0.53	Unstable
ELU OHAFIA	MS	25-50	0.61	8.72	12.26	52.12	0.47	Unstable
EBEM OHAFIA	MS	0-25	19.9	25.81	17.13	32.32	1.23	Medium
EBEM OHAFIA	MS	25-50	22.66	33.93	18.75	21.82	1.41	Stable
UMUNEOCHE: AMUODA	MS	0-25	2.92	14.2	16.14	50.66	0.61	Unstable
AMUODA	MS	25-50	11.71	33.22	15.7	30.31	1.08	Medium
OBINAOLU NGODO	MS	0-25	12.04	31.22	19.37	31.19	1.09	Medium
OBINAOLU NGODO	MS	25-50	1.38	15.2	14.33	50.74	0.57	Unstable
MEAN			7.85±7.91	17.64±10.61	13.96±4.63	45.31±13.01	0.79±0.43	
F-LSD0.05			19.6	22	12.01	28.17	0.84	
CV			100.7643	60.14739	33.16619	28.71331	54.43038	
Significant			NSD	NSD	NSD	NSD	NSD	

From the results of MWD in Table 8, it is observed that Ozuitem Ndiagho at the soil depth of 25-50cm (middle slope) recorded the lowest value of 0.13 and at 0.25cm recorded the highest value of 1.41 (Ozuitem Ndiagho) and Ebem Ohafia at the depth of 25-50cm respectively . From these results, all the study locations were affected by gully erosion on aggregate stability with an intensity ranging between severe moderate constituting 41.7% to very severe constituting values up to 58.3%. This implies that the aggregate stability of the soil has contributed to gully erosion ranging between 41.7 -58.3% in the selected communities. Table 8 shows the summary of the gully erosion on aggregate stability at the middle slope at the depths 0-25 and 25-50cm respectively. At 2mm, soil aggregates ranged from 0.61 to 22.66 where Elu (0-25cm) recorded the lowest value while Ebem recorded the highest value with the overall mean value of 7.85±7.91, at 1mm, soil aggregates ranged from 2.73 to 33.93 where Ndiagho recording the lowest value, while Ebem (0-25cm) recorded the highest mean value of 17.64±10.61. At 0.5mm, soil aggregates ranged from 8.24 to 19.37 with Ndiagho recording the lowest and highest values at 0-25cm respectively at the mean value of 13.96±4.63. At 0.25mm, soil aggregates ranged from 21.82 to 61.28 with Ngodo recording the lowest value at 0-25cm and Ndiagho showing the highest value at 25-50cm with a mean of 45.31±13.01 respectively. There was no significant difference existing between aggregate stability and MWD of the soil in the middle slope at $p>0.05$ at the different soil depths and various locations. Based on MWD, the recorded soil aggregate stability was as follows: stable at 17%, very unstable at 8%, medium at 25% and unstable at 50% with unstable soil aggregate stability showing the highest percentage.

Table 9. Critical levels for aggregate stability based on levels of Mean weighted diameter in the middle slope

S/No	Local Government Area/Community	Soil Depth (cm)	MWD (mm)	Critical limit	Description	Symbol
1	BENDE: Ozuitem Ndiagho	0-25	1.41	1- 2	severe moderate	SM
		25-50	0.13	0.5<0.1-5	Very severe	VS
2	Onu Ibina-Ukwu Igbere	0-25	0.51	0.5<0.1-5	Very severe	VS
		25-50	0.46	0.5<0.1-5	Very severe	VS
3	OHAFIA: Elu Ohafia	0-25	0.53	0.5<0.1-5	Very severe	VS
		25-50	0.47	0.5<0.1-5	Very severe	VS
4	Ebem Ohafia	0-25	1.23	1- 2	severe moderate	SM
		25-50	1.41	1- 2	severe moderate	SM
5	UMUNEOCHE: Amuoda	0-25	0.61	0.5<0.1-5	Very severe	VS
		25-50	1.08	1- 2	severe moderate	SM
6	Obinaolu Ngodo	0-25	1.09	1- 2	severe moderate	SM
		25-50	0.57	0.5<0.1-5	Very severe	VS

According to the results of the MWD in Table 9, Ndiagho recorded the lowest value of 0.128955 at the soil depth of 0-25 cm, while at the depth of (25-50 cm), Ndiagho recorded the highest value of 1.41045 with the mean value of 0.79±0.43. The levels for aggregate stability based on levels of MWD ranged from severe moderate (41.7%) to very severe (58.3%), indicating that locations situated in the middle slope are affected by gully erosion that ranges between severe moderate to very severe.

Table 10. MWD and Soil Aggregate Stability classes at the Lower Slope in Gully Erosion Site regarding soil depth and particle size

LOCAL GOVERNMENT AREA/ COMMUNITY	Soil Depth (cm)	2mm	1mm	0.5mm	0.25mm	MWD (mm)	Stability Status
BENDE: OZUITEM NDIAGHO	0-25	14.26	13.07	8.24	44.96	1.4	Stable
	25-50	1.89	14.34	6.55	55.62	0.52	Unstable
ONU IBINA-UKWU IGBERE	0-25	3.23	8.72	10.04	55.34	0.51	Unstable
	25-50	2.06	6.39	8.98	51.51	0.42	Unstable
OHAFIA: ELU OHAFIA	0-25	2.85	11.1	15.84	58.36	0.53	Unstable
	25-50	0.56	9.38	15.24	55.82	0.48	Unstable
EBEM OHAFIA	0-25	19.9	25.81	17.13	32.32	1.23	Medium
	25-50	2.78	9.92	16.12	58.95	0.57	Unstable
UMUNEOCHE: AMUODA	0-25	2.92	14.2	16.14	50.66	0.61	Unstable
	25-50	2.59	12.82	18.79	54.17	0.61	Unstable
OBINAOLU NGODO	0-25	12.04	31.22	19.37	31.19	1.09	Medium
	25-50	28.86	22.82	9.35	24.36	2.00	Stable
Mean		7.83±9.00	14.98±7.61	13.48±4.51	47.77±11.89	0.83±0.49	
CV		114.94	50.8	33.46	0.25	59.04	
F-LSD		18.75	19.5	10.07	29.4	1.042	
REMARK		NSD	NSD	NSD	NSD	NSD	

Table 10 shows the summary of the gully erosion on aggregate stability at the lower slope at the depths 0-25 and 25-50 cm respectively. At 2 mm, soil aggregates at the lower slope ranged from 0.56 to 14.26 with Elu (25-50cm) recording the lowest value and Ndiagho (25-50) recording the highest values with the overall mean value of 7.83±9.00. At 1mm, soil aggregates at the lower slope ranged from 6.39 to 31.22 and UkwuIgbere recorded the lowest value while Ngodo (0-25cm) recorded the highest values with the mean value of 14.98±7.61. At 0.5 mm. Soil aggregates at the lower slope ranged from 6.55 to 19.37 with Ndiagho (25-50) recording the lowest value and Ngodo recording the highest at 0-25cm respectively with the mean value of 13.48±4.51, and at 0.25mm. Soil aggregates at the lower slope ranged from 24.36 to 58.95 with Ngodo recording the lowest value at 0-25cm and Ebem having the highest value at 25-50cm with the mean value of 47.77±11.89 respectively. The coefficient of variance ranged from 0.25 to 114.94 (0.25-2 mm), and F-LSD ranged from 10.07 to 19.5 (0.5-1 mm) at 0.05%. Statistically, there was no significant difference at (p-value <0.05), indicating that soil aggregate stability in the lower course of the slope has no significance differences existing among the sampled communities. There was no significant difference existing between aggregate stability and MWD of the soil in the three sampled slopes at p>0.05 of the different soil depths at various locations. Uwanuruochi and Nwachukwu (2012) reported that when comparing aggregate stability of eroded and non-eroded soils, there was no statistical difference at 0.6 mm and 1.0mm, but there was a highly significant reduction of aggregate stability in eroded soils at 2mm aggregate size. Based on MWD, the recorded soil aggregate stability was shown as stable in Ndiagho and Ngodo constituting 17%, there was medium stability in Ebem and Ngodo with 17%, while the rest of the locations being unstable recording 66% of soil aggregate stability in the lower slope of the study area (Table 11). Above all, aggregate stability decreases with increasing the water content at aggregates with a diameter of 0.25mm fraction and affecting the three slopes within the agricultural land leading to a very poor soil quality (Figure 3).

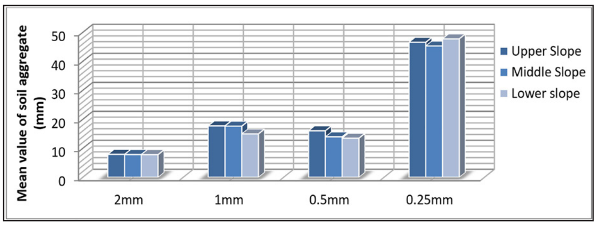

Figure 3. Water content at soil aggregate mean diameter fractions along the slopes.

Table 11. Critical levels for aggregate stability based on levels of Mean weighted diameter in the lower slope

Local Government Area/Community	Soil Depth(cm)	MWD (mm)	Critical limit	Description	Symbol
BENDE: Ozuitem Ndiagho	0-25	1.41	1- 2	Severe moderate	SM
	25-50	0.53	0.5<0.1-5	very severe	VS
Onu Ibina-Ukwu Igbere	0-25	0.51	0.5<0.1-5	very severe	VS
	25-50	0.42	0.5<0.1-5	very severe	VS
OHAFIA: Elu Ohafia	0-25	0.53	0.5<0.1-5	very severe	VS
	25-50	0.48	0.5<0.1-5	very severe	VS
Ebem Ohafia	0-25	1.23	1- 2	Severe moderate	SM
	25-50	0.57	0.5<0.1-5	very severe	VS
UMUNEOCHE: Amuoda	0-25	0.61	0.5<0.1-5	very severe	VS
	25-50	0.61	0.5<0.1-5	very severe	VS
Obinaolu- Ngodo	0-25	1.09	1- 2	Severe moderate	SM
	25-50	2.00	1- 2	Severe moderate	SM

The effect of location on the MWD revealed no significant difference from the results of mean weight diameter. Elu at the soil depth of 25-50cm recorded the lowest value of 0.48, while Ndiagho (25-50cm) recorded the highest value of 2.00 with the mean value of 0.83±0.49, with 59.04 CV and F-LSD 1.042 signifying that there is no significance difference among the communities in terms of mean weight diameter (MWD) in the lower slope at a 0.05% significance level. From the results obtained, the three studied slopes were susceptible to gully erosion leading to severe moderate (33%) to very severe (67%) based on the critical limit suggested by Lal (1986), implying that the sampled location recorded low aggregate stability with intensity ranging between severe moderate to very severe stability based on levels of Mean weighted diameter in the three slopes. Above all, the indices of macro aggregate stability in the gully sites and control showed that stability was lower, though lesser than control, which is thought to be decreasing the OC content and dominant sand in the gully-affected agricultural lands. The result is in agreement with Olusegun et al. (2011), who explained that the loss of organic binding agents through rain action resulted in the loss of finer soil particles to erosion and floodwater respectively. The low MWD values of the soils were attributed to low clay and organic-matter contents resulting in the weak aggregation of the soils along the slopes. The continued wetting and drying at the lower landscape position could lead to a decreased macro-aggregate stability, which is supported by Caron and Kay (1992), and Malgwi and Abu (2011). In addition, considering the translocation of the disintegrated aggregates along the slopes, the gentler the lower slopes, the larger the amount of disintegrated aggregates on the upper slopes can be added to the lower slopes, resulting in the increase of the amount of unstable aggregates on gentler slopes. This assumption was supported by previous results by Shinjo et al. (2000), showing that the gentler slope yielded a soil loss comparable to that on the steeper slope during the monitoring of water erosion over two rainy seasons.

4. Conclusions

The results of the soil physical and chemical parameters along the three slopes show high soil moisture and high bulk density which cause excessive drainage. The higher bulk density recorded along the three slopes were attributed to the coarse texture, low soil organic-matter content, and poorly-structured coarse particles dominated by the sand content, and low soil pH indicating acidity along the slopes. This finding suggests that the soil surface coverage can enhance the soil aggregate stability through the increasing of the organic-matter content, and that the slope gradient can increase the translocation of unstable aggregates, leading to the stabilization of soil in gully prone sites.

Acknowledgement

The authors are grateful to the staff of Nigeria Erosion and Watershed Management Project (NEWMAP), Abia State, during the course of the field work. The authors thank the laboratory Technicians of the Department of Environmental Management and Toxicology, Michael Okpara University of Agriculture, Umudike, Abia State who provided field assistance during the soil survey exercise in the study area.

References

Adekalu, K.O., Olorunfemi I. A., and Osunbitan, J. A. (2007). Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. Bioresource Technology, 98 (4), pp. 912-917.

Ajaero, C.K., and Mozie, A.T. (2011). The Agulu- Nanka Gully Erosion Menace In Nigeria: What Does the Future Hold for the Population at Risk? Climate Change and Migration: Rethinking Policies for Adaptation and Disaster Risk. Institute for Environment and Human Security United Nations University, Studies of the University: Research, Counsel Education publication series of UNU-EHS.No.15 pp74-81.

Amandine, E., Lauric, C., Frank, G. Catherine, R., Cédric, L., and Freddy, R. (2015). Increase in soil aggregate stability along a Mediterranean successional gradient in severely eroded gully bed ecosystems: combined effects of soil, root traits and plant community characteristics. Plant Soil,1104-015-2647-6.

Amezketa, E. M., Singer, J., and Le- Bissonnais, Y.(1996). Testing a new procedure for measuring water-stable aggregation. Soil Sci. Soc. Am. J. 60:888-894.

Arrouays, D., Balesdent, J., Mariotti , A., and Girardin , C. (1995). Modelling organic carbon turnover in cleared temperate forest soils converted to maize cropping by using 13C natural abundance measurements. Plant Soil 173, 191–196.

Bao, S.D. (2000). Soil and Agricultural Chemistry Analysis. China Agriculture Press, Beijing.

Barthès, B., and Roose, E. (2002). Aggregate stability as an indicator of soil susceptibility to runoff and erosion; validation at several levels. Catena 47(2):133–149.

Bronick, C.J., and Lal, R. (2005). Soil structure and management: a review. Geoderma 124, 3–22.

Burri , K., Graf, F., and Böll, A. (2009). Revegetation measures improve soil aggregate stability: a case study of a landslide area in Central Switzerland. For Snow Landsc Res 82(1):45–60.

Canton, Y., Sole-Benet, A., Asensio, C., Chamizo, S., and Puigdefabregas, J. (2009). Aggregate stability in range sandy loam soils: relationships with runoff and erosion. Catena 77, 192–199.

Caron, J., and Kay, B.D. (1992) .Rate of response of structural stability to a change in water content: Influence of cropping history. Soil and Tillage Research , 25 (2–3): pp. 16.

Cheng, M., Xianga, Y., Xueb, Z., An, S., and Darboux , F. (2015). Soil aggregation and intra-aggregate carbon fractions in relation to vegetation succession on the Loess Plateau, China. Catena 124:77–84.

Chinedu, I. O. , Jude , C. O., and Onweremadu , E. U. (2012). Modeling of Permanent Wilting from Particle Size Fractions of Coastal Plain Sands Soils in Southeastern Nigeria. International Scholarly Research Network ISRN Soil Science Vol. 2012, Article ID 198303, 5 pages.

Denef, K., Six J., Merckx, R., and Paustian, K. (2005).Short-term effects of biological and physical forces on aggregate Soil, 246, 185-200.

Dimoyiannis, D.G., Tsadilas, C.D., and Valmis, S. (1998). Factors affecting aggregate instability of Greek agricultural soils. Communications in Soil Science and Plant Analysis 29, 1239-1251.

FAO (2019) . Proceedings of the Global Symposium on Soil Erosion 2019. Rome.

Frei, M., Boll, A., Graf, F. Heinimann, H., and Springmann, S. (2003). Quantification of the influence of vegetation on soilstability. In: Lee CF, Tham LG (eds) Proceedings of the international conference on slope engineering. Hong Kong, China, pp. 872– 877.

Gee, G.W., and Or, D. (2002). Particle Size Analysis. In: Dane, J.H. and Topp, G.C., Eds., Methods of Soil Analysis, Part 4, Physical Methods, Soils Science Society of America, Book Series No. 5, Madison, 255-293.

Golchin, A., Baldock, J. A., and Oades, J. M. (1998). A model linking organic matter decomposition, chemistry, and aggregate dynamics. In: Soil Processes and the Carbon Cycle. pp. 245–266, Lal, R., Kimble, J. M., Follet, R. F., and Stewart B. A., Eds., CRC Press, Boca Raton, FL.

Gros, R., Monrozier, L. J., Bartoli, F., Chotte, J.L., and Faivre, P. (2004). Relationships between soil physico-chemical properties and microbial activity along a restoration chronosequence of alpine grasslands following ski run construction. Applied Soil Ecolog 27,pp. 7–22.

Grossman, R.B., and Reinsch, T.G. (2002). Bulk density and linear extensibility. pp. 201–228. In J.H. Dane and G.C. Topp (ed.) Methods of soil analysis.Part 4. SSSA Book Ser. 5. SSSA, Madison, WI.

Hitoshi, S., Haruhiro, F., Gus, G, . and Takashi, K. (2000). Soil aggregate stability under different landscapes and vegetation types in a semiarid area in northeastern Syria, Soil Science and Plant Nutrition, 46 (1) pp. 229-240.

Hossein, R. , Ali, A. J. , Ahmad, A. , Farzin , S. , and Khalil, V. K. (2015). Effect of Slope Position on Soil Properties and Types Along an Elevation Gradient of Arasbaran Forest, Iran.

Huang, Y.M., Liu, D., and An, S.S. (2015). Effects of slope aspect on soil nitrogen and microbial properties in the Chinese Loess region. Catena 125, 135–145.

Ibitoye, M.O., Ekanade O., Jeje L.K., Awotoye, O.O., and Eludoyin A.O. (2008). Characterization of gully formed in built up area in Southwestern Nigeria. Journal of Geography and Regional Planning , 1(9):pp. 164-171.

Idowu, O.J. (2003). Relationships between aggregate stability and selected soil properties in humid tropical environment. Communications in Soil Science and Plant Analysis 34, 695–708.

Igwe, C.A. (2004). Soil properties influencing stability of structure of B-horizons of Ultisols in semiarid Nsukka, Eastern Nigeria. Arid Land Res. Manag., 18, pp. 185-195.

Iheanyi, E. C. (2016).Assessment of soil properties from selected erosion sites in AbiaState, Southeastern Nigeria. Journal of Global Resources, 3,pp. 146-152.

Kalembasa, S. J., and Jenkinson, D.S. (1973). A comparative study of titrimetric and gravimetric methods for the determination of organic carbon in soil, J Sci Food Agric 24:pp.1085–1090.

Kalhoro, S. A. , Xuexuan, X. , Wenyuan , C. Rui, H., Sajjad, R. D., and Kang, D. (2017). Effects of Different Land-Use Systems on Soil Aggregates: A Case Study of the Loess Plateau(Northern China).Sustainability , 9, pp. 1349.

Kemper, D.W., and Rosenau R.C. (1986). Aggregate stability and size distribution. In: Methods of Soil Analysis, Part 1, (Ed. A. Klute). Am. Soc. Agron., 9, pp. 425-442.

Lal, R. (1986). Methods and Guidelines for Assessing Sustainable Use of Soil and Water Resources in the Tropics. Soil Management Support System, USDANRCS, Washington, DC.

Le Bissonnais, Y. (1996). Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. Eur. J. Soil Sci. 47,pp. 425–437.

Liu, H. U., Zhang, T. Y., Liu, B.Y. Liu, G., and Wilson, G. (2013). Effects of Gully Erosion and Gully Filling on Soil Depth and Crop Production in the Black Soil Region, Northeast China. Environ. Earth Sci., 68: pp. 1723–1732.

Malgwi, W. B., and Abu, S. T. (2011). Variations in some physical properties of soils formed on a hilly terrain under different land use types in Nigerian Savannah. Int. Journal of Sciences . 6 (3): pp. 150 – 163.

Mallam, I. Iguisi E.O., and Tasi'u .Y. R (2016). An Assessment of Gully Erosion in Kano Metropolis, Nigeria . Global Advanced Research Journal of Agricultural Science, 5(1) pp. 014-027.

Milne, R.M., and Haynes, R.J. (2004). Soil organic matter, microbial properties, and aggregate stability under annual and perennial pastures. Biology and Fertility of Soils 39, pp. 172–178.

Nelson, D.N., and Sommers, L.E (1982). Total carbon, organic carbon and matter. In: methods of soil analysis part 2 (Miller, A.D., and Keeney, D.K.M). American Society of Agronomy. pp 539-579.

NPC (2006). National Population Commission, 2006 Population Census Nigeria.

Nwite, J. N. , and Chukwuebuka, C. O. (2017). Organic carbon dynamics and changes in .some physical properties of soil and their effect on grain yield of maize under conservative tillage practices in Abakaliki, Nigeria. African Journal of Agricultural

Research , 12(26), pp. 2215-2222.

Nyberg, L. (1996) . Spatial variability of water content in the covered catchment at Gardsjon, Sweden, Hydrological Processes, 10, pp. 89–103.

Obalum, S. E. Nwite J.C., Oppong, J. Igwe, C.A. and Wakatsuki, T. (2011). Variations in selected soil physical properties with landforms and slope within an inland valley ecosystem in Ashanti region of Ghana. Soil & Water Res. 6: 73-82.

Oguike, P.C., and Mbagwu J.S.C. (2009). Variations in some Physical Properties and Organic Matter Content of soils of Coastal Plain Sand under different Land use types. World Journal of Agricultural Sciences 5 (1)63-69.

Okon, M. A, . Osujieke, D.N., Obi, C. I., Obasi, S. N., and Nkwopara, U.N. (2016). Aggregate Stability of Soils on a Sloppy Terrain in Owerri, Southeastern Nigeria. International Journal of Research in Agriculture and Forestry, 3 (12): 29-33.

Olusegun , O. A., Ogunkunle C O., and Adeniyi S.A. (2011). Assessment of soil quality under various land use practices in a humid agro-ecological zone of Nigeria . African Journal of Plant Sciences 5(10)pp 565-569.

Onweremadu, E.U., Izuogu, O.P., and Akamigbo, F.O.R. (2010) Aggregation and pedogenesis of seasonally inundated soils of the tropical watershed. Chiang Mai J. Sci. 37 (1): 74-84.

Oyegun, C. U., Erekaha, U.N., Eludoyin, O.S. (2016). Gully Characterization and Soil Properties in Selected Communities in Ideato South L.G.A., Imo State, Nigeria. Nat Sci. 14(2):34-50.

Quansah, C. (1997). Approaches to Replenishing Soil Fertility Depletion in Ghana; In Proceeding of International Seminar on Approaches to Replenishing to Soil Fertility in Africa – NGO, Perspectives ICRAF.

Quanchao, Z. Frédéric, D., Cheng, M., Zhaolong, Z., and Shaoshan, A. (2018). Soil aggregate stability under different rain conditions for three vegetation types on the Loess Plateau (China). CATENA, Elsevier, 167, pp.276–283.

Qui. L. Wei, X. Gao , J., and Zhang, X. (2015) . Dynamics of soil aggregate associated organic carbon along an afforestation chronosequence. Plant Soil 391:237–251.

Robinson, M., and Dean, T.J. (1993). Measurement of near surface soil water content using a capacitance probe. Hydrological Processes Joumal7, 77-86.

Salako, F. K., Hauser, S. , Babalola, O. , and Tian, G. (2001.) Improvement of the physical fertility of a degraded Alfisol with planted and natural fallows under humid tropical conditions. Soil Use and Management 17: 41-47.

Sanchez, P. A., Buresh R. J., Kwesiga F.R. , Mokwunye A.U., Ndiritu, C.G. Shepherd, K.D., Soule, M. J. and Woomer, P. L (1997). Soil Fertility Replenishing in Africa: An Investment in Natural Resource Capital pp. 121 – 129. In Proceedings of international Seminar on Approaches to Replenishing Soil Fertility in Africa – NGO Perspectives. ICRAF House Nairobi, Kenya

Shehu B.M., Jibrin J.M., and Samndi A.M. (2015). Fertility status of selected soils in the Sudan Savannah Biome of Northern Nigeria. International Journal of Soil Science, 10:pp.74 – 83.

Shinjo, H., Fujita, H., Gintzburger, G., and Kosaki, T. (2000). Impact of grazing and tillage on water erosion in northeastern Syria. Soil Sci. Plant Nutr., 46, pp. 151-162.

Singh, A.K., Rai, A., Pandey, V., and Singh, N. (2017a). Contribution of glomalin to dissolve organic carbon under different land uses and seasonality in dry tropics. Journal of Environmental Management 192: 142-149

Six, J., Bossuyt, H., Degryze, S. and Denef, K. (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Res. 79.

SPSS, (1999). SYSTAT 9 statistics I. SPSS Inc.: Chicago, IL. Igwe, C.A., and Nwokoch, D. (2005). Influence of soil properties on the aggregate stability of a highly degraded tropical soil in Eastern Nigeria . . Int. Agrophysics, , 19, pp. 131-139.

Ternan, .L., Williams, A.G., Elmes, A., and Hartley, R. (1996). Aggregate stability of soils in central Spain and the role of land management. Earth Surface Processes and Landforms, 21, 181-193.

Thalen, D. C. P. (1979) Ecology and utilization of desert shrub rangelands in Iraq. Dr. W. Junk. Publishers, The Hague.

Ubuoh, E. A., Akhionbare, W. N., Onweremadu, E. , Onifade , O. A. (2013). Characterization of Soil Quality in Erosion Prone Environment of Ukpor, Nnewi-South L.G.A. of Anambra State, Nigeria. International Journal of Advances in Applied Sciences, 2(1), pp. 1~8.

Ubuoh, E. A., Ufot, U. O., and Ezenwa, L. (2016). Influence of Temperature Dynamics on Phosphorus Availability in Humid Tropical Soils of Southeastern Nigeria. Journal of Basic and Environmental Sciences (JBES) 3:pp.140-147.

Ubuoh, E. A. , and Ogbonna, P. C. (2018). Effects of Some Anthropogenically Induced Environmental Hazards on Soil Fertility Indices, Germination and Growth of Maize and Soyyabeans in Imo State. African Journal of Agriculture Technology and Environment, 7 (2): pp.30-43.

Ubuoh, E. A., Uka, A., and Egbe, C. (2017) . Impact of flood disaster on soil quality dynamics in agro-ecological zone of Ebonyi State, Nigeria. JOFESD , 3 (1): pp.143-153.

Ukaegbu, E. P., Osuaku, S. K. and Okolo, C. C. (2015). Suitability Assessment of Soils Supporting Oilpalm Plantations in the Coastal Plains Sand, Imo State Nigeria . International Journal of Agriculture and Forestry , 5(2): 113-120.

Unger, P. W. (1997). Aggregate and organic carbon concentration interrelationships of a Torrertic Pale Stoll Soil and Till-age Research 42 95-113.

Uwanuruochi, A. O., and Nwachukwu, O. I. (2012).Impact of erosion on selected soil structural indices of four Local Government Areas of Abia State, Nigeria. PAT 8 (2): 127-133.

Uzoma, K. C., and Onwuka, B. M. (2018) . Variations in Aggregate Stability and selected Soil Chemical Properties Under Different Land Use Systems in Ikpe Ikot Nkon, Southeastern, Nigeria . Agri Res & Tech: Open Access J 17 (5): 1-9.

Walker, L. R., and del Moral, R. (2009). Lessons from primary succession for restoration of severely damaged habitats. Appl Veg Sci 12:55–67.

Walkley, A., and Black, A. (1934). An examination of the Detgareff method for determining soil organic carbon, chronic titration method. Soil Sci. 37: 2 – 38.

Wang , X. , Yost, R. S., and Linquist, B.A . (2001). Soil aggregate size affects phosphorus desorption from highly weathered soils and plant growth. Soil SciSoc Am J 65:139–146.

Wang, J. Bojie, F. Yang, Q. and Liding , C. (2001). Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China . Journal of Arid Environments , 48: 537–550 .

Wei Hu , M.. , Shao, A., Quan, J., Wang, J. F., Klaus, R. (2008). Spatial variability of soil hydraulic properties on a steep slope in the Loess Plateau of China. Sci. agric. (Piracicaba, Braz.) .65 (3): 268-276.

Xu, M., Li, Q., and Wilson, G. (2016). Degradation of Soil Physicochemical Quality by Ephemeral Gully Erosion on Sloping Cropland of the Hilly Loess Plateau, China. Soil & Tillage Research 155 pp. 9–18 .

Yang, T., Adams J. M., Shi Y., He J., Jing X., Chen L., Leho, T., and Haiyan, C. (2017). Soil fungal diversity in natural grasslands of the Tibetan Plateau: associations with plant diversity and productivity. New Phytol. 215 pp. 756–765.

Young, E. O. (2000). Hydraulic conductivity of saturated soil pp. 141 -181.In: R. A. Smith and Mullins (ed). Soil and Environmental Analysis: Physical Methods 2nd ed. Marcel Dekkar, Inc New York. NY.

Zhu, X. Zhu, B, . Chen, L., Zhu, B. Xing, B. (2017). Effects and mechanisms of biochar-microbe interactions in soil improvement and pollution remediation: a review . Environ. Pollut., 227 , pp. 98-115.