

ERODIBILITY OF SOILS OF VARYING LAND UTILIZATION TYPES AND LITHOLOGIC MATERIALS IN CENTRAL SOUTHEASTERN NIGERIA

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ABSTRACT

Land use and parent materials influence behaviour of soils including responsiveness to erosion forces. The study investigated some soil properties related to erodibility in Abia and Imo States of Nigeria. Soil sampling was guided by geology and land use type. Random sampling technique was adopted in field studies. Two parent materials and three land use types were chosen for the study. In each parent material, three land use types were studied and in each land use, three soil profiles were sunk, described, and sampled using FAO procedure. Soil samples were subjected to laboratory analyses and data generated were analyzed using descriptive and inferential statistical tools. Results showed that sand sized particles ranged from 533.10 to 778.80 g kg⁻¹ and this distribution differed significantly between parent materials. Silt content ranged from 141.70 g kg⁻¹ in soils derived from false-bedded sandstone to 202.20 g kg⁻¹ in shale-derived soils. Clay-sized particles ranged from 77.30 g kg⁻¹ in soils derived from false-bedded sandstone to 264.70 g kg⁻¹ in shale-derived soils, respectively. Water-stable aggregate ranged from 19.38% in false-bedded sandstone to 29.23% in shale-derived soils. The DR (dispersion ratio) mean values ranged between 4.26 in shale and 8.46 in false-bedded sandstone, while the CDI (clay dispersion index) mean values ranged between 2.17 in shale and 8.41 in false-bedded sandstone, respectively. The forest soils had the lowest values of both DR (6.89) and CDI (6.40) for soils of the false-bedded sandstone, 3.85 and 1.59 for those derived from shale. The clay flocculation index (CFI) had mean of 2.16 in false-bedded sandstone and 7.83 in shale. In soils of the varying land use types, the mean soil pH (H₂O) ranged from 4.28 to 4.64 in soils derived from false-bedded sandstone and 4.27-5.57 in those derived from Shale. From the results, parent material and land use influenced soil erodibility parameters (water-stable aggregates, mean-weight diameter, DR, CDI, and CFI) and other soil properties such as organic carbon, bulk density, and moisture content.

Key words: Soil erosion, land use, parent material, macro aggregate, micro aggregate

INTRODUCTION

Soil erosion has contributed tremendously to land cover change in Nigeria especially in southeastern part comprising Imo, Abia, Anambra, Enugu, Ebonyi, Akwa-Ibom and Cross River States. The rapidly changing land cover characteristics can in most times be attributed to the degree of soil damage, devastation and degradation with soil erosion being a major degrading factor (Onweremadu, 2006). Natural and anthropogenic forces interact to cause soil erosion (Ubuoh *et al.*, 2013) leading to varying levels of soil degradation- as responses of soils to erosive forces differ. Nonetheless, soil erosion results in loss of top-soil (Nyssen *et al.*, 2004; Ezechukwu and Madubuike, 2015), alteration of biodiversity (Keesstra *et al.*, 2018), depletion of soil flora and fauna (Lal, 2004), reduced agricultural productivity (Abdulfatai *et al.*, 2014), declining soil fertility (Liu *et al.*, 2013), increasing economic loss (Li *et al.*, 2016) and general reduction in soil quality (Xu *et al.*, 2016).

Erodibility characteristics of soils are related to lithologic materials (Ofomata, 1981) and land use (Akamigbo, 1999), parent materials, organic matter accumulation, soil aggregate stability (FAO, 2005), though this may be indirect through rate of weathering and basic cation release (Arbestain *et al.*, 2007). On the other hand, land use influences aggregate stability (Oguike and Mbagwu, 2009) as nutrient removals cause changes in structural stability (Mill and Fey, 2003).

Cultivation destabilizes soil aggregation (Wakene, 2001) and this reduces soil moisture retentivity: implying more volumes of soil water will be available for erosive action. Particle size distribution which differs among parent materials (Ahukaemere, 2015; Irmak *et al.*, 2007) influence aggregate stability indices of soils (Oguike and Mbagwu, 2009) and changes in organic matter content due to land use (Keesstra *et al.*, 2018). The relevance of soil aggregate stability indices such as dispersion ratio (DR), clay flocculation index (CFI),

mean-weight diameter (MWD) and water-stable aggregates (WSA) is obvious in sustaining soil's capacity to effectively perform vital ecosystem functions especially in Southeastern Nigeria with high rainfall amount, high precipitation rate and long duration falls. These erodibility indices including clay content, organic matter status and exchangeable sodium percentage are vital in regulating soil losses and soil quality (Kalhor *et al.*, 2017).

Given the spate of land degradation by soil erosion in Southeastern Nigeria coupled with increasing population amidst conflictive land use types and extreme climate aberrations, it becomes exigent to investigate some erodibility indices of selected soils of Southeastern Nigeria as they relate variation in lithologic origin and land use type. The major objective of this study was therefore to assess some erodibility indices of selected soils of Southeastern Nigeria in relation to parent material and land use.

MATERIALS AND METHODS

Study Area

The study was conducted at Umulolo Okigwe in Imo State and Itumbuzor, Bende in Abia State, both in Central Southeastern Nigeria (Lat. 4° 40' and 8° 50' North and Long. 6°40' and 8°15' East). Soils are derived from false-bedded sandstones (Umulolo Okigwe) and shale (Itumbuzor Bende). The study area lies within the humid tropics with annual rainfall ranging from 1800-2500 mm and characteristically bimodal having peaks at July and September with a dry spell in August. Annual temperature ranges from 26-30°C and a relative humidity of over 80% measured at 10.00 am during wet seasons. They have rainforest vegetation with plant species arranged in tiers, comprising emergent trees, overlying tree canopy types, shrubs and sun-hating plants at forest floor. Oil palm trees are dominant plant species in the area thus referred to as oil palm belt of Nigeria. Imo River is a major river in the area rising from Isuochi of Abia State passing through Umuna, Obowo, Mbaise and Ngor Okpala in Imo State, then through Ngwa and Ukwu (Abia State) and enters the Atlantic Ocean through Port Harcourt (River State). Major socioeconomic activities in the area include small scale farming, fishing, lumbering, gathering from the wild, artisanal activities and oil prospecting in some localities.

Brief Description of the Sampling Sites

Umulolo Okigwe (5° 52' 20.5" N; 7° 17' 51.7" E) is underlain by false-bedded sandstones known as Ajali Formation, and is characterized by lowlands with few gentle to undulating slopes. The sampling sites have secondary forest dominated by trees and shrubs, continuously cultivated lands and lands that have been under fallow for more than five years. Topsoils

are sandy with few stones, pebbles and gravels. Itumbuzor (5° 50' 37.5" N, 7° 68' 04.2" E) is in Bende area of Abia State, Nigeria. Its soils are derived from Bende-Ameki shale group. Soils are deep but moderately to poorly drained. Soils are grayish (5 YR 6/1, 5YR 5/1, 10YR 5/2 moist) and have mottles especially at endopedons. Soils are on plain to gentle and undulating slopes interspersed with some depressions. Soils are very sticky with trafficability constraints.

Field Studies

A reconnaissance visit preceded field studies which assisted in preparing for the latter. Geology map of the area guided location of sampling sites. Two parent materials namely, false-bedded sandstone and Bende-Ameki shale group were randomly selected for the study. In each lithologic group, three land use types were chosen at random for the investigation, and these land uses included secondary forest, cultivated and fallow lands. A transect of 150 m was cut in each of the land use types, and three soil profile pits were sunk 50 m apart, giving a total of 18 soil profile pits. Soil profile pits were described, and sampled using FAO (2006) guidelines. All soil profiles were georeferenced using handheld Global Positioning System (GPS) receiver (Garmin Ltd Kansas, USA). Field observations were made and recorded. Core samples were used to collect soil samples for bulk density determination.

Laboratory Studies

Soil samples were air-dried and sieved using 2.0 mm sieve in readiness for some laboratory analyses. Particle size analysis was performed using Bouyoucos hydrometer method (Gee and Or, 2002) while bulk density was measured by core method (Grossman and Reinch, 2002). Total porosity was calculated using a relationship between bulk density and particle density of the soil as follows:

$$TP = 1 - \frac{BD}{PD} \times 100 \dots\dots\dots (1);$$

where TP is percent total porosity, BD is bulk density, and PD is particle density assumed to be 2.65 Mg m⁻³. Soil moisture was measured gravimetrically thus:

$$\text{Soil moisture (\%)} = \frac{WS-DS}{DS} \times 100 \dots\dots (2);$$

where WS is weight of moist soil sample, and DS is weight of dry soil sample.

The following indices of microaggregate stability of the soil were also calculated using the relevant formulae (Igwe and Obalum, 2013):

$$\text{Dispersion ratio (DR)} = \frac{(\%Silt + \%Clay (H2O))}{(\%Silt + \%Clay (Calgon))} \times 100$$

$$\text{Clay dispersion index (CDI)} = \frac{\%Clay (H2O)}{\%Clay (Calgon)} \times 100$$

$$\text{Clay flocculation index (CFI)} = 100 - \text{CDI}$$

Soil aggregate stability (WSA and MWD) was calculated after wet sieving done by the method of Kemper and Rosenau (1986). Soil pH was measured in 1:2.5 soil-water suspension (Thomas, 1996). Available phosphorus in the soil, extracted with Bray 2 solution (Olsen and Sommers, 1982), was determined in the supernatant solution using the molybdo-vanadate method (Murphy and Riley, 1962). Soil organic carbon was determined by wet digestion method described by Nelson and Sommers, (1996), while total nitrogen was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982).

Data Analysis

Soil data were subjected to analysis of variance to test differences in soil properties in relation to land use, for significantly different parameters ($p < 0.001$, 0.01, 0.05). Means were separated using Least Significant Difference (LSD) while statistical difference between the two parent materials was ascertained using *t*-test. Correlation analysis was done to determine the relationship between soil properties.

RESULTS AND DISCUSSION

Physical Properties of the Soils in Relation to Erosion Hazard

Table 1 shows physical properties of soils, with sand-sized particle sizes dominant over other sizes irrespective of parent material and land use type. Sand-sized particles ranged from 533.10 to 778.80 g kg⁻¹ and this distribution differed significantly ($p < 0.05$) between parent materials. Significant differences were also recorded in other particle sizes. Silt content ranged from 141.70 to 202.20 g kg⁻¹ with false-bedded sandstone having minimum value (141.70 g kg⁻¹) and shale-derived soils having the maximum value (202.20 g kg⁻¹). Clay-sized particles ranged from 77.30 to 264.70 g kg⁻¹ with false-bedded sandstones and shale-derived soils having minimum and maximum values, respectively. Clays are lighter than other particle sizes thus readily eroded on the soil surface if other conditions are met.

Land use did not significantly alter the distribution of particle sizes. Results on particle size distribution show that in a short period of time, land use may not alter soil texture being an inherent property of soils, but this can change with prolonged weathering over a long chronological space, indicating the need for soil conservation irrespective of soil textural class. Similar textural behaviour was earlier reported by Denton *et al.* (2017). Total porosity of soils varied significantly ($p < 0.001$) between parent materials and among land use types with mean values ranging from 54.16% (shale) to 59.90% (false-bedded sandstone). Across the three different land use types studied, forested soils had

significantly higher pore spaces than the cultivated and fallow soils. Other factors are assumed constant, soils of the false-bedded sandstone and forest record more infiltration thereby minimizing runoff build-up. Using moisture content, results showed significant ($p < 0.001$) differences among soil groups with shale soils having maximum gravimetric moisture content of 12.49% and false-bedded sandstone having minimum value of 9.09%. It would be expected that the higher the moisture content the greater tendency of soil water to accumulate for movement via soils, but clays hold water tenaciously due to high content of micropores such that the water contained there may not be available for erosion. On the other hand, large macropores dominate the false-bedded sandstone; so, the soils hardly erode unless an imperious layer lies proximal to the soil surface. Generally, land use influenced bulk density, total porosity, moisture content, WSAs and MWD at $p < 0.001$, indicating impact of land use on these erodibility indices (Table 1). Obalum *et al.* (2013) reported that land use influenced soil bulk density and permeability; Ahukaemere *et al.* (2016) reported that fallow period influenced soil bulk density and moisture content.

Also, significant ($p < 0.001$) differences existed for the MWD of soils, ranging from 0.46 mm (cultivated soils) to 1.48 mm (forest) as well as for WSA of soils with minimum value of 12.58% (cultivated soils) and maximum value of 27.37% (forest) in soils derived from the false-bedded sandstone. In shale-derived soils, significant ($p < 0.001$) differences were recorded for MWD of soils, ranging from 0.79 mm (cultivated) to 2.07 mm (forest) and WSA of soils with minimum value of 19.00% (cultivated soils) and maximum value of 41.40% (forest) in soils derived from the shale. Higher values of WSAs in the shale-derived soils could be due to higher content of clay in these soils. As earlier posited, soil aggregation is dependent on clay, silt, and organic carbon content as well as ionic bridging among other factors (Bromik and Lal, 2005). Expectedly, soils of forest land use had significantly ($p < 0.001$) higher stable aggregates than other land use types irrespective of lithologic origin (Table 1), suggesting least erodibility. Tillage and removal of nutrients (Mill and Fey, 2003), tillage disturbances (Oguike and Mbagwu, 2009), differences in organic carbon content (Onweremadu and Okoli, 2017) as well as intensity of tillage (Lal, 2004) may have caused these differences in aggregate stability.

The DR and CDI differed significantly between the parent materials (Figure 1) and among the three land use types. The DR mean values ranged between 4.26 in shale and 8.46 in false-bedded sandstone while the CDI mean values ranged between 2.17 in shale and 8.41 in false-bedded sandstone, respectively.

Table 1: Physical properties and erodibility indexes of soils of the different parent materials and land use types

Land uses	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	BD (g cm ⁻³)	TP (%)	MC (%)	WSA (%)	MWD (mm)	DR	CDI	CFI
False-bedded sandstone											
Cultivated	781.80	148.00	70.20	1.12	57.78	8.26	12.58	0.46	9.35	9.87	1.87
Forest	775.10	141.30	79.10	0.93	64.45	10.02	27.37	1.48	6.89	6.40	3.60
Fallow	779.60	135.80	82.40	1.13	57.49	8.97	18.20	0.81	9.15	8.98	1.02
LSD	NS	NS	NS	0.08***	2.83***	1.21***	2.92***	0.19***	1.21**	1.13**	0.14**
Mean	778.80a	141.70a	77.30a	1.06a	59.90a	9.09a	19.38a	0.92a	8.46a	8.41a	2.16a
Shale											
Cultivated	517.00	210.00	272.40	1.29	51.62	9.83	19.00	0.79	4.01	2.53	7.47
Forest	532.20	212.00	255.80	1.08	60.89	14.80	41.40	2.07	3.85	1.59	8.41
Fallow	550.00	184.20	265.80	1.28	49.99	12.84	27.30	1.18	4.93	2.41	7.59
LSD	NS	NS	NS	0.09***	4.036***	1.49***	5.27***	0.306***	0.72**	0.32**	0.95**
Mean	533.10b	202.2b	264.7b	1.20b	54.16b	12.49b	29.23b	1.35b	4.26b	2.17b	7.83b

BD - bulk density, TP - total porosity, MC - moisture content, WSA - water-stable aggregate, MWD – mean-weight diameter; DR - dispersion ratio, CDI - clay dispersion index, CFI - clay flocculation index. LSD - least significant difference; ****p* < 0.001, ***p* < 0.01, **p* < 0.05, NS - not significant. Means with same lower-case letters are similar.

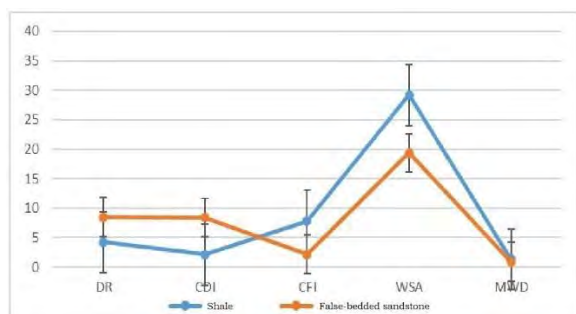


Figure 1: Effect of parent material on soil erodibility indexes

The forest soils had the least values of both DR (6.89) and CDI (6.39) for soils of the false-bedded sandstone, 3.85 and 1.58 for forest soils derived from shale. The CFI had mean of 2.16 in false-bedded sandstone and 7.82 in shale. Across the parent materials, forest soils had significantly higher CFI than fallow and cultivated soils. High CFI, low DR and CDI recorded in forest soils and soils derived from shaley lithology indicated least erosion hazards. The higher the DR and CDI, the more the ability of the soil to disperse, while the higher the CFI the better aggregated the soil (Basga *et al.*, 2018). Igwe and Udegbunam (2008) opined that CFI is a very good micro-aggregate index for predicting soil erodibility. According to Igwe *et al.* (1995), CFI ranked highest among other micro- and macro-aggregate indices in predicting potential soil loss in some soils of southeastern Nigeria.

Chemical Properties of Soils

The pH of soils was acidic in the two parent materials. In soils of the varying land use types, the mean pH (H₂O) values ranged from 4.28-4.64 in soils formed from false-bedded sandstone and 4.27-5.57 in those derived from shale (Table 2). Abua *et al.* (2010) and Iwara *et al.* (2011) reported similar results in some soils of Southeastern Nigeria. From the result, soil reaction differed significantly across the parent materials and land use types which could be a consequence of composition of the lithologic material, land use practices and topography of the areas. The organic carbon contents of soils differed significantly across the soils studied. The organic carbon contents of soils ranged between 17.59 and 22.08 g kg⁻¹. In the different land use types, organic carbon content was within the ranges of 12.03-38.47 g kg⁻¹ in false-bedded sandstone and 1.22-28.64 g kg⁻¹ in shale. From the results, forest soils contained significantly higher proportion of organic carbon than other land use types. The differences in organic carbon content may be linked to the heterogeneity of land use pattern and management practices. Soil organic carbon has been reported to decrease with vegetation density among land use types (Obalum *et al.*, 2012). The low values in the cultivated land could be due to agricultural practices that favour rapid decomposition. Conversion of natural forest to cultivated land modifies the microclimate with different canopy cover and litter fragmentation (Senjobi, 2007).

Table 2: Chemical properties of soils of the different land use types

Land Uses	pH-KCl	pH-H ₂ O	OC (g kg ⁻¹)	Total nitrogen (mg kg ⁻¹)	AvP (mg kg ⁻¹)	TEB (cmol kg ⁻¹)	Exch. acidity (cmol kg ⁻¹)	%ESP	%Base saturation
False-bedded sandstone									
Cultivated	3.73	4.62	12.03	3.60	14.91	4.72	0.90	0.78	83.58
Forest	3.64	4.64	38.47	14.33	19.50	4.86	2.38	2.12	65.85
Fallow	3.73	4.28	15.74	4.06	18.26	3.69	2.87	0.40	56.70
LSD	NS	0.31*	7.23***	2.48***	NS	NS	0.53***	0.81***	10.7***
Mean	3.69a	4.52a	22.08	7.33	17.56a	4.43a	2.05a	1.10a	68.71a
Shale									
Cultivated	3.63	4.38	11.22	2.01	22.92	2.98	0.84	0.73	78.80
Forest	3.72	5.57	28.64	10.49	17.20	6.60	0.63	1.63	86.70
Fallow	3.70	4.24	12.89	3.95	20.42	4.72	0.19	0.23	90.20
LSD	NS	0.26***	5.10***	4.356**	3.19***	2.346*	NS	1.19*	8.67*
Mean	3.69a	4.37b	17.58	5.48	20.85b	5.83b	0.55b	0.86b	91.42b

OC - organic carbon, TN – total nitrogen, AvP - available P, TEB - total exchangeable bases, ESP - exchangeable sodium percentage
LSD - least significant difference, ****p* < 0.001, ***p* < 0.01, **p* < 0.05, NS - not significant. Means with same lower-case letters are similar.

From the results, it was deduced that forest ecosystems appear to be the most conducive climatic environment for maximum organic carbon accumulation, thus aid in maintaining good soil aggregation, reduced erodibility and soil compaction.

Results of correlation show significant ($p < 0.001$) relationships between organic carbon and bulk density in soils derived from false-bedded sandstone and shale ($r^2 = 0.54$ and 0.81 , respectively) (Figure 2), implying that as organic carbon increases in the soils, bulk density decreases due to increases in macro-aggregation (Onweremadu and Okoli, 2017) and water infiltration into the soils (Attah, 2010). Organic carbon also had significant ($p < 0.001$) positive relationships with clay, CFI and WSA in soils of the false-bedded sandstone ($r^2 = 0.513$, 0.601 and 0.626 , respectively) and shale ($r^2 = 0.578$, 0.611 and 0.646 , respectively).

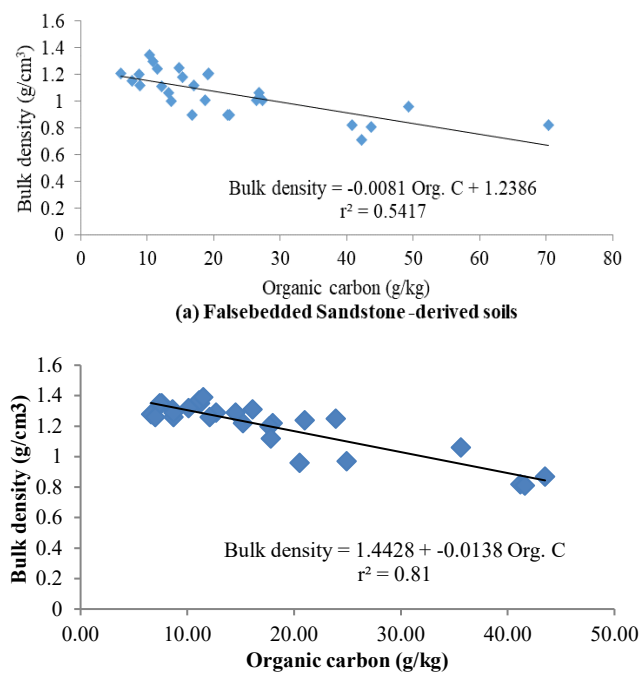


Figure 2: Relationship between soil organic carbon and bulk density for the (a) False-bedded sandstone-derived soils and (b) Shale-derived soils

CONCLUSION

The sand, silt and clay fractions differed significantly between parent materials. Parent material and land use influenced soil erodibility indices namely bulk density, total porosity, moisture content, and organic carbon, as well as macro- and micro-aggregate stability, indicating impact of lithological material and land use on these erodibility indices. Soils derived from shale and soils under forest land use had higher WSA, MWD and CFI than soils derived from false-bedded sandstone and those under fallow and

continuous cultivation. Also, forest soils had higher pH values and organic carbon than other land use types. Based on this finding, we suggest further research on erodibility capacity of soils of other parent materials and land uses in the tropics.

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