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Use of erodibility indices in assessing soil erosion in central and northern Cross River State, Nigeria

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ABSTRACT

Soil erodibility indices were used to assess erosion prone areas in central and northern Cross River State, Nigeria. Fourteen (14) composite soil samples were collected at a depth of 0-30 cm and analyzed using standard laboratory procedures. Results showed that the soils are coarse textured with high sand content dominated by textural class of loamy sand in both the central and northern. The vulnerability class used for rating of soil erodibility indices in the study showed that % water stable aggregate *(WSA)* was severe and moderate (mean values of 55.3 and 37.24%); indicating high and moderately vulnerable. The CV of the *%WSA* was high and moderate (38 and 34%) in the central and northern. Dispersion ratio (DR) was generally extreme (mean values of 0.36 and 0.32); indicating very high vulnerability. The CV of the *DR* was high and moderate (56 and 34%) in the central and northern. Clay ratio (CR) was generally moderate (mean values of 3.5 and 3.4); indicating moderately vulnerable. The CV of the *CR* was high (43 and 54%) in the central and northern. While that of clay flocculation index *(CFI)* was generally low (mean values of 0.87 and 0.85); indicating its inability to resist dispersion in water. The CV of the *CFI* was low (6%) in both the central and northern. The t-test analysis conducted on the *DR, CR* and *CFI* showed they were no significantly differences ($p>0.05$). While significantly differences ($p<0.05$) were observed in %WSA with sand, silt and clay of the water dispersed samples in the central and northern. Soil conservation measures such as contour farming, terracing, vegetative barriers and engineering measures such contour bunds and water ways should be adopted in the erosion prone areas to control the erosion.

1.0 Introduction

Soil erosion is one of the environmental issues threatening human life driven by unsustainable land management due to increasing human pressure enhanced by climate change (Hellden and Tottrup, 2008). Soil erosion is a natural process defined as the detachment, movement and deposition of soil or rock caused by the dynamic activity of erosive agents, such as water, ice (glaciers), snow, air (wind), plants, animals, and humans (SSSA, 2008; Apollo *et al.*, 2018).

Soil erosion occurs when raindrop impact on the soil surface displaces soil particles, and the water flowing over the land surface mobilizes soil particles to undesirable location (Reusser *et al.*, 2015). The soil particles detached from the soil mass adds sediment to the sediment load being transported down slope by floating, rolling, dragging and splashing and deposition of the transported particles or sediment eroded from soil clods in nearby depressions formed by the clods at some place lower in elevation (Brady and Weil, 2008).

Accelerated soil erosion induced by human activities, is extremely severe and create a negative impact including loss of life and property, decline of soil fertility, loss of nutrient for plant growth among others in the environment. It has been estimated that about 80–85% of agricultural land

suffers from soil erosion and six billion hectares of fertile land are being lost annually due to water erosion and other land degrading factors (Comino-Rodrigo *et al.,* 2015; Ganasri and Ramesh, 2016).

Soil erodibility indices also called aggregate stability indices are tools used for predicting soil erosion. Igwe and Nwokocha (2005) reported that, aggregate stability indices used for predicting soil erosion hazards are macroaggregate and microaggregate stability. The soil macroaggregate form is the water stable agregates (WSA) between 4.00 – 0.50 mm including the mean-weight diameter (MWD), geometric mean weight diameter (GMWD) and potential structural deformation index (PSDI) (Igwe, 2003). Macroaggregates have microaggregates as their building blocks and its collapse yield microaggregates (Igwe and Obalum, 2013). Indices of microaggregate stability commonly applied to tropical soils are clay ratio (CR), dispersion ratio (DR) and clay flocculation index (CFI) (Igwe and Obalum, 2013).

Cross River State soils are characterized by highly weathered and leached condition, structurally fragile and loosed, acidic and very susceptible to different forms of water erosion including catastrophic erosion due to heavy rainfall and human activities (Chikezie *et al.*,2010). Soil erosion prone areas of central and northern Cross River State have become a worrisome issue of concern due to the exacerbated negative impact on the surface cutting deep the soil especially in every rainfall event. Due to the havoc this has caused, there is an urgent need to assess the soil erosion prone areas to proffer solutions to control this scenario. Hence, the study uses erodibility indices to assess soil erosion in order to suggest appropriate coservation measures to curb the menace.

2.0 Materials and Methods

2.1. Study Area

The study was carried out on erosion prone areas in the central and northern Cross River State, Nigeria. The central were Inebor, Anong, Itigidi, Katabebe, Kekomkola, Obioko, and Njang Assam. While the northern were Ishibori, Igoli, Stadium, Okuku, Okpoma, Abonkep 1 and Abonkep 2. Cross River State lies between Latitude 05^0 58˙ N and Longitude 08^0 04˙ E. The climate is mostly tropical-humid in the tropical rainforest climatic zone with dry and wet seasons except on the Obudu plateau (500 feet above sea level) where due to altitude, it is temperate throughout the year. Average temperature ranges between 15^0C and 23^0C. The annual rainfall is 4300 mm. The soil belongs to the soil order, Ultisols which are deep, porous, and acidic with low organic matter content as a result of leaching from rainfall activity causing high susceptibility of the soil to accelerated erosion and land degradation (Eyong and Akpa, 2018). The underlying geological materials within the central consist of sandstone-shale intercalation in Yakurr and Abi, basalt (Basaltic lava) in Ikom. While those of the northern zone consist of sandstone in Ogoja and Yala, basement complex (granite, gneiss, quartzite and schist) in Obudu (Ibanga, 2006; Eyong *et al*, 2008 and Ekwueme, 2003). The natural vegetation of the areas is characterized by tropical rainforest, guinea savanna and derived savanna. In the central, the vegetation is predominantly tropical rainforest ecosystem with heavy upland forest, fresh water swamps and mangrove swamps mostly forest, grasses and shrubs that have three to four layers of tree conopies covering the land mass. While in the northern, the vegetation is characterized by grassland, mangrove, forest with pocket of immature and mature forest of the derived savanna zone and parkland vegetation. The land uses include cultivated, forest and grassland. The major crops planted in the areas include rice (*Oryza sativa*), oil palm *(Elaeis guinensis),* cocoa *(Theobroma cacao),* cassava *(Manihot spp.),* plantain *(Musa paradisiaca),* yam *(Dioscorea spp.),* pineapple *(Ananas comosus).* Common plant species found in the areas include guinea grass *(Panicum maximum),* elephant grass (*Pennisetum purpureum*), teak *(Tectona gradis),* Gmelina *(Gmelina arborea),* pear *(Dacryadis edulis)* and timber trees (Bulktrade, 1989; Effiong, 2011).

2.2. Soil Sampling

Fourteen (14) composite soil samples were collected, that is, seven (7) from central and seven (7) from northern on erosion prone areas at the depth of 0-30 cm using soil auger by random sampling and georeferenced using Legend H Garmin Global positioning system 12 etrex. The samples were bagged, labeled and transported to the University of Calabar Soil Science Laboratory for analysis.

2.3. Laboratory Analyses

2.3.1. Physical properties

Particle size distribution was determined by the hydrometer method following the procedures outlined by Gee and Bauder (1986), using sodium hexametaphosphate (Calgon) as a dispersant agent. The soil texture was determined using USDA soil textural triangle (SSS, 1999). Bulk density was determined using the core method as described by Blake and Hartge (1986). Particle density was determined by the pycnometer method following the procedures outlined by Bowles (1992). The saturated hydraulic conductivity (Ksat) was determined by the constant head method. The transposed Darcy's equation as outlined by Youngs (2000) was used for computation of Ksat.

$$\text{Ksat} = \frac{\text{QL}}{\Delta\text{HAT}} \quad (1)$$

Where; Q is the steady state volume of outflow from the entire soil column (cm^3), L is the length of soil column (cm), A is the cross sectional area of the soil column (cm^3), ΔH is the change in hydraulic head or the head pressure difference causing the flow (cm) and T is the time of flow (seconds).

Water stable aggregate was determined by measuring 100 g of air-dried soil sample into a 4.75 mm mesh and wet sieved by passing aggregates through set of net of sieves of 2, 1, 0.5 and 0.25 mm and submerged in water for 1 minute as outlined by Gilmour *et al.* (1948); Kemper and Rosenau (1986). The weight retained of each sieve was weighed and percent water stable aggregates on each sieve was calculated using the formula outlined by Lal and Shukla (2004).

$$\% \text{ WSA} = \frac{WR - WSF}{TSW - WS} \, x \, 100 \qquad (2)$$

Where; WSA is the water stable aggregate, WR **is** the weight retained, WSF is the weight of sand fraction, TSW is the total sample weight and WS is weight of sand

The water dispersed samples (WDC) was analyzed without calgon using Bouyoucos hydrometer method of particle size distribution described by Gee and Or (2002). The dispersion ratio (DR), clay ratio (CR) and clay flocculation index (CFI) were by calculation from the amount of sand, silt and clay in calgon-dispersed as well as water dispersed samples.

$$DR = \frac{\% \, Silt \, + \% \, Clay \, in \, water \, dispersed \, samples}{\% \, Silt + clay \, in \, calgon \, dispersed \, samples} \times 100 \qquad (3)$$

$$CR = \frac{\% \, Sand}{\% \, Silt + \% \, clay} \qquad (4)$$

$$CFI = \frac{(\% \, clay \, in \, calgon) - (\% \, clay \, in \, water)}{\% \, clay \, in \, calgon} \times 100 \qquad (5)$$

The higher the values of *DR* and *CR*, the greater is the tendency of the soil to disperse upon contact or slaking with water. While the higher the *CFI*, the better aggregated the soil.

2.3.2. Chemical properties

Soil pH was determined in soil water ratio of 1:2.5 by a glass electrode pH meter standardized in buffered solution 4.0 and 6.85 (Udo *et al.,* 2009*).* Organic Carbon was determined by the Walkley and Black method as outlined by Nelson and Sommers (1996) and rated using FDALR (1990) and Landon (1991).

2.4. ***Statistical analysis***

The data generated were analyzed using coefficient of variation (CV) and ranked according to the procedure of Wilding *et al.* (1994) where CV <15% = low variation, CV ≥ 15 % ≤ 35 % = moderate variation, CV >35 % = high variation and statistically using t-test at 5% probability level. The statistical tool of GENSTAT statistical software version 8.1 was used.

3.0 Results and Discussion

3.1. Soil physical properties

The physical and selected chemical properties are presented in Table 1 and 2. The result shows that the soils are coarse texture dominated by textural class of loamy sand. The silt content had mean values of 257.14 and 221.43 g/kg while the clay content had mean values of 27.14 and 25.71 g/kg and the sand content had mean values of 715.71 and 745.71 g/kg in the central and northern respectively. Tori and Barker (2013) reported that predominance of coarse particles is easily detached by the pounding action of the rain and this is the reason for instability of many tropical soils. The coarse texture nature of the soil could be attributed to their geologic materials and heavy rainfall with high temperature in the area. High sand content decreases erodibility as most of the rain water infiltrate into the soil and decrease the rate of runoff (Ramezanpour *et al.,* 2010). Also, Mbagwu (1986) stated that high sand contents result to occurrence of detachment of aggregates more easily than other soil particles. The coefficient of variation (CV) showed high variability of silt (36%) and clay (87%) and moderate variability of sand (16%) in the central. While in the northern, it showed moderate CV of silt (20%), high CV of clay (59%) and low CV of sand (5%). The silt is higher than the clay indicating an increase in erodibility. Blanco and Lal (2008) reported in literature that silt is the most erodible type of soils followed by sand and clay. This shows a clear indication that they contribute greatly in the soil erosion.

3.1.1. Saturated hydraulic conductivity (K_{sat})

The K_{sat} was generally moderate (mean values of 108.4 and 100.57 mm/h) with moderate CV of 23% in the central and low CV of 12% in the northern. This showed that the soils are moderately high in water movement which might be attributed to the high sand content. Park and Smucker (2005) observed high movement of water in soils under moderate to rapid condition of saturated hydraulic conductivity.

3.1.2. Bulk density (Db)

The bulk density was generally low (mean values of 1.50 and 1.49 g cm^{-3}) with low CV of 4 and 3% in the central and northern. Low bulk density indicates porous soil condition. Hunt and Gilkes, 1992; Mckenzie *et al.*,2004 reported that the critical values of bulk density for encouraging erosion and restricting root growth varies with soil type but bulk densities less than 1.68 g cm^{-3} discourage soil erosion and greater than 1.68 g cm^{-3} generally tend to restrict root growth. While higher bulk density indicates soil compaction which reduce infiltration and cause runoff to produce erosion.

3.1.3. Particle density

The particle density had mean values of 2.40 and 2.44 g cm^{-3} with low CV of 7 and 8% in the central and northern. The particle densities were lower than the value of 2.65 g cm^{-3} Stutter *et al*. (2004) recommended for tropical soils. In most mineral soils, mean particle density ranged from 2.6 to 2.7 Mg m^{-3} because the density of quartz and several feldspars which dominate the mineralogy of the soil is about 2.65 Mg m^{-3}. However, particle density values are bound to decrease when the presence of organic matter is in appreciable amount or quantity.

3.2. Chemical properties

3.2.1. pH

The soil pH (H_2O) varied from slightly acidic to neutral according to the rating of Myers (2010); indicating the weathered and acidic nature of the soils. The soil pH (H_2O) had mean values of 6.4 and 6.8 and low CV of 10% in both the central and northern. The acidic condition of the soils might be due to the high rainfall leaching out basic cations from the areas.

3.2.2. Organic matter (OM)

Organic matter *(OM*) performs very important function in the soil; acts as a binding agent for mineral particles, improves soil structure, maintain tilth and minimizes erosion. The *OM* was generally low according to the rating of FDALR (1990) and Landon (1991). The *OM* had mean values of 1.96 and 1.57%. The CV of the OM was high (37) in the central and moderate (34%) in the northern. The low organic matter contents could be attributed to the impact of soil erosion on the soil surface resulting in loss of soil fertility. Bare and exposed soils are low in OM due to absence of grasses and tree canopies to receive high raindrop impact and severity of soil erosion (Blanco and Lal, 2008).

3.3. Soil erodibility indices

The soil erodibility indices are presented in Tables 3 and 4. The percent water stable aggregate (%*WSA)* was severe and moderate (mean values of 55.3 and 37.24%); indicating high and moderately vulnerable according to the rating of Beskow *et al.*, 2009; Lal, 1994 and Ezeaku, 2010. The CV of the %WSA was high (38%) in the central and moderate (34%) in the northern. The t-test analysis of the %*WSA* showed positively significantly difference (2.4709*, $p<0.05$) between the central and northern (Table 5) indicating unstable aggregates which could be attributed to soil disturbance by erosion. The dispersion ratio (*DR)* was extreme (mean values of 0.36 and 0.32); indicating very high vulnerability according to the rating of Beskow *et al.*, 2009; Lal, 1994 and Ezeaku, 2010. The *DR* was greater than 15% or 0.15. The smaller the value of *DR* the more stable microaggregates and values greater than 0.15 is an indication of highly erodible soils (Igwe, 2005). The CV of the *DR* was high (56%) in the central and moderate (34%) in the northern. The t-test analysis of the *DR* showed positively not significantly difference (0.3875**, $p>0.05$) between the central and northern (Table 5). The clay ratio *(CR)* was moderate (mean values of 3.5 and 3.4), indicating moderately vulnerable according to the rating of Beskow *et al.*, 2009; Lal, 1994 and Ezeaku, 2010. This is an indication of high risk of soil erosion since higher clay ratio is associated with higher risk of soil erosion by water or wind. Mbagwu (1986) reported clay ratio values greater than 2.0 brings about high risk of erodible soils by water. The CV of the *CR* was high (43 and 54%) in both the central and northern. The t-test analysis of the *CR* showed negatively not significantly difference (-0.1703**, $p>0.05$) between the central and northern (Table 5). The clay flocculation index *(CFI)* was low (mean values of 0.87 and 0.85), indicating the inability of the soil to resist dispersion in water and withstand stable aggregate to erosion. The larger the value of *CFI* the more stable micro aggregates (Igwe and Obalum, 2013). The CV of the *CFI* was low (6%) in both the central and northern. The t-test analysis of the *CFI* showed negatively not significantly difference (-0.1605**, $p>0.05$) between the central and northern (Table 6).

Table 1: Soil physical properties, pH and Organic matter of the erosion prone areas in the central Cross River State

	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	TC	K_{sat} (mm/h)	BD (g cm^3)	PD (g cm^{-3})	pH	%OM
Inebor	780	210	10	LS	119.9	1.48	2.36	5.8	1.53
Anong	770	220	10	LS	118.5	1.45	2.54	6.0	1.88
Itigidi	740	250	10	LS	111.6	1.52	2.57	5.6	1.14
Njang Assam	530	400	70	SL	96.16	1.35	2.18	6.4	3.19
Katabebe	580	370	50	SL	58.6	1.53	2.50	6.4	1.31
Kekomkola	810	170	20	LS	127.7	1.42	2.51	7.3	2.31
Obioko	800	180	20	LS	126.6	1.44	2.23	7.0	2.34
Mean	715.71	257.14	27.14		108.4	1.50	2.40	6.4	1.96

CV (%)	16	36	87	23	4	7	10	37
CV Ranking	Moderate	High	High	Moderate	Low	Low	Low	High

TC = textural class, K_{sat} = saturated hydraulic conductivity, BD = bulk density, PD = particle density, OM = organic matter

Table 2: Soil physical properties, pH and Organic matter of the erosion prone areas in the northern Cross River State

	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	TC	K_{sat} (mm/h)	BD (g cm^{-3})	PD (g cm^3)	pH	%OM
Ishibori	750	210	40	LS	94.17	1.47	2.43	6.5	1.86
Igoli	790	190	20	LS	122.1	1.48	2.25	7.6	1.36
Stadium	730	260	10	LS	109.2	1.51	2.53	6.6	1.19
Okuku	780	170	50	LS	86.44	1.53	2.25	6.4	1.00
Okpoma	770	210	20	LS	88.45	1.54	2.26	6.3	1.18
Abonkep 1	690	300	10	SL	102.85	1.46	2.79	6.2	1.88
Abonkep 2	710	210	30	SL	100.79	1.42	2.58	7.9	2.55
Mean	745.71	221.43	25.71		100.57	1.49	2.44	6.8	1.57
CV (%)	5	20	59		12	3	8	10	34
CV Ranking	Low	Moderate	High		Low	Low	Low	Low	Moderate

TC = textural class, K_{sat} = saturated hydraulic conductivity, BD = bulk density, PD = particle density, OM = organic matter

Table 3: Erodibility indices of the erosion prone areas in the central Cross River State

	Water dispersed sample (%)			Erodibility indices			
	Sand	Silt	Clay	%WSA	DR	CR	CFI
Inebor	81.6	8.4	0/0	41.8	0.23	4.4	0.89
Anong	79.6	20.4	0.0	44.4	0.26	3.9	0.88
Itigidi	76.6	23.4	0.0	40.4	0.31	3.3	0.85
Njang Assam	50	39.4	10.6	75.6	0.65	1.5	0.79
Ketabebe	60.6	36.7	2.7	43.2	0.65	1.5	0.84
Kekomkola	82.6	16.7	0.7	94.6	0.21	4.7	0.92
Obioko	83.6	15.7	0.7	47.2	0.2	5.1	0.91
Mean	73.35	24.4	2.1	55.3	0.36	3.5	0.87
CV (%)	13	10	4	38	56	43	6
CV Ranking	Low	Low	Low	High	High	High	Low

%WSA= percent water stable aggregate; R=dispersion ratio; CR = clay ratio; CFI = clay flocculation index

Table 4: Erodibility indices of the erosion prone areas in the northern Cross River State

	Water dispersed sample (%)			Erodibility indices			
	Sand	Silt	Clay	%WSA	DR	CR	CFI
Ishibori	78.6	18.7	2.7	22.4	0.27	18.7	0.88
Igoli	84.6	13.7	1.7	53	0.18	13.7	0.87
Stadium	79.6	19.7	0.7	32.7	0.26	19.7	0.91
Okuku	68.6	31.4	0.0	47.9	0.46	31.4	0.87
Okpoma	79.6	0.7	19.7	22.6	0.26	0.7	0.79
Abonkep 1	67.6	32.4	0.0	47.9	0.48	32.4	0.79

Abonkep 2	73.6	24.7	1.7	34.2	0.36	24.7	0.84
Mean	76.03	20.19	3.39	37.2	0.32	20.19	0.85
CV (%)	8	54	187	34	34	54	6
CV Ranking	Low	High	High	Moderate	Moderate	High	Low

%WSA= percent water stable aggregate; R=dispersion ratio; CR = clay ratio; CFI = clay flocculation index

Table 5: Paired t-test of erodibility indices of central and northern Cross River State

	% Sand	% Clay	% Silt	% WSA	DR	CR	CFI
Central (mean)	73.5	2.1	24.4	55.3	0.36	3.5	0.87
Northern (mean)	76.03	3.79	20.19	37.24	0.32	3.44	0.85
T-test (5%)	-0.5406**	0.4728*	0.4899*	2.4709*	0.3875**	-0.1703**	-0.1605**

*Significant at p<0.05; **not significant at p>0.05

4.0. Conclusion

Soil erosion in the central and northern Cross River State, Nigeria is an issue of concern that had affected humanity and land sustainability. The soils of the area are loosed, fragile and coarse textured predominated by textural class of loamy sand with high sand content among other soils. Soil erodibility indices used to quantify the effects on these soils statistically showed they were no significantly difference between the central and the northern. Thus, the erosion prone areas had exacerbated a negative impact on the soil quality. Soil conservation like agronomic measures such as contour faming, vegatative barriers, terracing and engineering measures such as contour bunds and water ways are recommended to be adopted to control the erosion in the area.

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