Application of Erodibility Nomograph in the Assessment of Soil Erosion in Two Different Agro-ecological Zones

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Abstract

This study highlights application of erodibility nomograph to assess soil erosion in central and northern agro-ecological zones of Cross River State, Nigeria. Seventeen composite soil samples were collected from sites showing moderate to severe erosion problems to the depth of 0-30 cm with the use of soil auger by random sampling and analyzed using standard laboratory procedures. Results showed that the particle size analysis was coarse textured soils with high sand content giving dominant textural classes of sandy loam in central and loamy sand texture in northern agro-ecological zones. The soil separates were predominantly silt content in central and medium sand in the northern agro-ecological zones with mean values of 29.5 % and 26.3 %. The erodibility using nomograph showed low to medium (0.10 – 0.19 Mg ha-1 MJ mm-1) in the central and medium (0.20 – 0.29 Mg ha-1 MJ mm-1) in the northern agro-ecological zones with high CV (%) of 52.4 % in the central and 118.2 % in the northern agro-ecological zones suggesting erodible soils. Soil conservation measures such as contouring, mulching and cover cropping should be adopted to address and combat soil erosion to avoid serious soil erodibility.

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Key words: Soil erosion-erodibility-nomograph-assessment-agro ecological zones

INTRODUCTION

Soil erosion appears to be the greatest factor limiting soil productivity and impeding agricultural enterprise in the entire humid tropical region (Lal *et al.,* 2003) and constitutes one of the main environmental problem that cause soil erodibility in central and northern agro-ecological zones of Cross River State, Nigeria. The soils are structurally fragile, loose, highly weathered, leached, acidic and very susceptible to different forms of water erosion including catastrophic erosion due to heavy rainfall and and human activities (Chikezie *et al.,* 2010). The soils are strongly acidic with pH value ranging from 4.1 to 5.5 (Ibia *et al.,* 2011). The soils

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are characterized by weak, fine crumb surface horizons and weak sub-angular subsurface horizons (Esu *et al* ., 2008).

Erodibility or erodability denoted by K reflects the susceptibility of soil to erosion and is an inherent soil characteristic which cannot be readily controlled. The main soil properties affected by soil erodibility to erosion are soil texture, including the amount of fine sand in addition to the usual sand, silt, and clay, organic matter, structure, and permeability of the soil profile. Wischmeier and Smith (1978) stated that the unit plot, which is defined as the standard plot condition is used to determine the soil's erodibility on a condition where the LS factor = 1 (slope = 9 % and length = 22.13 m) and the plot is fallow and tillage is up and down slope and no conservation practices are applied (CP = 1). The K factor is influenced by the detachability of the soil, infiltration and runoff, and the transportability of the sediment eroded from the soil (Brady and Weil, 2008).

Clay soils have a low K value and resistant to detachment. Sandy soils have low K values and high infiltration rates, reduced runoff, and sediment eroded from these soils is not easily transported. The soil erodibility potential is low for high clayey soil and coarse to medium grained granular soils. Silt loam soils have moderate to high K values and easily detached, infiltration is moderate to low producing moderate to high runoff, and the sediment is moderate and easily transported. Silt soils have the highest K values and readily crust producing high runoff rates and amounts. The soil erodibility can be high to medium for low to non-plastic soil and soil with significant amount of silt and fine sand.

Wischmeier *et al.* (1971) developed the first analytical method to estimate soil erodibility which is a graphical representation (nomograph) based on an indirect combination of physical properties and percentage of organic matter. The soil erodibility nomograph provides a graphical solution for determining a soil's K value, and can be used if the percent sand and organic matter fractions in a particular soil are known. Vanelslande *et al.,* 1984; Obi *et al.,* 1989 concluded that the nomograph was developed with soils having substantial fine particles. According to Renard *et al.,* 1997; Morgan, 2005, the nomograph is adequate for surface soils, less aggregated soils and medium textured soils, not used for soils with high organic matter (more than 4%), swelling clays and soils in which aggregate stability is more influential than primary particle size. Wischmeier *et al.* (1971) stated that the factors considered in the K factor estimation in the nomograph (Fig. 1) consist of soil particles (% sand, % silt, % very fine sand and silt, and % clay), % organic matter, soil structure code and soil permeability class.

Erodibility can also be expressed in mathematical terms for calculation of the K factor instead of reading the nomograph. According to Wischmeier *et al.* (1971), the mathematical expression takes the form:

Blanco and Lal (2008) modified the mathematical expression where all the soil parameters found in the above equation have the same definition. The modified equation takes the form:

$0.00021 \times M^{1.14} \times (12\text{-}a) + 3.25 \times (b\text{-}2) + 3.3 \times 10^{-3}(c\text{-}3)$

100 Eqn. (2)

Where; M is the particle size parameter, given by M = (% silt + % very fine sand) × (100 - % clay)

a = % of organic matter content, b = soil structure class (1 = very fine granular; 2 = fine granular; 3 = medium or coarse granular; 4 = blocky, platy, or massive), c = soil profile permeability (saturated hydraulic conductivity) class [1 = rapid (150 mm/h); 2 = moderate to rapid (50 – 150 mm/h); 3 = moderate (12 – 50 mm/h); 4 = slow to moderate (5 – 15 mm/h); 5 = slow (1 – 5 mm/h); 6 = very slow (<1 mm/h)].

In West Africa, arbitrary relative grades of erosion risk observed by Landon (1991) for soil erodibility values were 0.09 t ha^{-1} MJmm^{-1} (low), 0.10-0.19 t ha^{-1} MJmm^{-1} (low to medium), 0.20-0.29 t ha^{-1} MJmm^{-1} (medium), 0.30-0.39 t ha^{-1} MJmm^{-1} (medium to high), 0.40-0.59 t ha^{-1} MJmm^{-1}(High) and 0.60 t ha^{-1} MJmm^{-1} or more (very high). Manrigue (1988) reported the following tropical values: K= 0.18 for Hawaii; K= 0.20 for Island of Mali and K= 0.31 for Panama soils. Vanelslande *et al.,* 1984; Obi *et al.,* 1989 compared soil erodibility values from runoff plots in Southern Nigeria using nomograph and mathematical term for evaluation

in the Universal Soil Loss Equation and showed significant existed between the two methods which shows inadequacies in the nomograph due to dominance of medium to coarse sand in the tropical soils. However, Obi *et al.*(1989) found that actual measurement of soil erodibility was 0.007 t ha^{-1} MJmm^{-1} by calculation compared with 0.012 t ha^{-1} MJmm^{-1} using the nomograph. Conversely, estimation of erodibility using the nomograph have been useful and satisfactory under the condition it was developed.

The study therefore applies erodibility nomograph in the assessment of erosion in two different agro-ecological zones.

MATERIALS AND METHODS

THE STUDY AREA

The research was carried out in central and northern agro-ecological zones of Cross River State., Nigeria. The central agro-ecological zone lies between Latitude 05^0 58' N and Longitude 08^0 04' E and the areas studied include Yakurr (Latitude 05^0 48' 05.9" N and Longitude 08^0 05' 36.2" E), Abi (Latitude 05^0 53' 12.0" N and Longitude $08^0$01' 58.3" E) and Ikom (Latitude 06^0 03' 40.8" N and Longitude 08^0 40' 01.9" E). While the northern agro-ecological zone lies between Latitude $06^0$43' N and Longitude $09^0$10' E (BulkTrade, 1989) and the areas studied include Ogoja (Latitude 06^0 39' 31.8" N and Longitude 08^0 48' 27.9" E), Yala (Latitude 06^0 42' 53.4" N and Longitude $08^0$46' 45.9" E) and Obudu (Latitude 06^0 40' 10.4" N and Longitude 09^0 09' 44.4" E) in the northern agro-ecological zone of Cross River State Cross River State. A Garmin Global positioning system 12 was used to geo-reference the area of the sampling location.

The climate is mostly tropical-humid which lies in the tropical rainforest climatic zone with dry and wet seasons except on the Obudu plateau (500 feet above sea level) in the agro-ecological zone of northern Cross River State 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 average sunshine hours ranges between 4.1 and 4.9 hours with mean of 4.5 hours (Nwajiuba and Onyeneke, 2010).

The underlying geological materials within the central agro-ecological zone consist of sandstone-shale intercalation in Yakurr and Abi, basalt (Basaltic lava) in Ikom. While those of the northern agro-ecological zone consist of sandstone in Ogoja and Yala, basement complex (granite, gneiss, quartzite and schist) in Obudu. The soils are commonly acidic in nature due to intensive rainfall in the areas. The soils are well drained, deep laterite fertile, sandy, clay, basalt and heavily leached. The areas are characterized by gently and steeply sloping landscape of 0-9 % overall without shoulder but the crest gradually sloping towards the valley bottom with moderate to high erosion conditions (Ibanga, 2006; Esu *et al* ., 2008; Ekwueme, 2003).

The natural vegetation of the areas are characterized by tropical rainforest, guinea savanna and derived savanna. In the central agro-ecological zone, the vegetation is predominantly tropical rainforest ecosystem with heavy upland forest, Fresh water swamps and Mangrove swamps. While in the northern agro-ecological zone, the vegetation is is characterized by grassland, mangrove, forest with pocket of immature and mature forest of the derived savanna zone and Parkland vegetation. The increase in rainfall amount and frequency lead to soil erodibility caused by erosion. Common plant species in the areas include guinea grass *(Panicum maximum),* elephant grass (*Pennisetum purpureum*), teak *(Tectona gradis),* Gmelina*(Gmelina arborea),* pear *(Dacryadis edulis)* and timber trees. The major crops 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)* and so on (BulkTrade, 1989; Effiong, 2011).

SITE SELECTION/FIELD WORK

Photogrammetric survey of the areas was carried out by aerial photograph to select major areas prone to erosion problems. Seventeen (17) composite soil samples were collected from sites showing moderate to severe erosion problems to the depth of 0-30 cm with the use of soil auger by random sampling in the study areas. The seventeen (17) composite samples were bagged, labeled and transported to the University of Calabar Soil Science Laboratory for analysis.

LABORATORY ANALYSES

The soil structure was carried out under field condition by visual soil evaluation (VSE) techniques as outlined by Emmet-Booth *et al.*(2018)**.** The soil profile permeability was obtained from saturated hydraulic conductivity (SHC) class (Blanco and Lal, 2008). Particle size analysis for determination of texture was analyzed by Bouyoucous hydrometer method using sodium hexametaphosphate (VII) (Calgon) as the dispersant (Udo *et al.,* 2009). 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). Soil separate was determined by washing the soil sample with calgon and water to allow the clay, silt and sand separates as described by Bouyoucos (1951) hydrometer method. The sand content was removed, dried and passed through set of sieves to obtain sand separates. Saturated hydraulic conductivity (K_{sat}) was obtained by the method outlined by Saxton *et al.* (1986). Organic Carbon was determined by the Walkley and Black method as outlined by Nelson and Sommers (1996). Erodibility, K was estimated by USLE nomograph from soil analysis of proportion of silt + very fine sand, amount of organic matter, structural class and permeability class as outlined by Wischmeier*et al.* (1971).
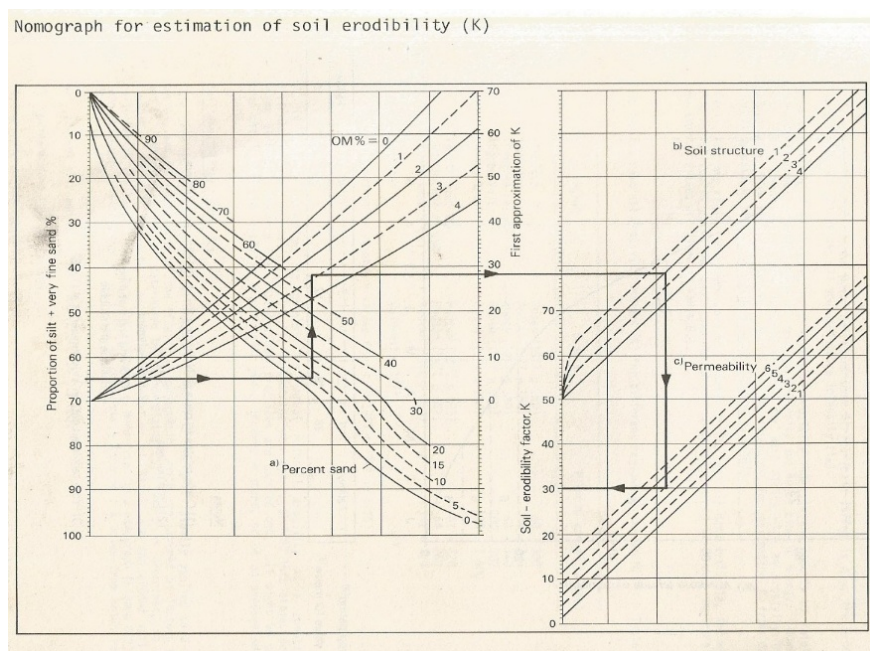
DATA STATEMENT/ ANALYSIS

There was no data available for this study. All the data were obtained from analysis and the results were subjected to coefficient of variation and simple descriptive statistics of mean and range.

RESULTS AND DISCUSSIONS

PHYSICAL PROPERTIES

The physical properties of soils in the central and northern Agro-ecological zones, Cross River State are presented in Table 1. The soils had high sand with low silt and clay contents giving dominant textural classes of sandy loam in the central zone and loamy sand in the northern zone. The high sand and low silt contents suggests how the soils are well drained and easily transported by water while the low clay content signifies low holding water capacity. Blanco and Lal (2008) reported that the most erodible type of soils is silt followed by sand and clay. The soil separates were predominantly silt in the central agro-ecological zone

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and medium sand in the northern agro-ecological zone. Silt particles are low in water holding capacities hence provide excellent drainage characteristics and easily detached of the soils because they are small and do not easily form aggregates. Medium sand are high in water movement, hence facilitate percolation and easily transportation of water which detach the soils more easily. The saturated hydraulic conductivity was generally moderate to rapid with mean values ranging from 50 – 150 mm/hr. in the two agro-ecological zones. This showed high water movement when the soil is saturated with water which might be attributed to the high sand content. Park and Smucker (2005) observed that high movement of water in soils result to condition of moderate to rapid saturated hydraulic conductivity due to their macroaggregate condition. The bulk densities were generally low in the two agro-ecological zones. Less than 1.4 g cm^{-3} generally indicates porous soil condition which leads to soil erosion. 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 1.8 g cm^{-3} encourage soil erosion and greater than 1.8 g cm^{-3} generally tend to restrict root growth. The particle densities of the soil obtained for this study were all lower than the value of 2.65 g cm^{-3} recommended for tropical soils in the two agro-ecological zones as reported by Stutter *et al.* (2004) except for Obudu in the northern agro-ecological zone, where their mean values were above 2.65 g cm^{-3}. The difference in their means were quite minimal and less than the average of 2.6 g cm^{-3} obtained by Chopra.and Kanwar (1991). The resulting CV of all the physical properties was high in both central and northern agro-ecological zones but decrease rapidly toward the northern zone, suggesting a relatively high variability.

Table 1: Soil physical properties in the central and northern agro-ecological zones, Cross River State

Location	SAMPLING POINT	DEPTH		PSA (%)		TC	SHC	BD	PD	CLAY	S
Central		(cm)	SAND	SILT	CLAY		(mm/hr.)	gcm^{-1}	gcm^{-1}		
Ugep	Katabebe. Upp.Sl.	0-30	58	37	5	SL	58.56	1.53	2.5	5	3
	Katabebe. Midd.Sl.	0-30	55	44	1	SL	73.73	1.53	2.39	0	4
	Katabebe. L.Slope	0-30	65	34	1	SL	96.09	1.46	2.35	0	3
	Katabebe.V.Bottom	0-30	62	36	2	SL	101.42	1.35	2.61	2	3
	Obioko, Ijiman	0-30	81	17	2	LS	127.68	1.42	2.25	2	1
	Kekomkolo, Ijiman	0-30	81	17	2	LS	127.68	1.42	2.51	2	1
Abi	Anong, Bahumono	0-30	77	22	1	LS	118.46	1.45	2.54	0	2
	Itigidi Bridge	0-30	74	25	1	LS	111.56	1.52	2.57	0	2
	Inebor, Itigidi	0-30	78	21	1	LS	119.93	1.48	2.36	0	2
Ikom	Njang Assam	0-30	53	40	7	SL	96.16	1.35	2.18	0	4
Min			53	17	1		58.56	1.35	2.18	0	1
Max			81	44	7		127.68	1.53	2.61	5	4
Mean			68.4	29.3	2.3		103.127	1.451	2.426	1.1	3
CV (%)			16.1	34.1	89.6		22.3	4.62	5.85	151	3
Northern											
Ogoja	Ishibori	0-30	75	21	4	LS	94.17	1.47	2.43	9	1
	Isbibori valley b.	0-30	81	14	5	LS	95.49	1.46	2.45	5	1
	Agiga-Igoli	0-30	79	19	2	LS	122.12	1.48	2.25	2	1
	Stadium Road	0-30	73	26	1	LS	109.24	1.51	2.55	0	2
Yala	Okuku	0-30	78	17	5	LS	86.44	1.53	2.2	5	1
Obudu	Abonkep	0-30	69	30	1	SL	102.85	1.46	2.79	0	3
	Abonkep midd slope	0-30	71	26	3	SL	100.79	1.42	2.58	3	2
Min			69	14	1		86.44	1.42	2.2	0	1
Max			81	30	5		122.12	1.53	2.79	9	3
Mean			75.14	21.9	3		101.586	1.476	2.4643	3.43	2
CV (%)			5.87	26	57.7		11.4	2.44	8.2	93.6	3

ESTIMATION OF ERODIBILITY USING NOMOGRAPH

The estimation of erodibility using nomograph were from proportion of silt plus very fine sand, percent sand, percent organic matter, soil structure and permeability. These are presented in Table 2. The soil structure under field condition was dominated by very fine and fine granular structures belonging to classes 1 and 2 in the both agro-ecological zones. This indicates poor soil structures which might be attributed to the architectural arrangement of the soil particles and their aggregates of different size, shape and stability by detaching power of rain. Blanco and Lal (2008) reported that fine granular structure are more detachable, unstable and susceptible to compaction resulting to low water infiltration and high runoff rates. The soil profile permability was in class 2 according to the range of saturated hydraulic conductivity values obtained in the both agro- ecological zones and this indicates high movement of water and could detach soil particles. The OM was generally medium in both agro-ecological zones according to the rating of FDALR. (1990) and Landon (1991). The medium OM may be probably due to low accumulation of litter from leaf falls or residues that provide few cover to the soil to promotes erosion. Blanco-Canqui *et al.* (2006) reported low to medium organic matter contents and this could lead to soil erosion because the soil is bare and exposed to raindrop impact. The CV (%) of the OM was high with 35.5 and 50.3 % in the central and northern agro-ecological zones, all suggesting low accumulation and this could lead to soil erodibility. The proportion of silt plus very fine sand was high with mean values of 31.9 and 22.7 % in both zones. The CV (%) was high with 31.1 and 27.5 % in both zones suggesting easily detach of soils by erosion. The percent sand was high with mean values of 69.2 and 75.1 % in both zones. The resulting CV (%) was high with 14 and 5.87 % in both zones suggesting porous condition of the soil. The erodibility, K values were low to medium $(0.10 – 0.19$ Mg ha^{-1} MJ mm^{-1}) in the central and medium $(0.20 – 0.29$ Mg ha^{-1} MJ mm^{-1}) in the northern agro-ecological zones. The values obtained conform with the similar values reported by Landon (1991). The erodibility values indicate less soil erodibilities which might be attributed to the high contents of silts and very fine sand. The CV (%) was high with 52.4 % in the central and 118.2 % in the northern agro-ecological zones indicating a relatively high variation.

Table 2: Soil parameters used for estimation of erodibility, K and values obtained in central and northern agro-ecological zones

Location	Sampling points	Depth	Structure	Organic	Pr. of silt + VFS	Proportion	Permeability	E
		(cm)	Class	Matter (%)	(%)	of sand	Class	(1
Central								
Yakuur	Katebebe,Ugep	0-30	2	1.97	28.1	71	2	0
	Katabebe. Upp.Slope	0-30	2	1.31	45.9	58	2	0
	Katabebe. Midd.Slope	0-30	4	1.31	45.49	55	2	0
	Katabebe. L.Slope	0-30	3	2.03	36.27	65	2	0
	Katabebe.V.Bottom	0-30	3	3.26	38.86	62	2	0
	Obioko, Ijiman	0-30	2	2.34	19.62	81	2	0
	Kekomkolo, Ijiman	0-30	2	2.31	20.84	81	2	0
Abi	Anong, Bahomono	0-30	1	1.88	24.24	77	2	0
	Itigidi bridge	0-30	2	1.14	26.99	74	2	0
	Inebor, Itigidi	0-30	2	1.53	23.25	78	2	0
Ikom	Njang Assam, Dap.H.	0 - 30	3	3.19	41.44	59	2	0
Minimum				1.14	19.62	55		0
Maximum				3.26	45.9	81		0
Mean				2.02	31.9	69.2		0
S.D				0.717	9.92	9.71		0
CV (%)				35.5	31.1	14.0		5
Northern								
Ogoja	Isbibori	0-30	1	1.86	17.64	75	2	0
	Ishibori, V. B.	0-30	1	2.03	15.89	81	2	0

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Location	Sampling points	Depth	Structure	Organic	Pr. of silt + VFS	Proportion	Permeability	E
	Agiga – Igoli	0-30	1	1.36	20.2	79	2	0
	Stadium Road	0-30	3	1.19	28.45	73	2	0
Yala	Okuku	0-30	1	0.1	18.22	78	2	0
Obudu	Abonkep	0 - 30	2	1.88	31.99	69	2	0
	Abonkep Middle slope	0-30	2	2.55	26.8	71	2	0
Minimum				0.1	15.89	69		0
Maximum				2.55	31.99	81		0
Mean				1.57	22.7	75.1		0
S.D				0.79	6.25	4.41		0
CV (%)				50.3	27.5	5.87		1

VFS = very find sand; CV = coefficient of variation; S.D = standard deviation; V.B = valley bottom

CONCLUSIONS

From the research carried out in the studied areas, the soils were erodible, coarse textured, structurally fragile, loose, highly weathered, acidic and susceptible to different forms of erosion with erodibilities of low to medium in the central agro-ecological zone and medium in the northern agro-ecological zone. Their coefficient of variation was high in all the physical properties and erodibility which does not show a good fit. The erosion in the area had posed minor problems which could hinder the productivity of the soils for crop growth, hence soil conservation measures such as contouring, mulching and cover cropping should be carried out to address and combat soil erosion to avoid serious soil erodibility.

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CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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