Predicting Soil Erodibility of Four Tropical Soils in South-Western Nigeria using Selected Soil Properties

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Abstract

This study was initiated to develop suitable models for predicting soil erodibility for tropical soils using selected soil properties. Four soil types, Plinthic Petraquept, Kanhaplic Haplaustalf, Typic Plinthustalf and Typic Haplaustalf were used. Predictive models from soil properties were devised using Origin Pro. 8.1 and model performance was evaluated using R^2 *(coefficient of determination). Predicted empirical soil erodibility (K) models that were significantly correlated with standard Universal Soil Loss Erodibility (USLE-*K_U*) and Water Erosion Prediction Project (WEPP-*K_w*) are* $K_U = [-10.57 - 0.247\ EA - 0.5018\ Na + 0.405\ ECEC + 0.127\ \%\ Sand + 0.097\ \%\ Silt + 0.0134\ SHC]$ *and* $K_w = [115.029 - 525.0\ OM + 15.531\ ECEC + 1.185\ SHC - 109.832\ Na + 31.762\ MWD - 1.753\ \%\ Porosity]$ *for Plinthic Petraquept;* $K_w = [718.382 + 1.005\ \%Silt - 5.802\ BS - 3.056\ \%Clay - 1.276\ \%Porosity]$ *and* $K_U = [0.725 + 0.645\ EA + 0.82\ \%\ Silt - 0.03\ HC - 0.037\ \%\ Clay]$ *for Kanhaplic Haplustalf;* $K_w = [-144.050 - 1.178\ OM + 3.414\ \%Porosity + 98.106\ Na + 0.473\ ECEC]$ *and* $K_U = [-4286 - 0.756\ EA + 1.564\ Na - 0.010\ \%\ Clay + 0.110\ \%\ Porosity]$ *for Typic Plinthustalf; and* $K_w = [-0.077 + 775.0\ MWD - 0.006\ SHC - 0.119\ EA]$ *and* $K_U = [2.770 - 1.709\ TN + 0.064\ OM - 0.03\ \%\ Porosity]$ *for Typic Haplaustalf. The predicted erodibility models conformed to standard WEPP and USLE erodibility (*$R^2 = 0.\ 95 - 1.00$*). The predicted model performances showed that suitability of these models are soil type dependent.*

Keywords: Modeling, soil erodibility, soil loss equation, soil properties.

Introduction

Soil erodibility is a key parameter for evaluating the soil's susceptibility to erosion (Wang *et al.*, 2013). Soil erosion which has been identified as the major cause of land degradation in most regions of the world depends not only on rainfall erosivity but also on the soil's resistance to erosion, which is usually measured as the soil erodibility factor (K) (O'Geen and Schwankl, 2006). Fundamentally, erodibility refers to the amount of soil loss per unit exogenic force or erosivity (the power of a storm to erode soil) such as rainfall, surface flow, and seepage. Soil erodibility is governed by five major soil properties which include soil texture, soil structure, permeability, organic matter content and soil water content (O'Geen and Schwankl, 2006). These aforementioned soil properties determine to a very large extent the soil erodibility potential of the sites and consequently used for erosion modeling. However, the complex erosion phenomenon, complicated nature of erodibility evaluation, and inadequate information from past erosion studies have instituted a wide gap in adequately predicting soil losses and establishing a good soil conservation programme. As a result, researchers have been putting in efforts to predict soil erodibility factor (K) from soil properties but always with different results. Wischmeier and Mannering (1969) earlier reported a dynamic relationship between soil properties and erodibility. Chandra and De

(1978) reported a high negative correlation (r = 0.77) between clay content and soil erodibility, suggesting that soils with high clay ratio tend to possess low erodibility index. Song *et al.* (2005) earlier noted that soil loss due to erosion was proportional to the (silt + clay) content. Idah *et al*. (2008) suggested that soils with less than 2% organic matter can be considered erodible. This laid more credence to the fact that increased organic matter content of soils reduces erodibility factor. Bryan *et al.* (1989) observed that there is a 2% rise in erodibility index for every 10% decrease in soil permeability.

In addition, the best erodibility models for a given group of soils at specific geographical location, outside the USA have not been ascertained. This is because the aforementioned models were developed from soil erosion database of the USA and its environs. Ezeabasili *et al.* (2014) also reported that the Universal Soil Loss Erodibility (USLE) and Water Erosion Prediction Project (WEPP) models were developed and suitable for temperate regions. Extrapolation of such models to tropical environments could either overestimate or underestimate the soil erodibility values for tropical soils due to soil heterogeneity (Obi *et al*., 1989). It is therefore imperative to obtain a simple model, which could accurately predict the erodibility of tropical soils for sustainable agricultural conservation. Thus, the objective of this study is to predict soil erodibility factor from tropical soil properties of South-western Nigeria.

Materials and Methods

Site description and soil sampling

The study was conducted at Iseyin Local Government Area of Oyo state in Southwestern Nigeria (Figure 1). The area is defined between latitudes 7° 8'10"N and 8°4'40"N and longitudes 3° 31'40"E and 3° 32'30"E with a total area of 69.83 ha. Rainy season lasts for at least 8 months with a mean annual rainfall between 1000 - 1500 mm. The mean annual minimum and maximum temperature are 22°C and 33°C respectively. The vegetation of the area is derived savanna; which is also called forest-savanna mosaic. The soils are ferralitic tropical soils with kaolinte as the dominant clay mineral (Gbadegesin and Akinbola, 1995). A soil survey assessment was carried out to identify soil types. The United States Department of Agriculture (USDA) taxonomy and World Reference Base for Soil Resources (WRB) procedures were adopted for identification of soil type (Soil Survey Staff, 2014; FAO/UISS, 2014). Four soil profiles were made and samples were collected from the lowest horizon to the uppermost horizon to avoid contamination of soil samples collected. Soil samples were analyzed for physical and chemical properties.

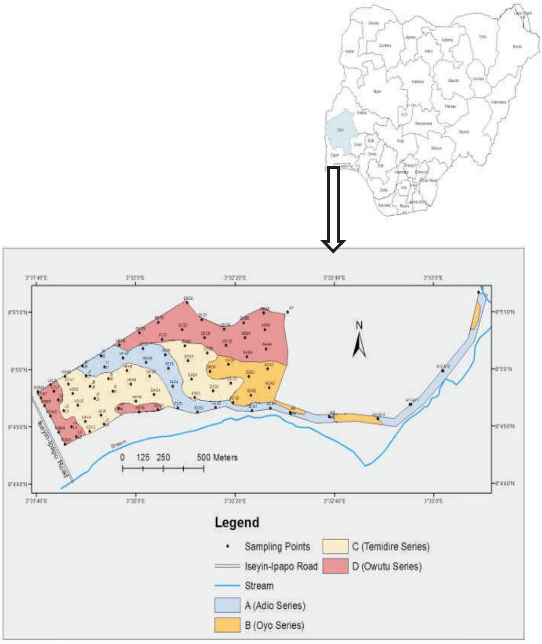

Figure 1: A Map Showing the Study Site

Particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962; Gee and Or, 2002). Bulk density was determined using core method (Grossman and Reinsch, 2002). Saturated hydraulic conductivity was determined by the constant head method (Singh, 1982). Mean weight diameter was determined by wet sieving method (Castellanos - Navarrete *et al.,* 2013). The soil pH was determined with the pH meter using glass electrode in a 1:1 soil to water ratio (IITA, 1979; Udo *et al.,* 2009). Total nitrogen was determined by Kjehdahl digestion method (Bremmer, 1996). Organic carbon was determined using the Walkey Black wet oxidation method (Nelsen and Sommers, 1982). Organic matter was calculated by using the van Bemmelen's correction factor of 1.724. Available phosphorus was determined with the aid of a spectrophotometer using Mehlich III as extractant (Jackson, 1958). Exchangeable bases were determined using neutral NH_4OAC leachate. Exchangeable Ca and Mg were determined by EDTA versanate titration method (McLean, 1982). Exchangeable Na and K were determined by the flame photometer method. Exchangeable acidity was determined by leaching the soil with 1N KCl and titrating with 0.05 N NaOH (McLean, 1982).

Estimation of soil erodibility equation (K)

The soil erodibility for each soil type was evaluated using Universal Soil Loss Erodibility (USLE) and Water Erosion Prediction Project (WEPP) models as outlined by Wang *et al*. (2013).

The two USLE models employed in this study to estimate the USLE soil erodility factor K include:

(i) El-Swaify and Dangler (1977)

$$K = -0.03970 + 0.00311X_2 + 0.00043M + 0.00185X_3 + 0.00258X_4 - 0.00823X_5 \qquad (1)$$

Where; X_2 is the proportion of unstable-aggregates >0.25 mm (%); X_3 is the soil water content; X_4 is the redefined silt (%) = %silt + %fine sand; and X_5 is the redefined sand fraction (0.01 - 2 mm).

(ii) Wischmeier and Mannering (1969)

$$K = (0.043\,R + 0.62/OM + 0.0082\,S - 0.0062\,C)\,\%\text{silt} \qquad (2)$$

Where *R* (soil reaction) is directly proportion to soil pH, OM is organic matter, *S* is percent sand (%sand), and *C* is the clay ratio.

$$\text{Clay ratio} = \frac{\%\,\text{sand} + \%\,\text{silt}}{\%\,\text{clay}} \qquad (3)$$

(i) WEPP soil erodibility coefficient

The WEPP model was employed in estimating soil erodibility K. Both inter-rill and rill erodibility WEPP models were used as reported by Wang *et al.* (2013). For soils having more than 30% sand, equations 4 and 5 were used to estimate soil erodibility K

$$K_{ib} = 2.728 \times 10^6 + 1.921 \times 10^7 fs \qquad (4)$$

$$K_{rb} = 0.00197 + 0.030fs + 0.03863e^{-1840M} \qquad (5)$$

Where K_{ib} is inter-rill erodibility, K_{rb} is rill erodibility, *fs* are fine sand (%) and *M* is organic matter (%).

Data analysis

Soil data were analyzed using Origin Pro. software version 8.1 to generate the best fit (soil erodibility factor) either for individual soil property or combined soil properties. Predicted linear equations and non – linear equations (Sine, Boltzman, Gauss, Lorentz, Hill, Quadratic and Cubic) were tested for performance using R^2 (coefficient of determination) and P – value statistics. Correlation between predicted empirical models and standard USLE and WEPP erodibility models were made to ascertain the degree of conformity.

Results

Soil type

Four soil types were identified and classified in the study location as Plinthic Petraquept (Adio series), Kanhaplic Haplustalf (Oyo series), Typic Plinthustalf (Temidire series) and Typic Haplaustalf (Owutu series) (Figure 1). The pedological classification and characteristics of the soil types are presented in Table 1. Land area occupied by Typic Plinthustalf, Typic Haplaustalf, Plinthic Petraquept and Kanhaplic Haplustalf soil types are 23.01 ha, 22.01 ha, 15.38 ha and 9.44 ha, respectively summing up to a total land area of 69.9 ha. Classification at series level showed that Plinthic Petraquept, Kanhaplic Haplustalf, Typic Plinthustalf and Typic Haplaustalf belonged to Adio series, Oyo series, Temidire series and Owutu series, respectively (Table 1).

Texturally, Plinthic Petraquept and Typic Haplaustalf are sandy loam while Kanhaplic Haplustalf and Typic Plinthustalf are sandy clay loam indicating that Kanhaplic Haplustalf and Typic Plinthustalf soils are finer than Plinthic Petraquept and Typic Haplaustalf (Table 2). As a result, Kanhaplic Haplustalf and Typic Plinthustalf have tendency to hold more water than Plinthic Petraquept and Typic Haplaustalf. In terms of chemical properties, the soil types varied in their nutrient status (Table 2). However, using Dangler *et al.* (1976) ratings for soil erodibility factor, Plinthic Petraquept is highly erodible (K5); Kanhaplic Haplustalf and Typic Plinthustalf are very highly erodible (K6), while Typic Haplaustalf is moderately erodible (K4).

Table 1: Soil Pedological Classification and Characteristics of the Site

Series	USDA Soil Taxonomy (Soil Survey Staff, 2014)	WRB (FAO/IUSS, 2014)	Characteristics	Area coverage	
				Ha	(%)
Adio	Plinthic Petraquept	Plinthic; Gleyic Cambisol	Soil at the lower slope associated with impeded drainage and waterlogging. Strongly mottled with plinthite and concretions from about 60 cm depth. Gleying and moderately light textured	15.38	22.00
Oyo	Kanhaplic Haplustalf	Haplic Lixisol (Plinthic)	Well drained yellowish -red in colour, clay illuviation with penetrable plinthic layer at about 80 cm depth	9.44	13.50
Temidire	Typic Plinthustalf	Petroplinthic Lixisol (Vectic)	Light textured, grayish coloured soils occurring immediately above mapping unit A in the landscape. Very workable soil. However, impenetrable petro-plinthite encountered at depth of 81cm.	23.07	33.01
Owutu	Typic Haplaustalf	Chromic Lixisol (Skeletic)	Soil of the upper and middle slope positions. Light textures surface soil with a mixture of pear shaped iron-manganese concretions and quartz gravel dominating at depth of 45 cm. down the profile are flakes of feldspar, mottled clay and highly deformed saprolites.	22.01	31.49

Source: Orimoloye *et al.* (2015).

Table 2: Mean Physical and Chemical Properties of Different Soil Types

Soil Property	Plinthic Petraquept	Kanhaplic Haplustalf	Typic Plinthustalf	Typic Haplaustalf
Sand (gkg^{-1})	714	602	608	676
Silt (gkg^{-1})	104	106	108	149
Clay (gkg^{-1})	183	292	284	175
Textural Class	SL	SCL	SCL	SL
Bulk density (Mgm^{-3})	1.68	1.61	1.47	1.42
SHC (cm hr^{-1})	7.23	11.34	34.02	20.82
Porosity (%)	39.1	38.5	45.1	46
MWD (mm)	0.83	0.94	1.0	0.89
Soil pH	6.9	6.9	7.0	7.0
Organic Matter (gkg^{-1})	17.48	12.24	11.07	21.28
Total Nitrogen (gkg^{-1})	1.24	0.84	0.72	1.3
Exchangeable bases (cmolkg^{-1})				
Ca	0.9	3.0	3.2	1.9
Mg	1.8	2.1	3.1	0.95
K	0.2	0.15	0.3	0.15
Na	0.65	0.75	0.75	0.70
E.A (cmolkg^{-1})	1.7	0.7	0.6	1.6
ECEC (cmolkg^{-1})	5.25	6.70	7.95	5.30
Base Saturation (%)	67.62	89.55	92.45	69.81
Av. P (mgkg^{-1})	3.1	3.5	6.9	5.8

MWD=Mean Weight Diameter; E.A= Exchangeable Acidity; Av. P= Available Phosphorus; SHC= Saturated Hydraulic Conductivity; SL = Sandy Loam; SCL = Sandy Clay Loam.

Table 3: Selected Prediction Models with High Performance Level for Plinthic Petraquept

Soil property	Regression fit	General equation	R^2	Model
Silt	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	0.95	$K = 1.88e^{17} - 1.29e^{16}Silt - 5.15e^{15}(Silt)^2 + 4.67e^{14}(Silt)^3$
Bulk density	Sine	$Y = y^o + A \sin [\pi (X - X_c)/w]$	0.96	$K = -5.56 + 54.48 \sin [\pi \{BD - (-0.19)\}/0.99]$
Porosity	Quadratic	$Y = a + B_1X + B_2X^2$	0.98	$K = 3959.19 - 211.21\ Porosity + 2.82(Porosity)^2$
Sand / Silt	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	1.00	$K = -4128.9 + 1233.1(Sand / Silt) - 119.9(Sand / Silt)^2 + 3.8(Sand / Silt)^3$
Exch. Acidity	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = -66.74 + 252.46EA - 194.02(EA)^2$
Base saturation	Sine	$Y = y^o + A \sin [\pi (X - X_c)/w]$	0.99	$K = 56.61 + 46.88 \sin [\pi \{BS - (-22.46)\}/ 1.59]$
Organic matter	Linear	$Y = a + bX$	1.00	$K = -1002.61 + 55.46\ OM$
ECEC	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	0.61	$K = -62.75 + 138.75ECEC - 69.71(ECEC)^2$
Na	Sine	$Y = y^o + A \sin [\pi (X - X_c)/w]$	0.81	$K = 24.47 + 23.19 \sin [\pi \{Na - (-0.08)\}/ 0.07]$

BD = Bulk density; OM = Organic matter; ECEC = Exchangeable cation exchange capacity; MWD = Mean weight diameter; EA = Exchangeable acidity; and BS = Base saturation.

Table 4: Selected Prediction Models with High Performance Levels for Kanhaplic Haplustalf

Soil property	Regression fit	General equation	R^2	Model
Organic matter	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 620.4 - 106\,OM + 4.2\,(OM)^2$
Base saturation	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 3316.66 - 72.64\,BS + 0.40(BS)^2$
ECEC	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	1.00	$K = 2220.4 - 1199.3ECEC + 2151.5(ECEC)^2 - 127.9(ECEC)^3$
SHC	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 58.56 - 10.49SHC + 0.62(SHC)^2$
Clay	Linear	$Y = a + bX$	1.00	$K = 95.08 - 2.33\,Clay$
Bulk density	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 7091.48 - 8955.64\,BD + 2832.80\,(BD)^2$
Sand / Silt	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 4.82 - 1.47e^{16}\,(Sand/\,Silt) + 1.09e^{15}\,(Sand\,/\,Silt)^2$
TN	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 620.4 - 1766.6\,TN + 1165.3\,(TN)^2$

T.N = Total nitrogen; OM = Organic matter; ECEC = Exchangeable cation exchange capacity; SHC = Saturated hydraulic conductivity; MWD = Mean weight diameter; BS = Base saturation; and BD = Bulk density.

Table 5: Selected Prediction Models with High Performance Levels for Typic Plinthustalf

Soil property	Regression fit	General equation	R^2	Model
MWD	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	1.00	$K = -18814.1 + 66748.9MWD - 76942.7(MWD)^2 + 28787.8(MWD)^3$
Silt	Quadratic	$Y = a + B_1X + B_2X^2$	0.99	$K = -814.92 + 197.90Silt - 10.63(Silt)^2$
Bulk density	Linear	$Y = a + bX$	1.00	$K = 248.64 - 123.49\,BD$
Porosity	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 8971.57 - 425.70Porosity + 5.08(Porosity)^2$
TN	Linear	$Y = a + bX$	1.00	$K = 90.69 - 37.26\,TN$
Na	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	1.00	$K = -184542.4 + 735583.5Na - 973260.4(Na)^2 + 427531.6(Na)^3$
Organic matter	Linear	$Y = a + bX$	1.00	$K = 45.58 + 2.07\,OM$
Base saturation	Linear	$Y = a + bX$	1.00	$K = -512.39 + 6.30\,BS$
Sand / Silt	Linear	$Y = a + bX$	1.00	$K = 24.76 + 5.76\,(Sand/\,Silt)$
ECEC	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	1.00	$K = 3031.39 - 1716.94\,ECEC + 325.95(ECEC)^2 - 20.23(ECEC)^3$

T.N = Total nitrogen; ECEC = Exchangeable cation exchange capacity; MWD = Mean Weight Diameter; OM = Organic matter; BD = Bulk density; and BS = Base saturation.

Prediction of soil erodibility models for different soil types

Tables 3 – 6 present the predicted erodibility models that gave best fits for Plinthic Petraquept, Kanhaplic Haplustalf, Typic Plinthustalf and Typic Haplaustalf. The best fits were cubic, sine quadratic and linear, with performance level (R^2) that ranged from 0.61 – 1.0 for Plinthic Petraquept. However, Kanhaplic Haplustalf, Typic Plinthustalf and Typic Haplaustalf had quadratic, cubic and linear as best fit with 1.0 performance level (R^2). Soil properties that predicted soil erodibility with high dependency were silt, bulk density

Table 6: Selected Prediction Models with High Performance Levels for Typic Haplaustalf

Soil Property	Regression fit	General equation	R^2	Model
MWD	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 666.12 - 176.40MWD + 129.70(MWD)^2$
SHC	Linear	$Y = a + bX$	1.00	$K = 5.64 + 0.30SHC$
Sand	Linear	$Y = a + bX$	1.00	$K = 93.24 - 1.27Sand$
Organic matter	Linear	$Y = a + bX$	1.00	$K = 22.28 - 0.64\,OM$
Base saturation	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 1873.77 - 61.73BS + 0.51(BS)^2$
Silt	Quadratic	$Y = a + B_1X + B_2X^2$	1.00	$K = 1.30e^{17} - 1.65e^{16}Silt + 5.02e^{14}(Silt)^2$
Porosity	Linear	$Y = a + bX$	1.00	$K = 3346.19 - 71.27Porosity$
Exch. Acidity	Cubic	$Y = a + B_1X + B_2X^2 + B_3X^3$	1.00	$K = 1500.16 - 3341.84EA + 2278.66(EA)^2 - 455.38(EA)^3$
TN	Linear	$Y = a + bX$	1.00	$K = 36.05 - 19.88TN$

T.N = Total nitrogen; EA = Exchangeable acidity; SHC = Saturated hydraulic conductivity; MWD = Mean weight diameter; BS = Base saturation; OM = Organic matter; and BD = Bulk density.

(BD), porosity, sand/silt ratio, exchangeable acidity (EA), base saturation (BS), organic matter (OM), effective cation exchangeable capacity (ECEC) and Na content for Plinthic Petraquept (Table 3). For Kanhaplic Haplustalf, OM, BS, ECEC, mean weight diameter (MWD), saturated hydraulic conductivity (SHC), porosity, clay, BD, sand/silt ratio and total nitrogen (TN) had greater influence on predicted soil K – value (Table 4). The MWD, silt, BD, porosity, TN, Na content, OM, BS, sand/silt ratio and ECEC properties had higher influence on predicted K – factor of Typic Plinthustalf (Table 5). Predicted K – factors for Typic Haplaustalf depend on MWD, SHC, sand, OM, BS, silt, porosity, BD, EA and TN (Table 6).

Relationship between predicted K – factor using simple (linear and non-linear) regression and standard erodibility factor (USLE and WEPP)

The predicted K – factor using simple linear and non-linear regressions for all identified soil types are presented in Tables 7a and 7b. Disparities in the conformity of the predicted models with standard USLE and WEPP erodibility factors were also presented in Tables 7a and 7b. For Plinthic Petraquept, predicted models with silt, BD, porosity, EA, sand/silt ratio and ECEC conformed well to standard USLE erodibility while predictive models with BS, ECEC, Na and OM conformed to standard WEPP erodibility factor (Table 7a). The predicted models with

Table 7a: Establishing Relationship between Predicted Models and Standard Erodibility Factors (USLE and WEPP)

		WEPP MODELS		USLE MODELS	
Soil type	Predicted models	Inter-Rill Erodibility	Rill Erodibility	Wischmeier and Mannering	El-Swaify and Dangler
Plinthic Petraquept	$K = 1.88e^{17} - 1.29e^{16}\mathit{Silt} - 5.15e^{15}(\mathit{Silt})^2 + 4.67e^{14}(\mathit{Silt})^3$	0.10	0.10	0.96	0.53
	$K = -5.56 + 54.48 \sin [p \{\mathit{BD} - (-0.19)\} /0.99]$	0.44	0.44	0.81	0.69
	$K = 3959.19 - 211.21\ \mathit{Porosity} + 2.82(\mathit{Porosity})^2$	0.23	0.23	0.87	0.54
	$K = -4128.9 + 1233.1(\mathit{Sand / Silt}) - 119.9(\mathit{Sand / Silt})^2 + 3.8(\mathit{Sand / Silt})^3$	0.08	0.08	0.96	0.51
	$K = -66.74 + 252.46\mathit{EA} - 194.02(\mathit{EA})^2$	0.41	0.41	0.71	0.71
	$K = 56.61 + 46.88 \sin [p \{\mathit{BS} - (-22.46)\} / 1.59]$	0.77	0.77	-0.12	0.54
	$K = -1002.61 + 55.46\ \mathit{OM}$	-0.52	-0.52	0.22	-0.20
	$K = -62.75 + 138.75\mathit{ECEC} - 69.71(\mathit{ECEC})^2$	-0.75	-0.75	-0.53	-0.80
	$K = 24.47 + 23.19 \sin [p \{\mathit{Na} - (-0.08)\} / 0.07]$	-0.80	-0.80	-0.12	-0.72
Kanhaplic Haplustalf	$K = 620.4 - 106.0\ \mathit{OM} + 4.2\ (\mathit{OM})^2$	0.50	0.50	0.37	0.68
	$K = 3316.66 - 72.64\ \mathit{BS} + 0.40(\mathit{BS})^2$	0.70	0.70	-0.27	0.28
	$K = 2220.4 - 1199.3\mathit{ECEC} + 2151.5(\mathit{ECEC})^2 - 127.9(\mathit{ECEC})^3$	0.12	0.12	0.06	0.29
	$K = -309.22 + 437.22\ \mathit{MWD}$	-0.64	-0.64	0.27	-0.42
	$K = 58.56 - 10.49\mathit{SHC} + 0.62(\mathit{SHC})^2$	0.49	0.49	0.96	0.84
	$K = 453.54 - 11.15\ \mathit{Porosity}$	0.80	0.80	-0.14	-0.36
	$K = 95.08 - 2.33\ \mathit{Clay}$	0.24	0.24	0.47	0.57
	$K = 7091.48 - 8955.64\ \mathit{BD} + 2832.80\ (\mathit{BD})^2$	0.34	0.34	0.99	0.74
	$K = 4.82 - 1.47e^{16}\ (\mathit{Sand/ Silt}) + 1.09e^{15}\ (\mathit{Sand / Silt})^2$	0.27	0.27	0.69	0.41
	$K = 620.4 - 1766.6\ \mathit{TN} + 1165.3\ (\mathit{TN})^2$	0.50	0.50	0.38	0.68

T.N = Total nitrogen; OM = Organic matter; ECEC = Exchangeable cation exchange capacity; SHC = Saturated hydraulic conductivity; MWD = Mean weight diameter; BS = Base saturation; EA = Exchangeable acidity; and BD = Bulk density.

sand/silt ratio, BD and SHC singly, gave good relationship with standard USLE erodibility while predictive models with OM, BS, MWD, TN and porosity conformed to standard WEPP erodibility (Table 7a). Also, predictive models with BD and sand/silt ratio gave good correlation with standard USLE erodibility while models with BD, ECEC and porosity correlated well with standard WEPP erodibility (Table 7b). However, predictive models from MWD, OM, silt, EA and porosity gave good conformity with standard USLE erodibility while models from MWD, TN, EA, OM and sand correlated well with standard WEPP erodibility respectively (Table 7b).

Relationship between predicted K – factor using multiple linear regression and standard erodibility factor (USLE and WEPP)

The predicted K – factor using multiple linear regression for all identified soil types are presented in Tables 8 and 9. For Plinthic Petraquept, EA, Na, ECEC, sand, silt and SHC formed the components of multiple linear regression (Predicted K – factor) that correlated well with USLE at $P = 0.01$ (Table 8). Also, silt, EA, SHC and clay formed the components of predicted K – factor for Kanhaplic Haplustalf that had significant high correlation ($r = 1$; $P = 0.01$) with USLE. For Typic Plinthustalf, EA, Na, clay and porosity formed the components of multiple linear regression (Predicted K – factor) that

Table 7b: Establishing Relationship between Predicted Models and Standard Erodibility Factors (USLE and WEPP)

		WEPP MODELS		USLE MODELS	
Soil type	Predicted models	Inter-Rill Erodibility	Rill Erodibility	Wischmeier and Mannering	El-Swaify and Dangler
Typic Plinthustalf	$K = -18814.1 + 66748.9\mathit{MWD} - 76942.7(\mathit{MWD})^2 + 28787.8(\mathit{MWD})^3$	0.08	0.08	0.69	0.02
	$K = -814.92 + 197.9\mathit{Silt} - 10.63(\mathit{Silt})^2$	0.03	0.03	-0.69	-0.05
	$K = 248.64 - 123.49\,\mathit{BD}$	0.87	0.87	0.66	0.93
	$K = 8971.57 - 425.7\mathit{Porosity} + 5.08(\mathit{Porosity})^2$	0.96	0.96	0.50	0.98
	$K = 90.69 - 37.26\,\mathit{TN}$	0.37	0.37	-0.55	0.20
	$K = -184542.4 + 735583.5\mathit{Na} - 973260.4(\mathit{Na})^2 + 427531.6(\mathit{Na})^3$	0.48	0.48	0.43	0.40
	$K = 45.58 + 2.07\,\mathit{OM}$	-0.48	-0.48	0.42	-0.30
	$K = -512.39 + 6.3\,\mathit{BS}$	0.22	0.22	-0.41	0.22
	$K = 24.76 + 5.76\,(\mathit{Sand}/\,\mathit{Silt})$	0.58	0.58	0.47	-0.53
	$K = 3031.39 - 1716.94\,\mathit{ECEC} + 325.95(\mathit{ECEC})^2 - 20.23(\mathit{ECEC})^3$	-0.90	-0.90	-0.06	-0.88
Typic Haplaustalf	$K = 666.12 - 176.4\mathit{MWD} + 129.7(\mathit{MWD})^2$	1.00	1.00	-0.60	0.89
	$K = 5.64 + 0.3\mathit{SHC}$	-0.53	-0.53	-0.25	-0.80
	$K = 93.24 - 1.27\mathit{Sand}$	0.78	0.78	0.81	-0.33
	$K = 22.28 - 0.64\,\mathit{OM}$	0.77	0.77	-0.62	0.64
	$K = 1873.77 - 61.73\mathit{BS} + 0.51(\mathit{BS})^2$	-0.25	-0.25	-0.46	-0.19
	$K = 1.30e^{17} - 1.65e^{16}\mathit{Silt} + 5.02e^{14}(\mathit{Silt})^2$	-0.40	-0.40	0.04	0.97
	$K = 3346.19 - 71.27\mathit{Porosity}$	-0.09	-0.09	0.81	0.34
	$K = -3780.72 + 2689.4\mathit{BD}$	0.43	0.43	0.46	0.78
	$K = 1500.16 - 3341.84\mathit{EA} + 2278.66(\mathit{EA})^2 - 455.38(\mathit{EA})^3$	1.00	1.00	-0.57	0.90
	$K = 36.05 - 19.88\mathit{TN}$	0.91	0.91	0.83	-0.56

T.N = Total nitrogen; ECEC = Exchangeable cation exchange capacity; SHC = Saturated hydraulic conductivity; MWD = Mean weight diameter; BS = Base saturation; OM = Organic matter; EA = Exchangeable acidity; and BD = Bulk density.

Table 8: Correlation between Predicted K - factor (Multiple Linear Regressions) and USLE Erodibility Factor

Soil type	**Predicted K-Factor**	**r**	**R^2**
Plinthic Petraquept	$K = -10.57 - 0.247\ EA - 0.5018\ Na + 0.405\ ECEC + 0.127\ \%\ Sand + 0.097\ \%\ Silt + 0.0134\ SHC$	1.0**	0.99
Kanhaplic Haplustalf	$K = 0.725 + 0.645\ EA + 0.82\ \%\ Silt - 0.03\ SHC - 0.037\ \%\ Clay$	1.0**	1.00
Typic Plinthustalf	$K = -4286 - 0.756\ EA + 1.564\ Na - 0.010\ \%\ Clay + 0.110\ \%\ Porosity$	1.0**	1.00
Typic Haplaustalf	$K = 2.770 - 1.709\ TN + 0.064\ OM - 0.03\ \%\ Porosity$	0.99**	1.00

$^{**}P<0.01$; $^{*}P<0.05$; T.N = Total nitrogen; ECEC = Exchangeable cation exchange capacity; SHC = Saturated hydraulic conductivity; OM = Organic matter; and EA = Exchangeable acidity.

Table 9: Correlation between Predicted K – factor (Multiple Linear Regressions) and WEPP Erodibility Factor

Soil type	**Predicted K-Factor**	**r**	**R^2**
Plinthic Petraquept	$K = 115.029 - 525.0\ OM + 15.531\ ECEC + 1.185\ SHC - 109.832\ Na + 31.762\ MWD - 1.753\ \%\ Porosity$	0.9*	0.90
Kanhaplic Haplustalf	$K = 718.382 + 1.005\ \%\ Silt - 5.802\ BS - 3.056\ \%\ Clay - 1.276\ \%\ Porosity$	1.0**	1.00
Typic Plinthustalf	$K = -144.050 - 1.178\ OM + 3.414\ \%\ Porosity + 98.106\ Na + 0.473\ ECEC$	1.0**	1.00
Typic Haplaustalf	$K = -0.077 + 775.0\ MWD - 0.006\ SHC - 0.119\ EA$	1.0**	1.00

$^{**}P<0.01$; $^{*}P<0.05$; T.N = Total nitrogen; ECEC = Exchangeable cation exchange capacity; SHC = Saturated hydraulic conductivity; OM = Organic matter; BS = Base saturation; and EA = Exchangeable acidity; MWD = Mean weight diameter

Table 10: Soil Erodibility (K) ranges used to Develop Soil Erodibility Classes as Compared with the Standard and Predicted Erodibility

Soil Erodibility Class	Erodibility Risk	*K* Range	Soil Type			
			Standard USLE	Standard WEPP	Predicted USLE	Predicted WEPP
K1	Very Low	0.00 – 0.10				
K2	Low	0.10 – 0.20				
K3	Moderate	0.20 – 0.30	Typic Haplaustalf	Typic Haplaustalf		Kanhaplic Haplustalf and Typic Plinthustalf
K4	Moderately High	0.30 – 0.40				
K5	High	0.40 – 0.50	Plinthic Petraquept	Plinthic Petraquept	Typic Haplaustalf	Typic Haplaustalf
K6	Very High	>0.50	Kanhaplic Haplustalf and Typic Plinthustalf	Kanhaplic Haplustalf and Typic Plinthustalf	Plinthic Petraquept, Kanhaplic Haplustalf and Typic Plinthustalf	Plinthic Petraquept

correlated well with USLE at P=0.01 (Table 8). In addition, TN, OM and porosity formed the components of predicted K – factor for Typic Haplaustalf significantly correlated (r = 0.99; P= 0.01) with USLE (Table 8). Also, Plinthic Petraquept components (OM, ECEC, SHC, Na, MWD and porosity) of predicted K – equation significantly correlated (r = 0.9; P= 0.01) with WEPP (Table 9).

For Kanhaplic Haplustalf, silt, BS, clay and porosity, which formed the component of multiple linear regression (Predicted K – factor), correlated well with WEPP at P=0.01 (Tables 9 and 10). Also, the predicted K – equation (OM, porosity, Na and ECEC) for Typic Plinthustalf significantly correlated (r = 1.0; P= 0.01) with WEPP (Tables 9 and 10). Predicted K-equation (MWD, SHC and EA) for Typic Haplaustalf significantly correlated (r = 0.99; P= 0.01) with WEPP (Tables 9 and 10).

Discussion

Plinthic Petraquept and Typic Haplaustalf with sandy loam texture had a higher erodibility value than Kanhaplic Haplustalf and Typic Plinthustalf with sandy clay loam texture. This could be attributed to the higher clay content of Kanhaplic Haplustalf and Typic Plinthustalf soils which was responsible for their less susceptibility to erosion. Higher erodibility values obtained from Plinthic Petraquept and Typic Haplaustalf soils could be attributed to the presence of plinthite and concretions, which are impediment to drainage. Bulk density expressed an inverse relation with soil erodibility, as it increased with decreasing erodibility factor (USLE), but had direct relation with WEPP erodibility model except for Typic Haplaustalf soils with inverse relationship. This is could be attributed to the fact that WEEP erodibility model is a process based model which takes cares of structural changes while USLE is empirically based and lack ability to account for structural changes.

Direct relationship existed between saturated hydraulic conductivity (Ks) and USLE erodibility, and an inverse relationship with WEPP erodibility factor, reflecting inability of USLE erodibility model to take care of soil structural changes. Therefore, Typic Plinthustalf and Typic Haplaustalf are more structured soils than Plinthic Petraquept and Kanhaplic Haplustalf, making Typic Plinthustalf and Typic Haplaustalf less erodible. This confirms the work of Amezketa *et al.* (2003) that noted that soils with low mean weight diameter (poorly structured soils) were generally more easily detachable with higher erodibility value. There were disparities in the relationship between soil pH and erodibility factor (K – value). Lower soil pH in Plinthic Petraquept and Kanhaplic Haplustalf gave rise to high erodibility value, while higher soil pH in Typic Plinthustalf and Typic Haplaustalf culminated in higher erodibility value. This difference could be attributed to the difference in structural composition of the soils. Low pH value could have favoured soil binding agents such as sesquioxides and dehydrated oxides of Al and Fe, which could influence the soil structural composition. Wischmeier and Mannering (1969) reported that the role of pH to erodibility depends on soil structure and silt content. Similarly, the soil organic matter status of soils decreased with increasing soil depths, culminating in a direct relationship with soil erodibility factor. Contrastingly, Lujan (2003) reported that soil erodibility had an inverse relationship with organic matter content. However, Wischmeier and Mannering (1969) remarked that inverse relationships between erodibility and organic matter may not hold for all soil types. Total nitrogen exhibited a direct relationship with soil erodibility factor, which could be responsible for the decrease in erodibility factor down the profile. This was inconsonance with reports of O'Green and Schwankl (2006), which reported that soil organic matter and total nitrogen were strong factors influencing soil erodibility. Similarly, soil erodibility factors were directly related to the K, Ca, Na, and Mg contents of the soils. This suggests that the exchangeable bases decreased with decreased erodibility for tropical soils. However, effective cation exchange capacity (ECEC), exchangeable acidity (EA) and base saturation (BS) also had direct relationships with soil erodibility respectively.

The very highly erodible status of Kanhaplic Haplustalf and Typic Plinthustalf could be attributed to their hardened plinthic property, while the light textured nature of Plinthic Petraquept and Typic Haplaustalf could be responsible for their lower erodibility risk. Zhou and Wu (1993) and Zhang *et al*. (1992) reported erodibility value range of 0.0713 – 0.4467 and 0.31 for the Loess Plateau and plano sol of the Heilongjiang province respectively in China. Wang *et al.* (2013) also established erodibility values of 0.38 for loamy soil, 0.27 for sandy loam, and 0.28 for clay soils of Hebel province in China. Similarly, Typic Haplaustalf and Plinthic Petraquept soils had K values of 0.2 and 0.4, respectively. This indicates that Typic Haplaustalf and Plinthic Petraquept soils of South-western Nigeria are moderately and highly erodible, respectively.

Wischemeier and Mannering (1969) USLE erodibility values obtained using the study site properties were contrary to El-Swaify and Dangler (1977) USLE erodibility factor. This could be attributed to the organic matter and clay ratio regarded as major indicators of Wischmeier and Mannering (1969) USLE model, which was low in this study area. For example, Wischmeier and Mannering (1969) USLE erodibility value obtained using the study site properties showed that Typic Plinthustalf is the least erodibile soil series while El-Swaify and Dangler (1977) model presented Typic Plinthustalf as the most erodible.

With regards to WEPP erodibility factor, Dangler *et al.* (1976) erodibility index ratings showed the order of erodibility as, Typic Haplaustalf < Plinthic Petraquept < Kanhaplic Haplustalf < Typic Plinthustalf, which is in-line with USLE erodibility factor. However, the results obtained from both models (USLE and WEPP) showed that the soil types were highly erodible with exception of Typic haplaustalf. This could be attributed to the low K-value observed in the USLE model and rill erodibility of the WEPP model. However, Wischmeier and Smith (1965) earlier noted that the lower *K*-values in soils was as a result of the inherent characteristics of soils like texture, structure, plasticity, organic matter content as well as soil porosity.

The high dependency level range of 61% to 100% obtained from the relationship between predicted K - factor with WEPP erodibility factor in Plinthic Petraquept suggests the use of these models as a good predictor of soil erodibility using the appropriate regression fits. Similarly, the 100% perfect dependency level between the predicted K - values and WEPP erodibility factors in Kanhaplic Haplustalf and Typic Haplaustalf reveal effectiveness of the predictive tool in estimating soil erodibility of these soils. The 99% to 100% dependence associated between predicted K - values and

WEPP erodibility factor in Typic Plinthustalf indicated that the models are good predictors of soil erodibility of the area. It must be noted that components of the predicted K – factor varied among soil types, suggesting that suitability of the predicted K – factor is soil type specific. Thus, universal adoption of erodibility models may not be effective due to soil heterogeneity. However, the disparities in the conformity of the predicted K models with standard USLE and WEPP erodibility models show that the precision of the predicted models in evaluating soil erodibility is soil type specific. Thus, the need to employ the corresponding predicted models posing a good relationship with either standard USLE or standard WEPP models is highly imperative.

The multiple regression models perfectly correlated with USLE erodibility factor suggesting strong prediction capability for Plinthic Petraquept, Kanhaplic Haplustalf, Typic Plinthustalf and Typic Haplaustalf soils. Similarly, the 90 – 100% reliability and dependency level observed between predicted multiple regression models and USLE and WEPP erodibility for all the soil types indicate that the predicted models have a very strong prediction potential for Kanhaplic Haplustalf, Typic Plinthustalf, Typic Haplaustalf and Plinthic Petraquept.

Conclusion

Soil erodibility models predicted from soil properties of Plinthic Petraquept, Kanhaplic Haplustalf, Typic Plinthustalf and Typic Haplaustalf conformed to Universal Soil Loss Equation (USLE) and Water Erosion Predicted Project (WEPP) in both inter-rill and rill erodibility models with coefficient of determination (R^2) that ranged from 95% to 100%. It is also discovered that predictive models are soil-type specific nullifying universal adaptability of proposed equations. This could be explained by the fact that combination of soil parameters forming erodibility model for each soil type differ. Generated regression fits that best predicted erodibility values for soil types were varied indicting that each soil type has its own peculiar characteristics. Therefore, universal adaptability of soil erodibility model could lead to uncertain results, especially for soils of different genesis. The predicted models should be evaluated on similar soils elsewhere to ascertain the constraints and limitations that could militate against applicability of these models.

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