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Erodibility Indices under Different Land Uses of Okaba Soil

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ABSTRACT

The study of erodibility characteristics of Okaba soil was carried on forested, cultivated and residential land uses. Soil samples were collected at a depth of 0 – 20cm from the three different land uses identified on topographic map of the area using soil auger. The samples were preserved to the laboratory and analyzed for Particle-Size by hydrometer method. Standard Laboratory procedures described by ASTM D 422 were performed for erodobility indices. Values of modified clay ratio (MCR), clay ratio (CR), dispersion ratio (DR), and erosion ratio (ER) were observed to be the highest at Ogane, whereas, water stable aggregates (WSA) were highest at Okaba Town location. Among different land uses these indices were in the order of cultivated > forest > residential but, the value for ER were equal at Forested and residential land uses. However, WSA followed the opposite trend. Soil loss and the erodibility indices were statistically correlated. Highly positive correlation of MCR and CR (R^2 = 0.992 and 0.889 respectively) were experienced with soil loss except for WSA index where the value was negative (0.021). DR and ER has weak correlation coefficient (R^2 = 0.374 and 0.227 respectively). MCR and CR were observed to be better indices of soil erodibility in the study area these correlations were significant at 1% level of significance for MCR and CR, DR, ER and WSA.

Key words: Okaba, land use, Soil erodobility indices, soil loss

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INTRODUCTION

Soil is a vital natural resource for all land based activities to meet the provisions of food, fuel, fodder, fiber etc of mankind and to control this resource on continued basis is one of the very important issues under present scenario, when the pressure on soil is increasing day after day.

Soil erosion is one of the most significant physical and socio-economic problems affecting development in most part of the world today. It constitutes a threat to the environment and causes destruction to infrastructure, highways, as well as creates a major problem on agricultural land thereby interfering seriously with mass food production. The greatest threat to the environmental settings of Idah – Ankpa Plateau of Anambra basin Nigeria which includes Lower Coal Measure Geological Formations known as (Mamu Formation) is the gradual but constant derelict of the landscape by soil erosion by water and continuous removal of the top soil by water and wind. Therefore, erosion problems in the tract have become a subject of discussion among soil scientists, environmentalist, geographers, geologists, engineers and social scientists.

The Okaba tract of Idah – Ankpa Plateau of Anambra Basin of Nigeria known as Lower Coal Measure (Mamu Formation) Geological Formation of Anambra Basin Nigeria was affected by erosion because it has been subjected to bush burning, continuous cultivation, cutting down of trees for fire wood/charcoal making for commercial purposes and mining of coal, which are common and long term traditional practices in the area. Crop or cultivated lands are the most susceptible to erosion in this area because of the scarce vegetation cover and seasonal interruption of the surface soil. The susceptibility of croplands to erosion is determined by management practices and by a range of physical conditions, including climate [1], lithology [2], topography, [3] and soil texture [4]. The main dangerous periods for runoff and soil erosion happen when the vegetation cover is minimal and rainfall intensities are relatively high.

When erosion occurs it washes away the topsoil, resulting in a rearrangement of soil particles, soil moisture and aeration status and compaction thus soil structure is directly affected [5]. Consequently, soil structure influences all processes that take place in the soil including water and nutrient movement within the soil [6]. According to [7] soil erosion is a natural process. It becomes intolerable when it accelerated by human and or the amount of soil loss affect soil quality and reduces crop productivity [7], [8]. Moreso, it is called intolerable when it starts to reduce soil fertility, soil thickness, water storage capacity of soil, and thus crop productivity [9]. [10] e]revealed that the sediments of the lower coal measures (Mamu Formation) are not prone to degradation except where gullying process is triggered and accelerated by anthropogenic activities. However, the increase in demand for firewood, timber, pasture, food, and residential dwelling, the hardwood forests are being degraded or converted to cultivated land at an alarming rate in the Lower Coal Measure Geological Sediment (Mamu formation) of the Anambra Basin, Nigeria, during the last few decades, and continuous local mining of Coals in the area. However, very little or no information is available on the erodibility indices for the soils of this tract. Realizing the seriousness of the problems, the present investigation was initiated to evaluate Soil erodibility indices under different land uses namely forested, cultivated and residential and their relationship with soil loss.

Various studies carried out indicate that soil erodibility is a function of soil texture, aggregate stability, particles size distribution, shear strength, infiltration capacity, organic matter content, hydraulic properties, water content and chemical contents [11], [12], [13], and [14]. Soil erodibility is one of the main factors controlling soil erosion.

In this study various soil erodibility indices were used to estimate soil erodibility based on soil characteristics. Erodibility indices like dispersion ratio [15], clay ratio [16], modified clay ratio [17] and erosion ratio [18] and aggregate stability have been employed to assess the soil erodibility.

MATERIALS AND METHODS

Description of the Study Area

The study was undertaken in Okaba area in Ojoku district with Okaba as the district headquarter situated in Ankpa Local Government and it is 16 km NE of Ankpa town located in the middle belt of Nigeria. Its geographical coordinates are 7° 23' 0" North, 7° 44' 0" East (i.e. between latitudes 7^0 20^1 – 7^0 43^1 N of the Equator and longitudes 7^0 22^1 – 7^0 52^1 E of the Prime Meridian).

The area consists of lowlands and hills with an average elevation of 274.5m located near the base of the Enugu escarpment. Geologically, Okaba is underlain by Mamu Formation at the northern, northeastern, northwestern and central parts and Ajali Formation at the southern part. The climate of the area is influenced by the movement of the Inter – Tropical Discontinuity (ITD). The area has 6 -7 rainy months, the mean annual rainfall for Okaba is 1250 mm. Monthly temperature values ranges from 29^0C to over 34^0C in the area. The mean annual sunshine hours at Lokoja is 2300 h, while the daily mean duration of sunshine hours in July is 4 – 5 h during the dry season, the values of relative humidity ranges from 36 – 80 %, while rainy season values are between 70 and 90 % in January and July, respectively at Makurdi (7^0 44' 1N 8^0 32'E). The dormant vegetation type is the derived savanna. 95% of the populace is Igala speaking people. The samples location comprises of Okaba Coal Site, Ogane, Okpokwu, Okaba Town, Ogbagbala and Odagbo.

Land in the study areas is used for resident, agriculture, industry and forestry. As of the time of this study the Coal Mining industries were no longer in operations but local mining activities were being carried out occasionally by the resident of the area. The inhabitants of Okaba districts are mainly engaged in agrarian pursuits of cultivating arable crops and rearing livestock on a free-range and semi intensive basis. The soils are mainly loamy (sandy loam) suitable for all kinds of crops cultivation. Forest resources (economic trees) such as mahogany, dick nut (ogbono), locust bee, cashew, mango, iroko and orange are all present. Crops like groundnut, plantain, yam, sorghum and cassava are prominent produce in the area. Others include pepper, rice, beans, maize, and Bambara nut. The domestic animals reared are goat, pig, chicken and duck.

The study of erodibility characteristics of the soil was carried out in six locations under three lands uses viz. forested, cultivated and residential land uses. A total of eighteen (18) soil samples were collected at a depth of 0 – 20cm under the three different land uses which was determined using topographic map of the area for the point locations. Soil auger was used to collect the soil sample from the three (3) different land uses with six (6) samples from each of the land uses. 4kg of soil was collected from each of the eighteen (18) locations and were labeled for ease of identification according to the location. The samples were sealed in clean black polythene bags to prevent moisture loss during handling and transportation to the laboratory. ASTM D 422 - Standard Test Method for Particle-Size Analysis of Soils using sieve and hydrometer method were performed to determine the percentage of different grain sizes contained within a soil. The percentage of silt, sand, and clay were determined by taking the reading from the Plot of the grain size curve D versus the adjusted percent finer on the semi logarithmic sheet. Moisture content is determined by drying the sample to a constant weight. The water content is then expressed as the percentage, by weight, of the dry sample. Specific gravity was determined based on fine-grained soil by density bottle method as per Indian Standard: 2720 (part 111/sec 1) – 1980 G_s measured at room temperature. Particle density was determined using pycnometer method. Bulk density (ρd) was measured with samples taken from 0 to 20 cm soil layer using metal cylinders of approximately 100 cm^3 volume (5.02 cm in diameter and 5.05 cm in height), with three replicated samples taken from each land use. The samples were weighed and dried until they reached a constant weight. Soil pH was measured using pH meter. Determination of soil organic content (SOC) was carried out using the Walkley-Black method [19] as modified by [20]. The soil permeability was also determined using constant head permeameter. Soil textural class was determined using soil textural triangle.

Soil porosity was calculated using bulk density and particle density according to the equation: total porosity (%) = (1-$\rho d/\rho p$) ×100. A wet sieving method was used to determine the percentage of aggregate stability (Water stable aggregates, WSA %) soil aggregates that are greater than 2.0mm after wet sieving. The size distribution soil aggregate was measured by sieving following the procedure of [21].

Mean annual rainfall of the study area from 2000 to 2014 were used in calculation. Soil erodibility was determined based on [16],

$$K = \frac{\%\,SAN\ + \%\,SIL}{\%\,CLA} \qquad (1)$$

Where: SAN, SIL and CLA are percent sand, silt and clay, respectively.

While the revised universal soil loss equation (RUSLE) by [22] was used in calculating the soil losses for the various sampling locations.

$$A\ = 2.24RK \qquad (2)$$

Where; A is the Soil loss in tons/ha/yr. The soil loss converted to tons/ha/yr. by multiplying by 2.24

$$R\ = 0.5H \qquad (3)$$

Where R is the mean annual rainfall factor, H is the mean annual rainfall, and K is the erodibility factor.

Various soil erodibility indices (dispersion ratio, erosion ratio, clay ratio, modified clay ratio and water stable aggregate) used in the calculation were in Table 1.

Table -1 Formula used in Calculation of various soils erodibility indices.

Erodibility Index	Formula
Dispersion Ratio (DR) =	$[(\%\text{ silt } + \%\text{ clay})\text{in undispersed soil}]/[(\%\text{ silt } + \%\text{ clay})\text{after dispersion of soil in water}]$
Clay Ratio (CR) =	$((\%\text{ sand } + \%\text{ silt}))/(\%\text{ clay})$
Modified Clay Ratio (MRC) =	$(\%\text{ sand } + \%\text{ silt}))/(\%\text{ clay } + \%\text{ Organic matter})$
Erosion Ratio (ER) =	$\text{DR}/(\text{colloidal content}/\text{Moisture equivalent ratio})$
Water stable Aggregates (WSA) =	$\%\text{ of soil aggregate } > 2\ mm\ after\ wet\ sieving$

RESULTS AND DISCUSSION

The results of basic soil characteristic of the study area were presented in Table 2, and Values of Basic Physico-chemical Properties of soil from the Study Area were presented in Table 3 while soil erodibility indices at six locations was presented in Table 4 and soil erodibility index (K) and predicted soil loss calculated results were presented in Table 5. The correlation graph was in figure 1.

Table -2 Values of Basic Characteristic of soil from the Study Area

Location	Land use	Coarse Sand (%)	V. Fine Sand (%)	Silt (%)	Clay (%)
Coal Site	Forested	32	20	39	9
	Cultivated	31	30	35	4
	Residential	7	43	30	20
	Mean	23	31	35	11
Ogane	Forested	32	20	42	6
	Cultivated	28	40	28	4
	Residential	8	41	45	6
	Mean	23	34	38	5
Okpokwu	Forested	16	29	46	9
	Cultivated	32	27	32	9
	Residential	14	31	42	13
	Mean	21	29	40	10
Okaba Town	Forested	49	16	25	10
	Cultivated	21	24	44	11
	Residential	24	25	43	8
	Mean	31	22	37	10
Ogbagbala	Forested	17	23	50	10
	Cultivated	45	25	24	6
	Residential	60	10	21	9
	Mean	41	19	32	8
Odagbo	Forested	66	5	20	9
	Cultivated	67	2	20	11
	Residential	76	2	12	10
	Mean	70	3	17	10

Physical characteristics of the soil particles from six locations under different land uses are presented in Table 2 and the mean values of each locations were as follows; Coarse sand content was highest at Odagbo location (70%) followed by Ogbagbala (41%), Okaba Town (31%), Okaba Coal Site and Ogane (23%) each and Okpokwu (21%) whereas fine sand content was highest at Ogane (34%) followed by Okaba Coal Site (31%), Okpokwu (29%), Okaba Town (22%), Ogbagbala (19%) and Odagbo (3%). Silt content was highest at Okpokwu (40%) followed by Ogane (38%), Okaba Town (37%), Okaba Coal Site (35%), Ogbagbala (32%) and Odagbo (17%). Clay content was the highest at Okaba Coal Site (11%), followed by Okpokwu, Okaba Town, and Odagbo (10%) each, Ogbagbala (8%) and lowest at Ogane (5%).

Table -3 Values of Basic Physico-chemical Properties of soil from the Study Area

Location	Land use	MC (%)	OC (%)	Pb (cm/h	ρd g/cm^3	ρp g/cm^3	P (%)	G_s	pH
Coal Site	Forested	10.52	0.39	11.61	1.26	2.65	52.45	2.73	6.75
	Cultivated	2.89	0.38	11.99	1.39	2.65	47.55	2.70	5.73
	Residential	22.86	0.12	12.60	1.49	2.80	46.79	2.62	4.72
	Mean	12.09	0.30	12.07	1.38	2.70	48.93	2.68	5.73
Ogane	Forested	6.04	0.56	11.07	1.22	2.58	52.71	2.86	7.80
	Cultivated	5.90	0.54	12.33	1.26	2.60	51.54	2.86	7.10
	Residential	6.02	0.56	12.69	1.29	2.63	50.95	2.86	7.15
	Mean	5.99	0.55	12.03	1.26	2.60	51.73	2.86	7.35
Okpokwu	Forested	9.53	0.68	10.10	1.29	2.68	51.87	2.85	6.50
	Cultivated	5.13	0.66	10.44	1.34	2.75	51.27	2.90	6.48
	Residential	7.57	0.62	11.61	1.36	2.78	51.08	2.89	6.45
	Mean	7.41	0.65	10.72	1.33	2.74	51.41	2.88	6.48
Okaba Town	Forested	7.67	0.64	10.80	1.36	2.65	53.96	2.74	7.12
	Cultivated	7.49	0.62	10.44	1.34	2.68	57.46	2.78	7.13
	Residential	6.64	0.58	12.33	1.27	2.69	59.11	2.72	7.14
	Mean	7.27	0.61	11.19	1.32	2.67	56.84	2.75	7.13
Ogbagbala	Forested	8.70	0.60	12.15	1.30	2.56	60.94	2.80	6.97
	Cultivated	6.80	0.60	12.60	1.46	2.67	57.68	2.81	7.02
	Residential	7.86	0.58	12.69	1.44	2.67	58.43	2.91	7.05
	Mean	7.79	0.59	12.48	1.40	2.63	59.02	2.84	7.01
Odagbo	Forested	6.41	0.74	12.53	1.32	2.54	54.33	2.66	7.15
	Cultivated	5.60	0.72	12.33	1.38	2.64	54.17	2.72	7.20
	Residential	5.57	0.70	12.69	1.41	2.72	54.78	2.91	7.25
	Mean	5.86	0.72	12.52	1.37	2.63	54.43	2.76	7.2

MC = Moisture Content, OC = Organic Content, pH = Hydrogen ion Concentration, G_s = Specific Gravity, ρd = Dry Bulk Density, ρp = Particle Density, Pb = Permeability.

Table 3 present basic physico – chemical properties of the soil. Among different land uses, forest soils had the lowest bulk density (1.29 g/cm^3), which may be ascribed to higher organic carbon content (0.60 %) or undisturbed soil surface under this land use. Cultivated bulk density is 1.36 g/cm^3 with organic carbon (0.59 %) and residential soils have bulk density of 1.38 g/cm^3 and organic carbon (0.53 %). Forested land use has pH of (7.05) while cultivated land use has pH of (6.78) and residential land use has pH of (6.63) this shows that the pH become more acidic as land use increases. Among different land uses residential soil had the highest specific gravity (2.82), follow by cultivated soil (2.80) while forested soil was (2.77) this shows that residential soil is more suitable as a construction material than cultivated and forested soils. This is in agreement with [23], who stated that higher value of specific gravity gives more strength for roads and foundations. The low specific gravity observed in the forested soil might due to high organic carbon content in the forested soil than the cultivated and residential soil. The result from permeability indicate that water move faster or percolate more in the forest soil (11.38 cm/h) than cultivated and residential soil which have permeability of (11.69 cm/h and 12.44 cm/h) respectively.

Table -4 Soil erodibility indices at six locations under different land uses

Land Use	Coal Site	Ogane	Okpokwu	Okaba Town	Ogbagbala	Odagbo	Mean
Dispersion Ratio (DR)							
Forested	0.81	0.88	0.84	0.80	0.83	0.69	0.78
Cultivated	0.90	0.88	0.81	0.84	0.80	0.71	0.81
Residential	0.68	0.88	0.84	0.84	0.72	0.64	0.78
Mean	0.80	0.88	0.83	0.83	0.78	0.68	
Clay Ratio (CR)							
Forested	10.11	15.67	10.11	9.00	9.00	10.11	9.27
Cultivated	24.00	24.00	10.11	15.67	15.67	8.09	12.78

Residential	4.00	15.67	6.69	11.50	10.11	9.00	8.72
Mean	12.70	18.45	8.97	12.06	11.59	9.07	
Modified Clay Ratio (MCR)							
Forested	9.41	13.49	8.95	8.11	8.16	8.85	8.25
Cultivated	21.38	19.47	8.97	7.37	13.37	7.27	10.63
Residential	3.96	13.49	6.18	10.22	9.10	8.03	7.82
Mean	11.58	15.48	8.03	8.57	10.21	8.05	
Erosion Ratio (ER)							
Forested	0.88	0.76	0.79	0.55	0.60	0.43	0.84
Cultivated	0.58	1.05	0.41	0.52	0.77	0.33	0.89
Residential	0.77	0.76	0.45	0.62	0.63	0.32	0.68
Mean	0.74	0.86	0.55	0.56	0.67	0.36	
Water Stable Aggregate (WSA)							
Forested	0	0.18	0.33	21.03	0.62	0.12	2.87
Cultivated	0.20	1.42	0.09	6.25	0.17	0.12	2.62
Residential	0.29	0	0.66	6.48	0.13	0.27	2.16
Mean	0.16	0.53	0.33	11.25	0.31	0.17	

Various soil erodibility indices derived from soil physical properties have been tabulated in Table 4. Among different locations, dispersion ratio (DR) was observed to be the highest for Ogane (0.88) location. Whereas, among different land uses it was the lowest under forest and residential land use (0.78) each, erosion ratio (ER) was the highest at Ogane (0.86) whereas at other locations it ranges between 0.36 and 0.74. Among different land uses it was in the order of cultivated (0.89) > forested (0.84) > residential (0.68). The clay ratio (CR) and modified clay ratio (MCR) values were the highest at Ogane (18.45 and 15.48) and the lowest at Okpokwu (8.97 and 8.03), respectively. The MCRs were higher than CRs; this might be because of enclosure of organic matter in the denominator in case of MCRs. In general, residential and forest soils had lower values of DR, MCR and ER. Percentage of water stable aggregates > 2 mm (WSA) was the highest at Okaba Town followed by Ogane, Okpokwu, Ogbagbala, Odagbo and Okaba Coal Site. Among different land uses, the percentage of WSA was in the order of forest > cultivated > residential soils.
Using the criterion of [15]; soils having dispersion ratio > 0.15 and erosion ratio > 0.10 are erodible in nature. So, the soils were found to be highly erodible under all land uses by these criteria. The soils under forest cover had higher water retention and infiltration rate. Forest soils and residential soils had lower values of dispersion and erosion ratios as compared to cultivated soil. Also from this study residential and forested soils had lower clay and modified clay ratios compared to cultivated soil. Forested soil has highest WSA compared to cultivated and residential soils. [24], preferred aggregate stability as the well-organized index of soil erodibility. He used the proportion of water stable aggregates > 0.5 mm in the soil as indicator of soil quality. [25], also opined that content of water stable aggregates were more reliable index of erodibility of soils. [26], finalized that both ER and DR are equally good indices of soil erodibility. However, [27] in his studying of vertisol soils of Karnatka experiential that ER was better index of soil erodibility than DR.

Table -5 Erodibility Factor (K) and Predicted Soil Loss

Land Use	OkabaCoal Site	Ogane	Okpokwu	Okaba Town	Ogbagbala	Odagbo	Mean
Erodibility Factor (K)							
Forested	0.10	0.16	0.10	0.09	0.09	0.10	0.11
Cultivated	0.24	0.24	0.10	0.08	0.16	0.08	0.15
Residential	0.04	0.16	0.07	0.12	0.10	0.09	0.10
Mean	0.13	0.19	0.09	0.10	0.12	0.09	
Predicted Soil Loss (Tons/ha/yr.)							
Forested	14.80	23.68	14.80	13.32	13.32	14.80	15.79
Cultivated	35.52	35.52	14.80	11.84	23.68	11.84	22.20
Residential	5.92	23.68	10.36	17.76	14.80	13.32	14.31
Mean	18.75	27.63	13.32	14.31	17.27	13.32	

Table 5 present the calculated erodibility factor K and the predicted soil loss in the area. The results of erodibility factors were as follows; Cultivated > Forested > Residential this might due to high clay content in the residential land use than any of the two land uses (forested and cultivated). Among all the locations presented in Table 5, K is lowest at residential land use in Okaba Coal Site which has the highest content of clay soil (20%) as indicated in Table 1. The K was highest in Okaba Coal Site and Ogane both locations have the lowest content of clay soil (4%) content as presented in Table 1.

The predicted soil loss was high in cultivated land use than the forested and residential land uses. The predicted soil losses were in order of Cultivated > Forested > Residential.

Relationship of Soil Erodibility Indices with Soil Loss

Figure 1 shows the relationship between soil loss and erodibility indices. Soil loss was observed to be positively correlated with all the erodibility indices except WSA. Correlation coefficient was the highest for MCR (0.996), followed by CR (0.943), DR (0.611) and ER (0.476). It was negatively correlated with WSA (-0.146). These correlations were significant at 1% level of significance for MCR and CR, DR, ER and WSA. Negative correlation of WSA index with soil loss indicates that when the aggregation increases, the soil loss is lower this is in agreement with [28]. It also implies that the less the colloidal content of the soil the more the soil loss. Colloids are made up of clay and organic matter particles. The graph revealed a linear relationship between soil loss and MCR, CR, DR, and ER indicating that the more the MCR, CR, DR and ER the more the soil loss. A higher MCR and CR imply that there is more proportion of sand and silt to clay. Sandy and silty soils are more vulnerable to erosion.

A weak correlation coefficient (R) however was noticed at erosion ratio and water stable aggregate hence ER and WSA could not be relied upon while evaluating erodibility of soil in the study areas. $R^2 = 0.992$ and $R^2 = 0.889$ for MCR and CR respectively it thus appears that MCR and CR are the better indices of soil erodibility in the study area.

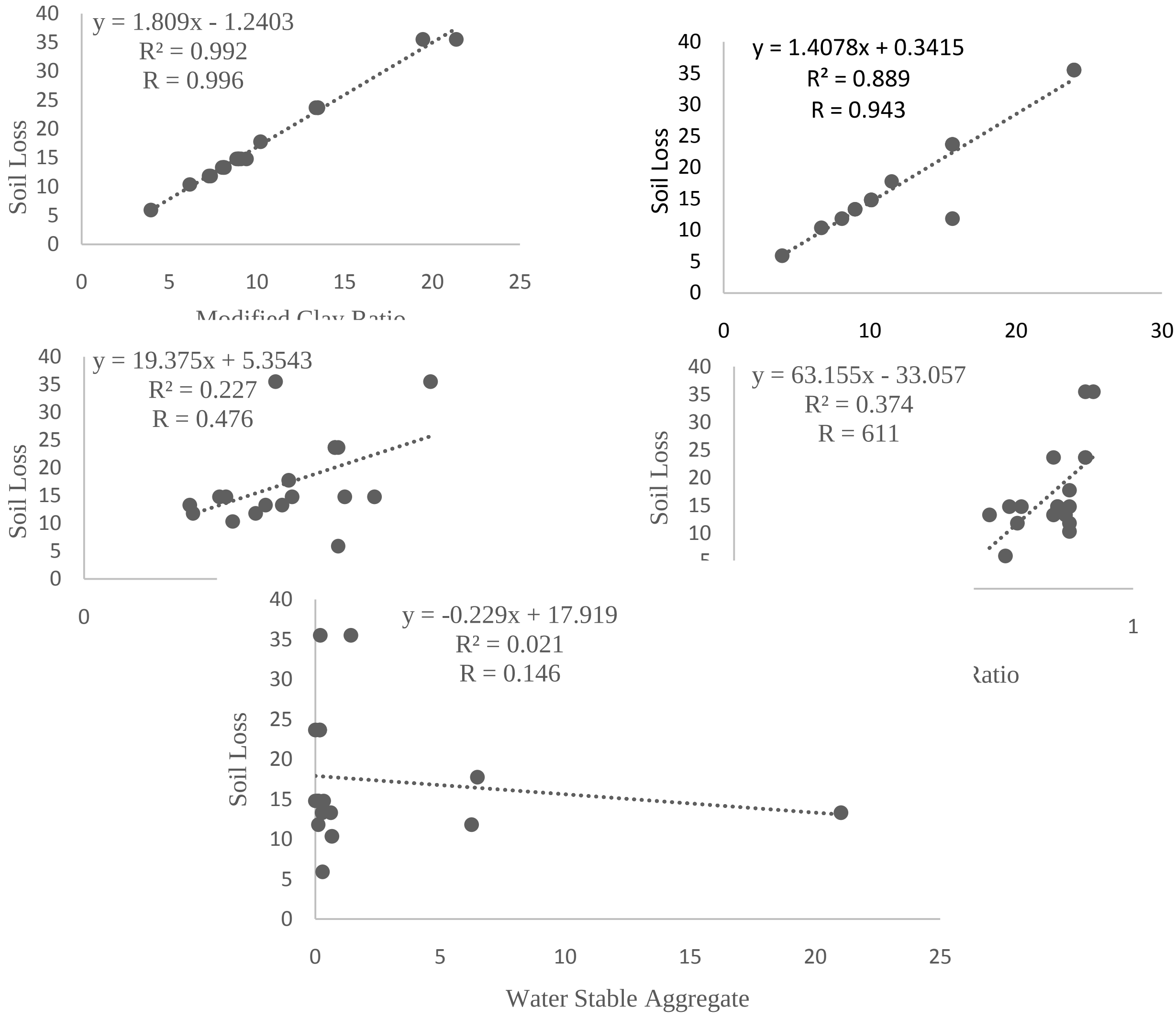

Fig. 1 Relationship of soil loss with various soil erodibility indices

CONCLUSION

The results of this study lead to the following deductions:

1. The soils from the study area were found to be highly erodible under all land uses.
2. Forest soils and residential soils had lower values of MCR, CR, DR and ER as compared to cultivated soil while the percentage of WSA was in the order of forest > cultivated > residential soils.

3. Soil loss was positively correlated with all the erodibility indices except WSA and the highest Correlation coefficient was MCR (0.996), followed by CR (0.943), DR (0.611) and ER (0.476) and was negatively correlated with WSA (0.146). These correlations were significant at 1% level of significance.
4. A weak correlation coefficient was observed at ER and WSA which is an indication that ER and WSA could not be relied upon while evaluating erodibility of soil in the study areas.
5. There was a linear relationship between soil loss and all the erodibility indices.
6. MCR and CR are the better indices of soil erodibility in the study area.

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