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Soil Erodibility Potential of Northern Part of Ondo State, Southwestern Nigeria

Falowo O. Olumuyiwa*

Department of Geology, Faculty of Physical Science University of Benin, Benin City, Edo State, Nigeria

Corresponding Author:** ***Falowo O. Olumuyiwa, *Department of Geology, Faculty of Physical Science University of Benin, Benin City, Edo State, Nigeria*

Abstract: *The erodibility map and predicted erosion soil loss for northern part of Ondo State were developed by computing erodibility factor (K) using universal soil equations. The erosion indices calculated are dispersion ratio (DR), modified clay ratio (MCR), and erosion ratio (ER). The calculated erodibility factor are high, ranging from 0.01 to 0.11, indicative of low clay/silt content present in the soil which serves as binding material. The predicted soil losses show that area having high erodibility factor (k) are also characterized by high soil loss. Therefore soils in Akoko and Owo areas have the highest values of "A" ranging from 63 to 185 tons/ha/yr, while Ose area have values between 19 and 60 tons/ha/yr. The erodibility map classifies the soil in the area into different erosion potential zones as High (greater than 0.1), Moderate (0.05 – 0.1), and Low (0 – 0.05). The high Erodibility soil accounts for 2% occurring as a small closure in Owo, while moderate and low Erodibility as 68 % and 30 % respectively. A correlation analysis between soil loss and the indices of erodibility shows a positive correlation coefficient, however MCR, ER, and K are better indices of soil erodibility showing strong correlation.*

Keywords: *Erodibility factor, Erosion indices, Correlation coefficient, Physical tests, Ondo north*

1. Introduction

Soil erosion by general description is the loosening, removal and transport of soil material from one place to another (detachment, transportation and deposition). It is a natural geomorphic process occurring continually over the earth's surface [1]. It is a universal or natural occurrence wherever there is soil, and by agents such as wind, water, and/or ice. Soil erosion begins with detachment, which is caused by the breakdown of aggregates by rain impact, shearing, or the drag force of water [2]. The loss or removal of the superficial layer of the soil by the action of water, wind, or by the activities of man is now a global natural disaster which every country, as a matter of urgency must assess and mitigate against it in any form [3]. However, the acceleration of this process through anthropogenic perturbation can have severe impacts on soil and environmental quality. Detached particles are transported by flowing water, overland flow, inter-flow, and wind, then deposited when the velocity of water decreases by the effect of slope or ground cover. It is also of universal importance as man's activities, directly or indirectly, depend on the soil.

The fertility or the productive capacity of the soil depends on the mineral it contains; consequently soil erosion has led to food shortage all over the world due to depletion of the mineral content of the top layer or damage it, thus reducing the fertility of the soil. The factors influencing the extent to which the soil erosion is depleted or will occur are: distribution of rainfall, intensity and amount of rainfall, slope of the ground, nature of the soil, vegetation cover, and soil management [4]. The Susceptibility of soil to erosion is influenced by its physical, hydrological, chemical, biological, and bio-chemical properties as well as its profile characteristics [5]. Important soil physical properties that affect the resistance of soil to erosion include texture, structures, water retention and transmission properties, and unconfined compressive and shear strength. The importance of these properties in relation to soil erosion has been reviewed [3], [6-7].

Unequal distribution of rainfall during the year results in heavy rainfall being restricted to a few months of the year. The soil is unable to absorb this heavy rainfall and therefore there is plenty of run-off water which removes layers of the soil as it moves along, resulting in soil erosion. Also if the land has steep slope, then infiltration of rain water decreases and the runoff is much faster resulting in more soil erosion [8]. In addition, if equal slopes are exposed to the same type of rainfall, then well compacted fine material will produce more run off than loose sands. Vegetation holds the soil in place by forming a network of roots of the plants. Rain falling on thick vegetation cover gets soaked into the ground, is partly absorbed by the vegetation and partly evaporates. Soil erosion is negligible due to less surface run-off. On the other hand, rain falling on bare land causes soil erosion as the top soil is loose and is easily carried by rain water. Also faulty methods of surface drainage, over-grazing, etc., can aggravate soil erosion. The interactions of human activities such as mining, quarrying/rock blasting with severe climatic factors have resulted in land degradation such as soil erosion.

Soil erosion is a major threat to the social and economic lives of the people of the northern part of Ondo State, Nigeria especially Akoko, Owo, and Ose. Soil samples from different parts of the northern area of Ondo comprising all the four local government areas of Akoko, Owo and Ose Local Government Areas were studied for their susceptibility to erosion [9]. Soil properties and indices of erodibility which is a function of soil texture, aggregate stability, shear strength, infiltration capacity, organic, and chemical contents [10] were determined and an erodibility map was developed. Similar work had been undertaken by several authors such as [3], [10-13]. All these researchers examined the spatial variability of erodibility of soil types in their studied environment by estimation of K factors from soil type. [14] reported classes of erodibility based on different values of erodibility factor (K) and nature of soils and classified erodibility of various soils as low, moderate, high and very high based on the range of erodibility factor.

The study area is located within the northern part of Ondo State, Nigeria (Fig 1). The selected areas include Owo, Akoko, and Ose. These areas are located within longitudes 5°20´E and 6°10´E and latitudes 6°30´N and 7°40´N. The area is accessible through the Benin - Ifon highway, Abuja - Lokoja Highway and Ado-Akure highway. The study area has a topographical elevation varying from 40 m – 750 m above the sea level (Fig 2). The northern part of the study area is a rugged terrain (i.e. hilly) especially in Akoko area [15]. The lowlands are widespread at Ute and Okeluse axes of the area with gentle slope, while the gradient of the northern areas are generally steep. The channels of the smaller streams are dry for many months, especially from November to May. Another aspect of the relief of the area is the prevalence of many erosion gullies along hill slopes. The gullies are very common and rather devastating in Owo, Ifon, Ikare, Oke Agbe and Isua.

The area is situated within the tropical rain forest region, with a climate characterized by dry and wet seasons. According to Federal Meteorological Survey [16] the annual rainfall ranges between 1000 and 1800 mm, with a mean annual rainfall of 1500 mm, and average wet days of about 100. The mean annual temperature is between 21°C and 33°C with mean temperature of 24°C and mean humidity of 80% [17-18]. The vegetation is the rainforest type and is composed of teak, Gmelina/pulp wood, tall crowned trees mixed with thick undergrowth and of woody savanna (Fig 3a). Over most of the area, the natural vegetation has been very much degraded as a result of human activities, the chief of which is based on the rotation of bush fallow system. Consequently, the original forest is now restricted to forest reserves [19].

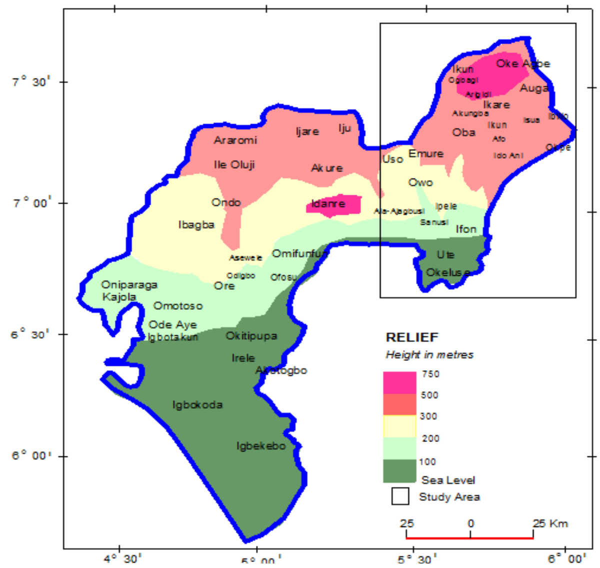

Figure1. *Relief Map of Ondo State, showing the Study Area (Modified After Federal Meteorological Survey [15]*

The geology of study area falls within the southwestern basement complex (Fig 3b.) and consists of migmatite, granite gneiss, fine grained quartzite, pegmatite and quartzo-feldspathic veins, schist, and quartz schist. These rock types dominate Owo and Akoko areas, notably along Owo – Oba Akoko, Iwaro – Akungba, Akungba – Supare, Ikare, Epinmi, Sosan, Oke Agbe, and Ido Ani. The migmatite complex which is the most widespread basement rock in the area is mainly medium grained gneiss. They are strongly foliated rocks frequently occurring as outcrops. On the surface of these outcrops, severely contorted, alternating bands of dark and light coloured minerals can be seen. These bands of light coloured minerals are essentially feldspar and quartz, while the dark coloured bands contain abundant biotite. A small proportion of the area especially to the northeast, overlies the coarse grained granites and gneisses, which are poor in ferromagnesian minerals. These rocks are covered by regoliths with thickness variation across the town.

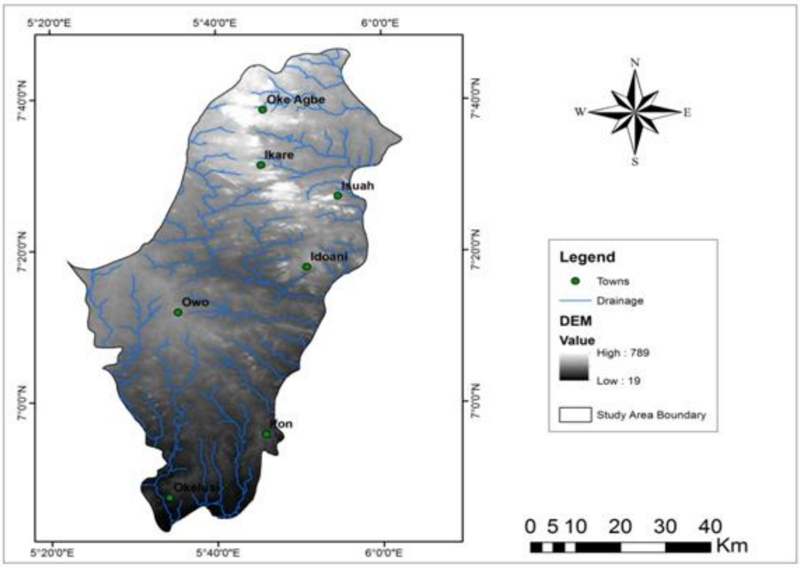

Figure2. *Digital Elevation Model (DEM) of the Study Area*

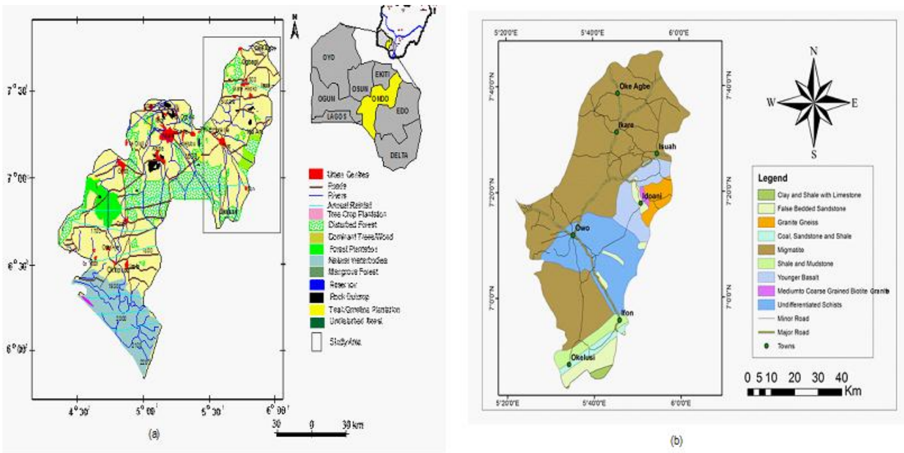

Figure3. *(a) Land Use Map of the Study Area showing predominant Teak/Gmelina Plantation and Disturbed Forest. Inset: Location of Ondo State on Nigeria Map (b) Local Geology Map of the Study Area with the Basement rocks occupying 90% of the area, while the sedimentary rocks/deposits occupy a little portion of the southern area (Modified After Geological Survey [20])*

2. Material and Methods

The scope of investigation of the study is divided into direct and indirect methods. The indirect methods include topographic map interpretation and the study of existing geological reports/map, and soil surveys. Direct methods comprised geologic field reconnaissance, including the examination of in-situ materials, man-made structures, etc. Borings/trial test pits from which representative disturbed / undisturbed samples of the in-situ materials at a depth not less than 3 m were obtained and analyzed for physical properties, such as compaction test, specific gravity, natural moisture content, grain size analysis, permeability test and porosity.

Prior before samples collection, information about some areas with serious erosion problem was obtained from the Ondo State Ministry of Land and Housing, and Ministry of Environment, Ondo State. The same erosion sites were identified by field visits. Soil samples collection sites were identified using the administrative map of the area and gridded (Fig 4). This was to ensure that soil samples that will give a fair representation of the soil type within the area were collected. Laboratory analysis of the soil samples were carried out in the Civil Engineering Geotechnical Laboratory and Engineering Geological Laboratory of the Federal University of Technology Akure, Ondo State. Standard laboratory procedures were followed for all the laboratory analyses. The subset topographical map, Aster DEM, Landsat EMT+ surface reflectance image of the study area were acquired and pre-processed for geometric correction, haze reduction and re-sampling.

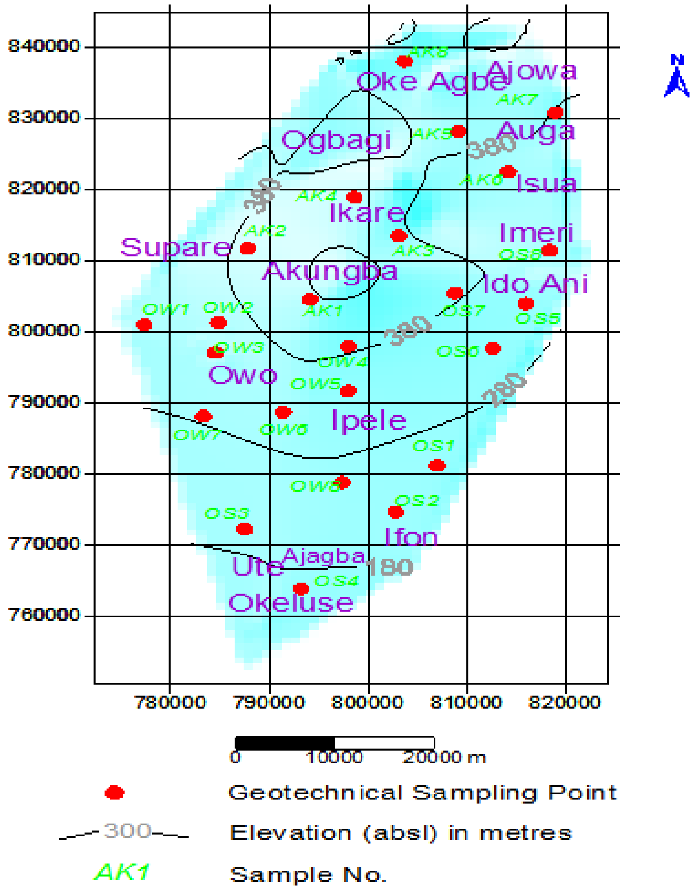

Figure4. *Base map for the Study showing the sampling points*

The following indices Erodibility Indices were determined using the relationships in Equations 1 to 4.

i. Dispersion Ratio (DR):

$$DR = \frac{\%\,silt + \%\,clay\ \ in\ undispersed\ \ soil}{\%\,silt + \%\,clay\ \ after\ \ dispersion\ \ in\ water} \tag{1}$$

ii. Modified Clay Ratio (MCR)

$$MCR = \frac{\%\,sand + \%\,silt\ soil}{\%\,clay + \%\,organic\ \ matter} \tag{2}$$

iii. Erosion Ratio (ER):

$$ER = \frac{Dispersion\ \ ratio}{Colloidal\ \ content} \times moisture\ equivalent\ ratio \tag{3}$$

iv. Erodibility Factor (K):

$$K\ (\%) = \frac{\%\,sand + \%\,silt\ soil}{\%\,clay} \times 100 \tag{4}$$

The predicted soil losses for the study area were done using the revised Universal Soil loss equation as given by Hudson [21] as;

$$A = 2.24RK \quad (5)$$

Where A = soil loss converted to tons/ha/yr.

R = Rainfall factor and given as 0.5H

H = Mean annual rainfall

The soil erodibility factor (K-factor) is a quantitative description of the inherent erodibility of a particular soil; it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff [22-23]. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion (e.g., infiltration rate, permeability, total water capacity, dispersion, rain splash, and abrasion) are the same. Texture is the principal factor affecting K, but structure, organic matter, and permeability also contribute.

3. Results and Discussion

The results of the soil tests are presented in Tables 1-2, while Figure 5 shows the Erodibility map of the study area. The result of the moisture content showed the soils generally have moderately low moisture content ranging from 4.3 - 17.4%; with sample AK-5 in Akoko area having the highest value, with migmatite as the parent rock. Low moisture content influences the cohesiveness between the soil particles hence making them easily dispersible by erosive agent such as water. The specific gravity of soil is a product of its structure, texture and compactness. It is an important physical property of soil. The specific gravity recorded for the soil samples ranges from 2.64 to 2.76. From Table 1, the grain size analysis shows % sand variation of 42.2 and 76.0; % clay content varies between 18.1 and 42.0; and % silt ranges from 10.1 and 32.1. Therefore the soil is generally sandy with little proportion of clay and silt (fines) serving as bonding materials. Since the presence of fine materials provide the required bonding between the soil particles, resulting in formation of more stable aggregate that are resistive to shearing force of flowing water thus making the soils less vulnerable to erosion [24]. However the % of fines increase or higher in Ose area (OS-samples). This suggests that very high force is required to detach and transport the soil particles therefore making them less susceptible to erosive agents.

Table1. *Summary of the Results of the Soil Tests*

Easting	Northing	Sample No.	M.C (%)	G.S.D			S.G	P (%)	Pr (%)	Compaction	
				% clay	% Sand	% silt				OMC (%)	MDD (Kg/m³)
772390	803105	OW 1	6.4	20.1	60.2	18.7	2.67	31	9.1×10^{-6}	15.3	1852
787531	793171	OW 2	8.3	21.0	53.5	22.3	2.69	30	9.5×10^{-6}	16.2	1816
784339	794652	OW 3	4.3	8.1	76.0	14.6	2.66	28	8.1×10^{-6}	11.9	1996
781649	799811	OW 4	5.4	10.2	73.7	14.0	2.68	29	8.4×10^{-6}	11.3	2019
784531	797215	OW 5	6.5	14.0	74.7	10.1	2.65	28	8.2×10^{-6}	10.4	2065
788427	794510	OW 6	6.4	15.4	65.9	17.4	2.64	29	8.1×10^{-6}	11.2	2035
793408	788385	OW 7	6.5	15.2	61.3	23.5	2.65	28	8.3×10^{-6}	18.6	1738
785689	799244	OW 8	7.6	20.0	59.8	19.0	2.64	30	8.9×10^{-6}	19.5	1703
806211	766533	OS 1	6.7	40.1	44.2	14.3	2.68	39	11.5×10^{-6}	25.9	1586
786129	750478	OS 2	11.3	41.2	42.2	13.4	2.68	41	11.3×10^{-6}	27.0	1549
788018	757534	OS 3	11.1	42.0	45.4	11.3	2.75	38	10.6×10^{-6}	27.5	1532
815697	808379	OS 4	12.4	33.5	46.1	19.3	2.76	35	10.6×10^{-6}	26.3	1572
815629	808313	OS 5	11.4	24.0	66.2	8.6	2.76	30	10.1×10^{-6}	19.0	1741
806467	816260	OS 6	12.2	38.0	50.6	10.1	2.76	37	10.3×10^{-6}	19.8	1711
824164	809340	OS 7	12.3	35.3	47.2	17.5	2.74	36	10.6×10^{-6}	18.8	1749
823627	809220	OS 8	14.4	38.8	45.9	14.1	2.74	40	11.1×10^{-6}	19.7	1715
797777	808035	AK 1	16.4	18.0	55.6	18.4	2.72	28	5.4×10^{-4}	14.2	1910
810810	839346	AK 2	12.2	14.2	64.7	18.0	2.73	25	5.1×10^{-4}	12.1	1988
820372	825640	AK 3	12.7	14.4	51.4	18.3	2.72	29	5.2×10^{-4}	15.0	1879
817238	844512	AK 4	9.3	13.0	70.9	15.0	2.73	28	5.1×10^{-4}	11.1	2027
821979	831501	AK 5	17.4	13.3	51.4	26.0	2.73	25	5.2×10^{-4}	16.0	1824
806618	836440	AK 6	16.2	14.2	49.7	32.0	2.70	26	5.2×10^{-4}	16.5	1804
803374	822628	AK 7	14.4	12.3	51.3	32.1	2.70	29	5.3×10^{-4}	14.8	1885
801898	826986	AK 8	8.2	13.1	68.7	15.1	2.69	28	4.9×10^{-4}	11.8	1988

G.S.D – Grain size analysis, M.C – Moisture content, S.G - Specific gravity, P – Porosity, Pr – Permeability (m/s), OMC – Optimum moisture content, MDD – Maximum Dry Density

The porosity of the soils varies from 25 % (Akoko area) to 41% (Ose area). Low porosity is an indication that the soil is dense and contains low volume of voids relative to the volume of solids. Clay sand (less porous) are the most predominant soil in the area and less cohesive which could make the m prone to erosive effect of water during storm in the area. The permeability of the soil samples is between 8.1×10^{-6} and 5.4×10^{-6} m/s. This is relatively low and in line with [25] classification. This is suggestive of soil with low pore pressure and agrees with [26] which opined that low permeability increases the shear strength of soil and consequently makes it less susceptible to erosion. This is in agreement with experimental studies by [27] that the shear strength of soil particles is closely related to erosion, that is, an increase in shear strength normally generates an increase in the critical shear stress for erosion and a decrease in erosion rate.

The compaction characteristics of the soil samples show an Optimum Moisture Content variation of 10.4 – 27.5% and Maximum Dry Density of 1532 – 2065 kg/m^3. All samples have moderately low OMC at high MDD. The results obtained from the calculation of the Dispersion ratio (DR), Modified Clay Ratio (MCR), Erosion Ratio (ER), Erodibility Factor (K), and predicted Soil Loss (A) are presented in Table 2. DR shows values ranging from 0.60 – 0.85 (Fig 9a). According to [28] soils having dispersion ratio greater than 0.15 are erodible in nature. Also [29] corroborated this view by reporting that susceptibility to erosion is significantly related to the dispersion ration. Consequently the soils in the area are prone to erosion.

Table2. *Calculated values of Erodibility indices and predicted Soil Loses*

Easting	Northing	Sample No.	DR	MCR	ER	K	A
772390	803105	OW 1	0.72	3.76	0.23	0.04	67
787531	793171	OW 2	0.81	3.45	0.27	0.04	72
784339	794652	OW 3	0.60	8.08	0.17	0.11	185
781649	799811	OW 4	0.71	7.83	0.19	0.10	168
784531	797215	OW 5	0.67	5.30	0.22	0.06	101
788427	794510	OW 6	0.77	4.92	0.25	0.05	84
793408	788385	OW 7	0.69	5.31	0.30	0.06	105
785689	799244	OW 8	0.78	3.75	0.33	0.04	65
806211	766533	OS 1	0.85	1.39	0.57	0.01	20
786129	750478	OS 2	0.84	1.33	0.47	0.01	21
788018	757534	OS 3	0.81	1.32	0.44	0.01	19
815697	808379	OS 4	0.82	1.88	0.51	0.02	41
815629	808313	OS 5	0.80	2.99	0.46	0.03	60
806467	816260	OS 6	0.81	1.56	0.55	0.02	42
824164	809340	OS 7	0.83	1.78	0.51	0.02	41
823627	809220	OS 8	0.79	1.56	0.57	0.02	41
797777	808035	AK 1	0.63	3.70	0.34	0.04	63
810810	839346	AK 2	0.56	5.18	0.33	0.06	94
820372	825640	AK 3	0.53	4.38	0.27	0.05	84
817238	844512	AK 4	0.62	6.14	0.29	0.07	117
821979	831501	AK 5	0.66	4.57	0.38	0.06	104
806618	836440	AK 6	0.64	4.81	0.35	0.06	107
803374	822628	AK 7	0.62	5.98	0.30	0.07	116
801898	826986	AK 8	0.59	5.99	0.24	0.07	113

Figure 5 shows a weak correlation coefficient of 0.4913 (49%) between A and DR. Figure 6a shows area with high DR to include Ido Ani, Imeri, Ifon, Isuada, etc., while moderately high values are widespread in Akungba, Irun, Oke Agbe and Ajowa.

The calculated erosion (ER) of the soil samples varies between 0.17 (OW-3) and 0.55 (OS-5). These values can be considered high compared to standard values given by [30] of less than 0.10. Hence the soils could be vulnerable to erosion. Figure 7 shows that dependence of soil loss on erosion dispersion is very high as the coefficient of correlation is 99%. Figure 6b shows spatial variation of erosion ratio, and the range of 0.26 – 0.36 shows high dominance, occupying 30% of the study area. The modified clay ratio ranges from 1.32 (OS3) to 8.08 (OW3). These values obtained are generally low indicating low clay content of the soils in the area. The graphical plot of Soil loss and MCR showed a positive relationship with high coefficient of correlation/dependence of 95% (Fig 8) and corroborates [1]. The MCR in the range of 3 – 5 occupied 60% of the study area while small closure of high MCR (greater than 7) is found in Owo (Fig 6c).

The calculated erodibility factor is shown in Table 2 and Figure 10b, as it ranges from 0.01 to 0.11. It can be observed that soils OW and AK soil samples have high Erodibility factor denoting soils taken from Owo and Akoko areas. This high erodibility factor could be attributed to low clay/silt content present in the soil which serves as binding material and strengthens inter-molecular forces which increases cohesion of soil particles and helps in resisting detachability of soil by erosion agents [1]. The predicted soil losses in the study area is presented in Table 2, shows that area having high erodibility factor (K) are also characterized

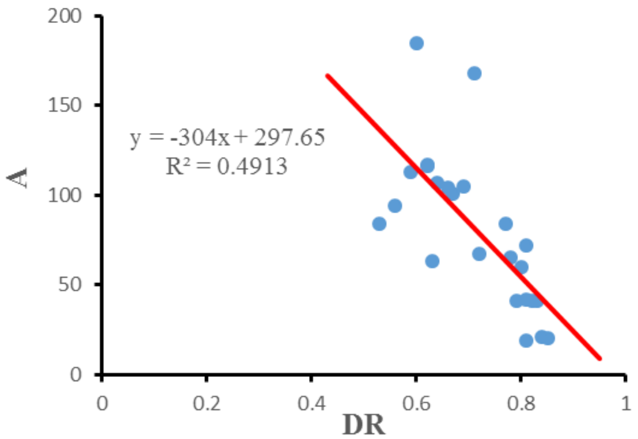

Figure5. *Relationship between Soil loss (A) and Dispersion Ratio showing a positive weak correlation coefficient*

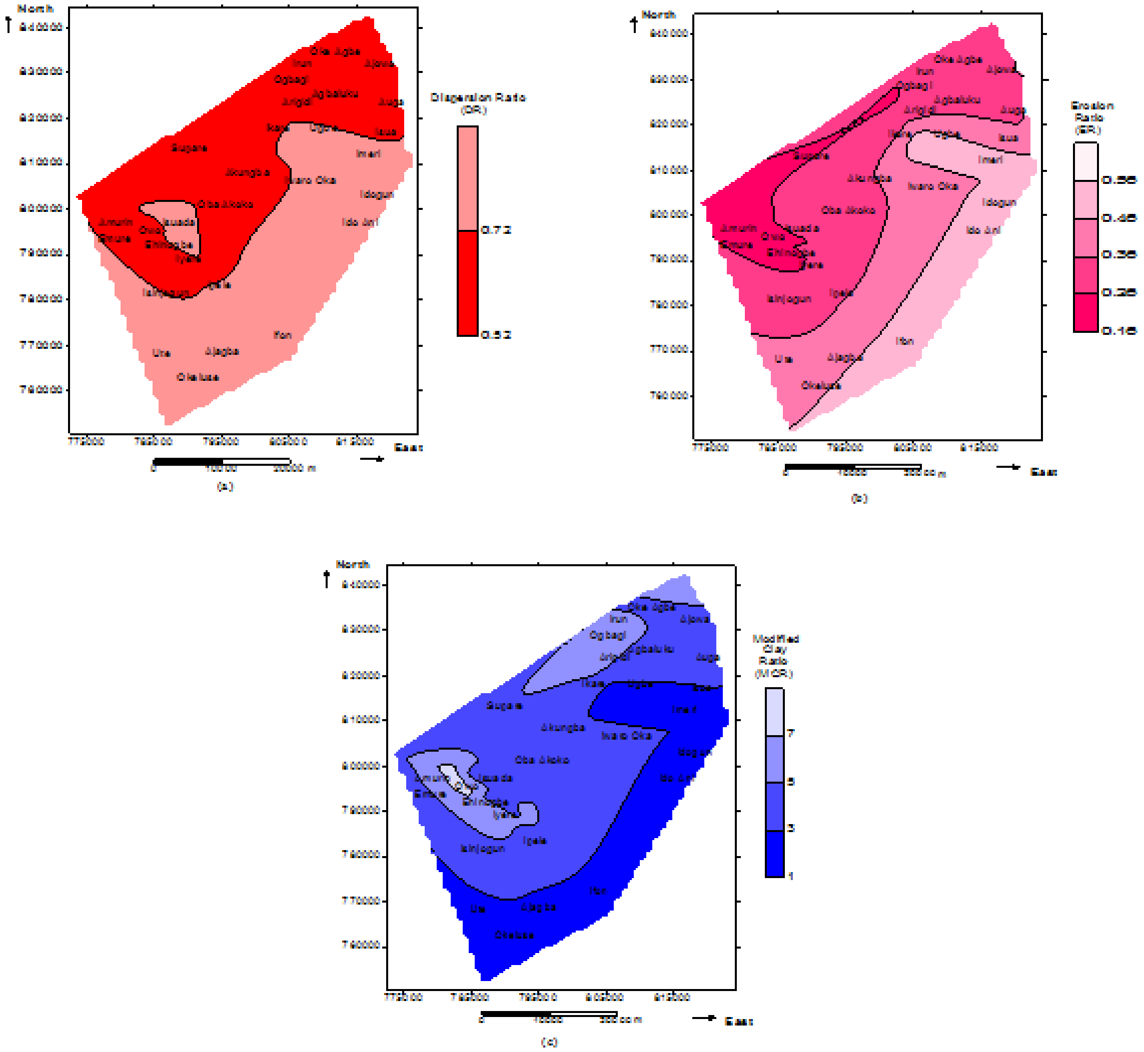

Figure6. *Spatial Variation of (a) Dispersion Ratio (DR) (b) Erosion Ratio (ER) (c) Modified Clay Ratio (MCR)*

By high soil loss (Fig 10). Therefore soils in Akoko and Owo areas have the highest values of A ranging from 63 to 185 tons/ha/yr, while Ose area have values between 19 to 60 tons/ha/yr (Fig 10a). This could be attributed to high amount of sand in the soil samples lacking cohesion. Consequently require little drag force to detach and transport it by the action of moving water. The Erodibility map classifies the soil in the area into different erosion potential zones as High (greater than 0.1), Moderate (0.05 – 0.1), and Low (0 – 0.05). The high Erodibility soil accounts for 2% occurring as a small closure in Owo, while moderate and low Erodibility as 68 % and 30 % respectively.

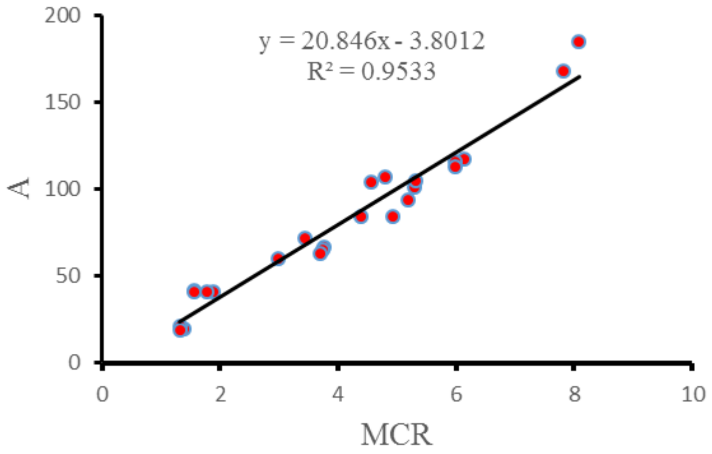

Figure7. *Relationship between Soil loss (A) and Modified Clay Ratio showing a positive strong relationship*

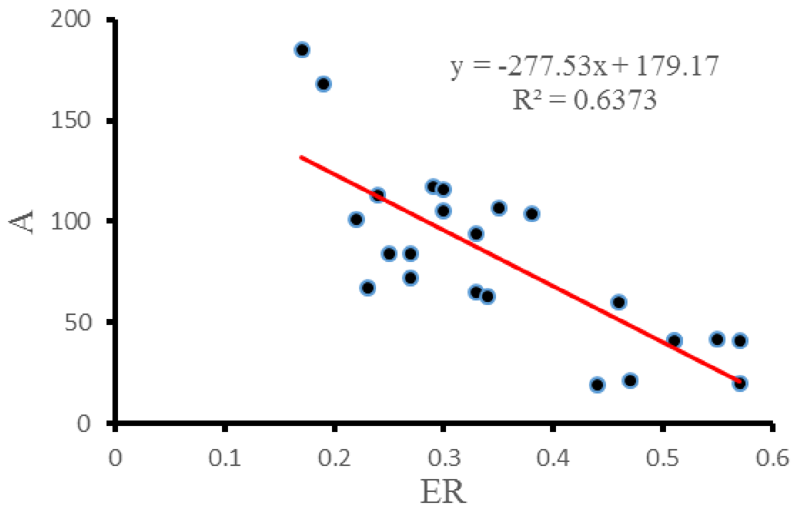

Figure8. *Relationship between Soil loss (A) and Erosion Ratio showing a strong positive correlation coefficient*

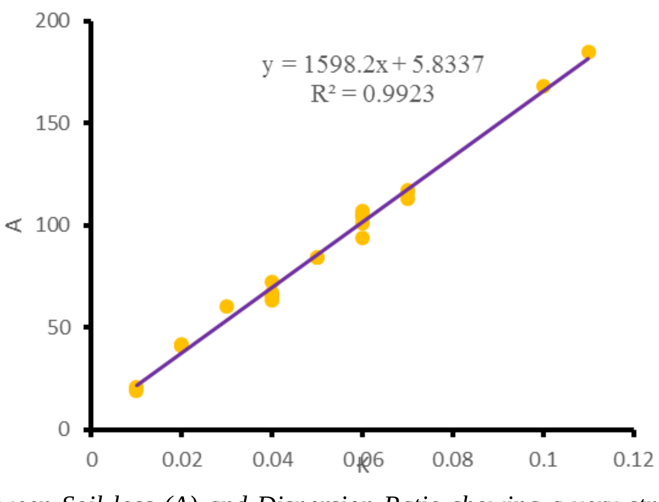

Figure9. *Relationship between Soil loss (A) and Dispersion Ratio showing a very strong positive correlation coefficient*

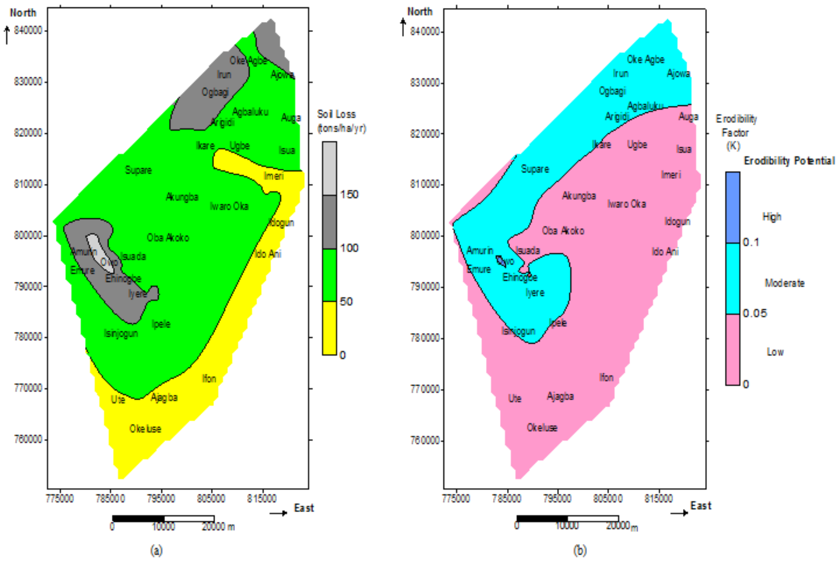

Figure10. *Spatial Variation of (a) Predicted Soil Loss (A) (b) Erodibility Factor (K)*

4. Conclusion

Erodibility potential of soils in northern part of Ondo State, Nigeria has been undertaken by critically determining the various soils properties in relation to their degree of influence on soil's susceptibility to erosion. Findings show that the soil are generally sandy with little proportion of clay and silt (fines) serving as binding materials; since the presence of fine materials provide the required bonding between the soil particles, resulting in formation of more stable aggregate that are resistive to shearing force of flowing water thus making the soils less vulnerable to erosion. The results obtained from the calculation of the dispersion ratio (DR) shows a weak correlation coefficient of 0.4913 (49%) with soil loss (A). The calculated erosion (ER) of the soil samples are high (greater than 0.10 max). The dependence of soil loss on erosion ratio is very high as the coefficient of correlation is 99%. The modified clay ratio ranges from 1.32 (OS3) to 8.08 (OW3). The erodibility map classifies the soil in the area into different erosion potential zones as High (greater than 0.1), Moderate (0.05 – 0.1), and Low (0 – 0.05). The calculated Erodibility factor ranges from 0.01 to 0.11 and OW and AK soil samples have high erodibility factor denoting soils taken from Owo and Akoko areas. The predicted soil losses map in the study area shows that area having high Erodibility factor (k) are also characterized by high soil loss. The high erodibility soil accounts for 2% occurring as a small closure in Owo, while moderate and low erodibility have 68 % and 30 % respectively.

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