Erodibility of Soils of the South West Benue State, Nigeria.

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ABSTRACT

Soil Erosion by water is a major threat to the social and economic lives of the people of the South-West Benue State, Nigeria. Data on the soils from this area which is necessary for the completion of the Universal Soil Loss Equation, soil erosion risk assessment, and design of conservation structures, is lacking. Soil samples from different parts of the South West Benue comprising Ogbadibo, Ohimini, and Okpokwu Local Government Areas were studied for their susceptibility to erosion.

Some soil properties and indices of erodibility were determined and an erodibility map was developed. Moisture content, porosity, shear strength, and clay content were low while permeability, specific gravity, and bulk density were high. Dispersion ratio and modified clay ratio were found to be averagely high while erosion ratio and water stable aggregates were low. Erodibility factor K was computed and found to range between 0.03 at Okpoga and Idobe to 0.32 at Orokam. Soil loss was also noticed to be highest at Orokam (65 t/ha/yr). A correlation analysis between soil loss and the indices of erodibility was carried out where it was observed that DR, MCR correlated positively with soil loss while negative correlation existed between soil loss with Erosion ratio and Water Stable Aggregates. Based on known standards and values of Erodibility factor (K) obtained Erodibility map of the South-West Benue State was developed.

(Keywords: erodibility factor, permeability, dispersion ratio, erosion ration, texture, infiltration)

INTRODUCTION

Soil has continued to be the most important agricultural input essential to the survival of man. The interactions of human activities with severe climatic factors have resulted in land degradation such as soil erosion. Soil degradation by flowing water is a severe problem and will remain so in the 21st Century especially in developing countries of the tropics and subtropics. Erosion is a natural geomorphic process occurring continually over the Earth's surface. However, the acceleration of this process through anthropogenic perturbation can have severe impacts on soil and environmental quality.

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 universal or natural occurrence wherever there is soil, and agents such as wind, water, and/or ice. It is also of universal importance as man's activities, directly or indirectly, depend on the soil. Our attitude towards it and our treatment of it determines our degree of success or failure in certain endeavors in life. Soil erosion thus constitutes a national hazard, which containment is a prerequisite to national development.

Soil erosion begins with detachment, which is caused by the break-down of aggregates by rain impact, shearing, or the drag force of water. 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 (Lal, 2001).

Soil erosion occurs when soil particles are carried by water or wind and deposited somewhere else (Relf, 2001). Soil erosion is a function of two opposing forces (i.e., the driving force of the erosion agent and the resisting force of the soil). Different soils respond differently to the identical kinetic energy of raindrops or the shear stress exerted by moving fluid. Their responses depend on their mechanical makeup and chemical composition. Because of differences in their inherent properties, soils exhibit different degrees of susceptibility (soil erodibility) to the forces generated by erosion agents. Susceptibility of soil to erosion is influenced by its physical, hydrological, chemical, biological, and bio-chemical properties as well as its profile characteristics. 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 (Bryan, 2000).

In many engineering settings, not only is the erodibility of the soil at the surface of interest but also the erodibility with depth. Earthen spillways are examples in which erosion exposes different materials with depth and erodibility of these materials is important in the performance of the spillway under concentrated flow conditions. Measuring erodibility directly is often difficult in most settings. Therefore development of measurable soil parameters that indicate erodibility is attractive.

Soil erodibility refers to the resistance of soil to detachment and transport of particles and aggregates. Erodibility is a function of soil texture, aggregate stability, shear strength, infiltration capacity, organic, and chemical contents (Morgan, 2001). The erodibility of soil as a material with greater or lesser degree of coherence is defined by its resistance to two energy sources: the impact of raindrops on the soil surface, and the shearing action of runoff between clods in grooves or rills. Hjulström, who carried out the first studies on the erodibility of materials, showed that there were three sectors, depending on water velocity and the diameter of soil particles. Analysis of the erosion sector shows that the diameter of the particles of the most fragile matter is about 100 microns, which is fine sand. With finer matter, cohesion develops simply as the surfaces of the clay rub together, while coarser clumps become increasingly heavy and therefore harder to transport. This kind of trial is concerned with resistance to the erosive force of river or runoff in a wet environment.

Bryan (2000), highlights the importance of the inherent resistance of soil to erosion processes. Results of his research showed that many components of erosion response, such as threshold hydraulic conditions for rill erosion, rill network configuration, and hilly slope sediment delivery, are strongly affected by spatially variable and temporally dynamic soil properties. Ogban (2005) studied soil properties in relation to gully erosion in Ogbadibo local Government Area of Benue State and concluded that the physical characteristics of the soil were stable and not significantly affected by the erosion action of the gully. Kahlon and Khera (2000) examined the spatial variability of erodibility of soil types based on a case study in India. The estimation of K factors from soil type can in general be problematic because soil classifications are often not based on parameters reflecting erodibility. Chouliaras (2000) reported classes of erodibility based on different values of erodibility factor (K) and nature of soils. Erodibility of various soils was classified as low, moderate, high and very high based on the range of erodibility factor.

MATERIALS AND METHODS

Study Area

Benue South-West is made up of Ohimini, Okpokwu, and Ogbadibo Local Government Areas with 95% of its populace comprising of Idoma-speaking people. Inhabitants of this area are mainly preoccupied with subsistence farming and trading. Crops like maize, yam, and cassava are the major crops grown, while palm oil is the main source of income. Oil palm fruits are processed into palm oil at commercial rates and palm wine is tapped from oil palm trees for commercial purposes too. Idekpa, Okpoga and Otukpa are the Headquarters of Ohimini, Okpokwu, and Ogbadibo Local Government Areas, respectively.

The area has a typical tropical climate, which is marked by two prominent seasons, rainy season (April – October) and dry season (November – March). This area is constituted of gently undulating hills with high altitudes. The sloppy nature increases the velocity of runoff in the area.
The study area (Ogbadibo, Ohimini, and Okpokwu Local Government Areas of Benue State) lies between latitude $6^{o}45'$ and $7^{o}15'$N and longitude $7^{o}30'$ and 8'00 E. The area has average annual temperature of 28^{0}C. The average relative humidity is highest in September and lowest in December or January with an average of 80%. The average annual rainfall in this area is 1650mm. The major soil type is sandy with red color. It is very firm and friable, weak sub-angular blocks. Camisole and regosol are also found in Otukpa with high percentage of sand-size particle.

The geology is predominantly of sedimentary formation, underlain by complex marine sediment shales, sandstone, siltstone and lateritic formation (Abah, 2000). The area is located within the Guinea savannah zone that is a mixture of both grasses and forest species.

Reconnaissance Survey, Site Selection, and Sample Collection

Information about some areas with serious erosion problem was obtained from the Soil Conservation Unit of Benue State Ministry of Water Resources and Environment, Makurdi. The same erosion sites were identified by field visits. Soil samples collection sites were identified using the administrative map of the area.

The local governments were each divided into 5 parts North, South, West, East and Central. This was to ensure that soil samples that will give a fair representation of the soil type within the area were collected. In collecting soil sample, a profile pit of area $1m^2$ and depth 1.7m was dug. 40kg of soil was collected and marked for identification.

Laboratory Analysis of Soil Samples

Laboratory analysis of the soil samples were carried out in the Civil Engineering Laboratory of the University of Agriculture, Makurdi. Standard laboratory procedures were followed for all the laboratory analyses.

Erodibility Indices: The indices of erodibility were determined using the relationships in Equations (1) – (4):

i. Dispersion Ratio (DR)

$$DR = \frac{\%silt + \%clay\ in\ undispersed\ soil}{\%silt + \%clay\ after\ dispersion\ in\ water} \quad \textbf{(1)}$$

ii. Modified Clay Ratio (MCR)

$$MCR = \frac{\%sand + \%silt\ soil}{\%clay + \%organic\ matter} \quad \textbf{(2)}$$

iii. Erosion Ratio (ER)

$$ER = \frac{Dispersion\ ratio}{Colloidal\ content} \times moisture\ equivalent\ ratio \quad \textbf{(3)}$$

Determination of Erodibility Factor and Predicted Soil Loss:

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

The predicted soil losses for the various areas was done using the Revised Universal Soil Loss (RUSLE) equation as given by Hudson (1995).

$$A = 2.24RK \quad \textbf{(5)}$$

where A = soil loss converted to tons/ha/yr by multiplying by 2.24.

R **=** Rainfall factor and given as 0.5H

H = Mean annual rainfall

K = Erodibility factor

Statistical Analysis of Erodibility Indices and Soil Loss

Regression and correlation analyses were carried out on Dispersion Ratio (DR), Modified Clay Ration (MCR), Erosion Ratio (ER) and Water Stable Aggregates (WSA). From the analyses, equations of the linear relationship between these variables and soil loss were derived and their correlation coefficients (R) determined.

RESULTS AND DISCUSSION

The results of the soil tests are presented in (Tables 1 – 3). Figures 1 – 4 show the graphical representations of the erodibility indices calculated while Figure (5) shows the erodibility map of the study area.

Soil Physical Properties

i. Moisture Content

Results of the moisture content test showed that most of the soils have low moisture content ranging from 3.5 - 18.4%; with Otukpa in Ogbadigbo L.G.A having the least (Table 1).

Table 1: Summary of Results of Soil Test.

S/N	A	B	C	D					E	F	G	H	I	J
				Sand (%)	Silt (%)	Clay (%)	MDD Kg/m³)	OMC (%)						
1	Adumoko	5.6	2.78	64	28	8	1.83	12.2	$5.8x10^{-3}$	6.1	1.99	7.20	Red	2.0
2	Otukpa	3.5	2.73	77	19	4	1.70	12.0	$5x10^{-3}$	12.1	1.81	5.10	Brown	5.10
3	Orokam	4.2	2.82	74	23	3	0.90	11.8	$1.2x10^{-2}$	36.1	2.0	5.05	Red	2.0
4	Idabi	4.0	2.83	68	28	4	1.79	11.4	$5.0x10^{-3}$	6.1	1.93	5.25	Brown	32
5	Owukpa	5.4	2.77	65	31	4	1.80	12.0	$5.0x10^{-3}$	6.1	1.78	5.17	Brown Red	20
6	Ugbokolo	6.6	2.66	62	27	11	1.78	14.9	$8.3x10^{-3}$	84.3	1.96	5.65	Dark Brown	7
7	Ajide	7.0	2.71	58	34	8	2.14	9.0	$5.5x10^{-3}$	71.0	2.26	5.90	Dark Brown	17
8	Idobe	6.3	2.81	36	42	22	1.80	14.6	$5.1x10^{-3}$	68.4	2.0	5.17	Red	28
9	Ichama	18.4	2.46	63	21	16	1.54	20.9	$4.4x10^{-3}$	185.1	1.78	5.85	Yellow	39
10	Okpoga	10.4	2.68	67	19	24	2.02	8.6	$5.0x10^{-3}$	12.0	2.14	5.50	Brown	8
11	Ochobo	4.1	2.46	43	37	20	1.88	17.4	$9x10^{-3}$	144.4	1.74	5.52	Yellow	40
12	Liami	4.2	2.86	64	29	7	2.01	11.4	$5.2x10^{-3}$	161.7	2.18	6.0	Brown	10
13	Awulewu	4.1	2.43	79	13	8	1.52	17.4	$3.4x10^{-3}$	144.4	1.70	6.10	Dark Brown	19
14	Ogwanoku	5.6	2.57	66	20	14	1.73	15.0	$8.9x10^{-3}$	65.8	1.93	6.45	Yellow	12
15	Onyagede	5.6	2.77	74	21	5	1.76	11.7	$9.0x10^{-3}$	167.5	1.90	5.95	Dark Brown	11

KEY: A=Sample Location, B=Miosture content (%), C=Specific gravity (g/cm³), D=Seive analysis, E= Permeability (cm/s), F=UCS (KN/m³), G=Bulk density (g/cm³), H=pH, I=Colour, J= Porosity (%)

Table 2: Calculated Values of Erodibility Indices.

S/No	Location	DR (%)	MCR (%)	ER(%)	WSA (%)
1	Adumoko	0.69	9.19	0.45	4
2	Otukpa	0.65	13.97	0.26	6
3	Orokam	0.68	14.96	0.32	2
4	Idabi	0.74	15.84	0.34	3
5	Owukpa	0.66	12.93	0.40	3
6	Ugbokolo	0.53	6.60	0.40	9
7	Ajide	0.52	8.68	0.40	7
8	Idobe	0.53	3.26	0.37	18
9	Ichama	0.56	4.06	1.16	12
10	Okpoga	0.62	3.10	0.72	15
11	Ochobo	0.52	3.46	0.34	16
12	Liami	0.66	9.04	0.32	6
13	Awulewu	0.62	9.34	0.29	6
14	Ogwanoku	0.70	5.42	0.29	8
15	Onyangede	0.61	13.98	0.29	4

Table 3: Erodibility Factor (K) of Locations and Predicted Soil Loses Using (Hudson, 1995).

S/No	Location	Erodibility factor (k)	Soil loss (tons/ha/yr)
1	Adumoko	0.18	37.01
2	Otukpa	0.24	49.55
3	Orokam	0.32	65.80
4	Idabi	0.24	49.35
5	Owukpa	0.24	49.35
6	Ugbokolo	0.08	16.45
7	Ajide	0.11	22.61
8	Idobe	0.03	6.17
9	Ichama	0.05	10.28
10	Okpoga	0.03	6.16
11	Ochobo	0.04	8.22
12	Liami	0.13	26.73
13	Awulewu	0.11	22.62
14	Ogwanoku	0.12	24.67
15	Onyangede	0.18	37.01

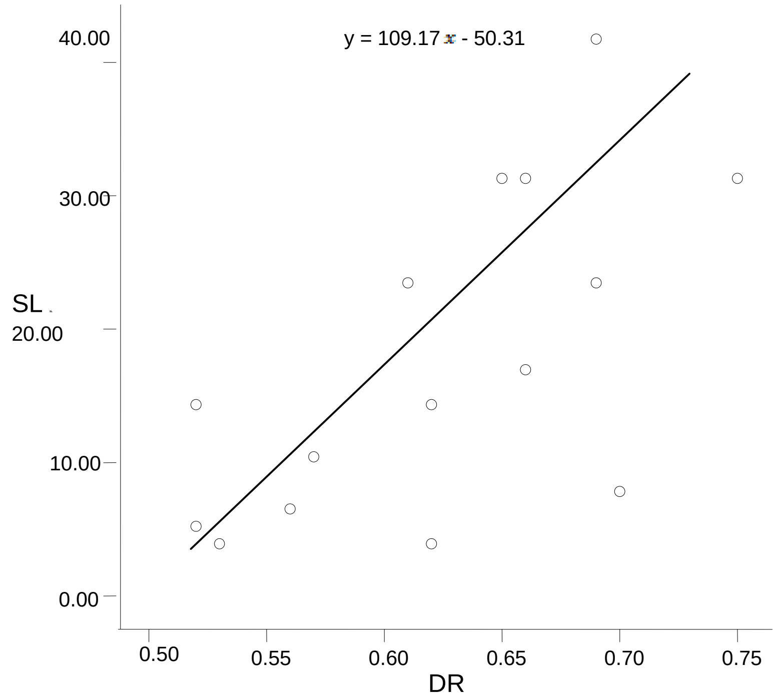

Figure 1: Relationship between Soil Loss (SL) and Dispersion Ratio (DR).

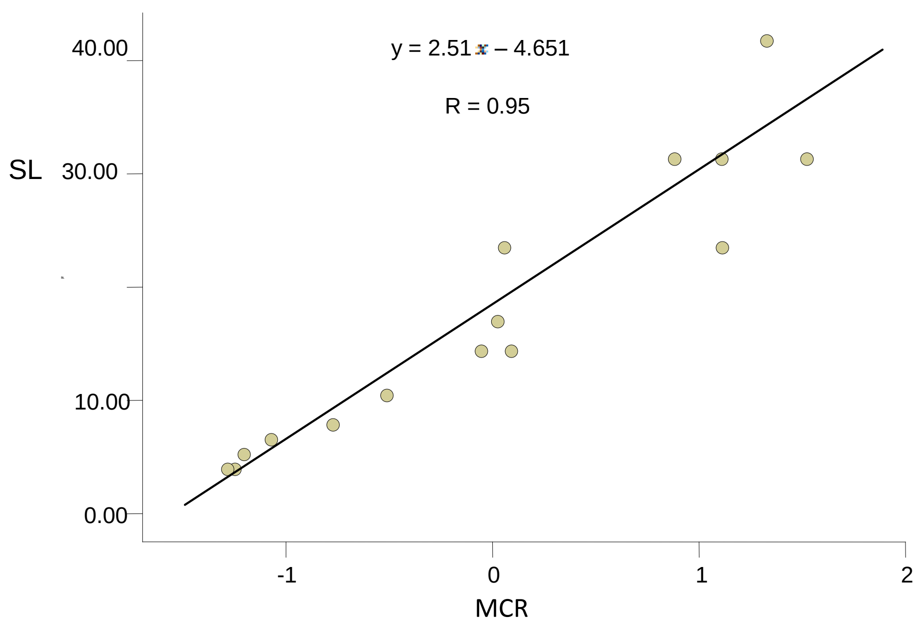

Figure 2: Relationship between Soil Loss (SL) with Modified Clay Ratio (MCR).

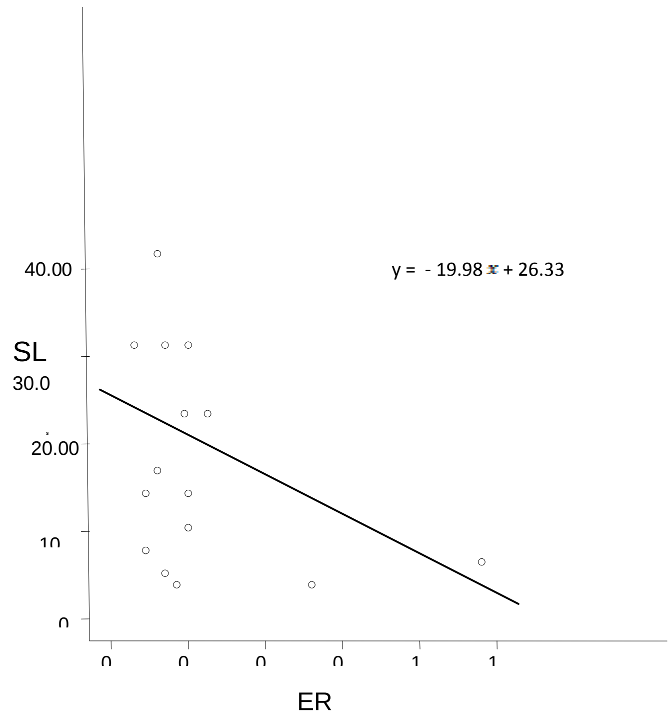

Figure 3: Relationship between Soil Loss (SL) and Erosion Ratio (ER).

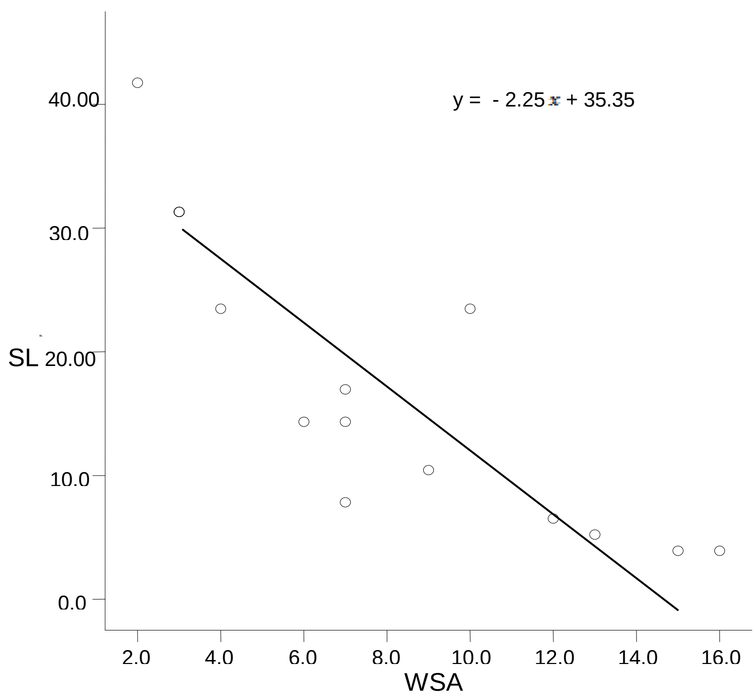

Figure 4: Relationship between Soil Loss (SL) and Water Stables Aggregates (WSA).

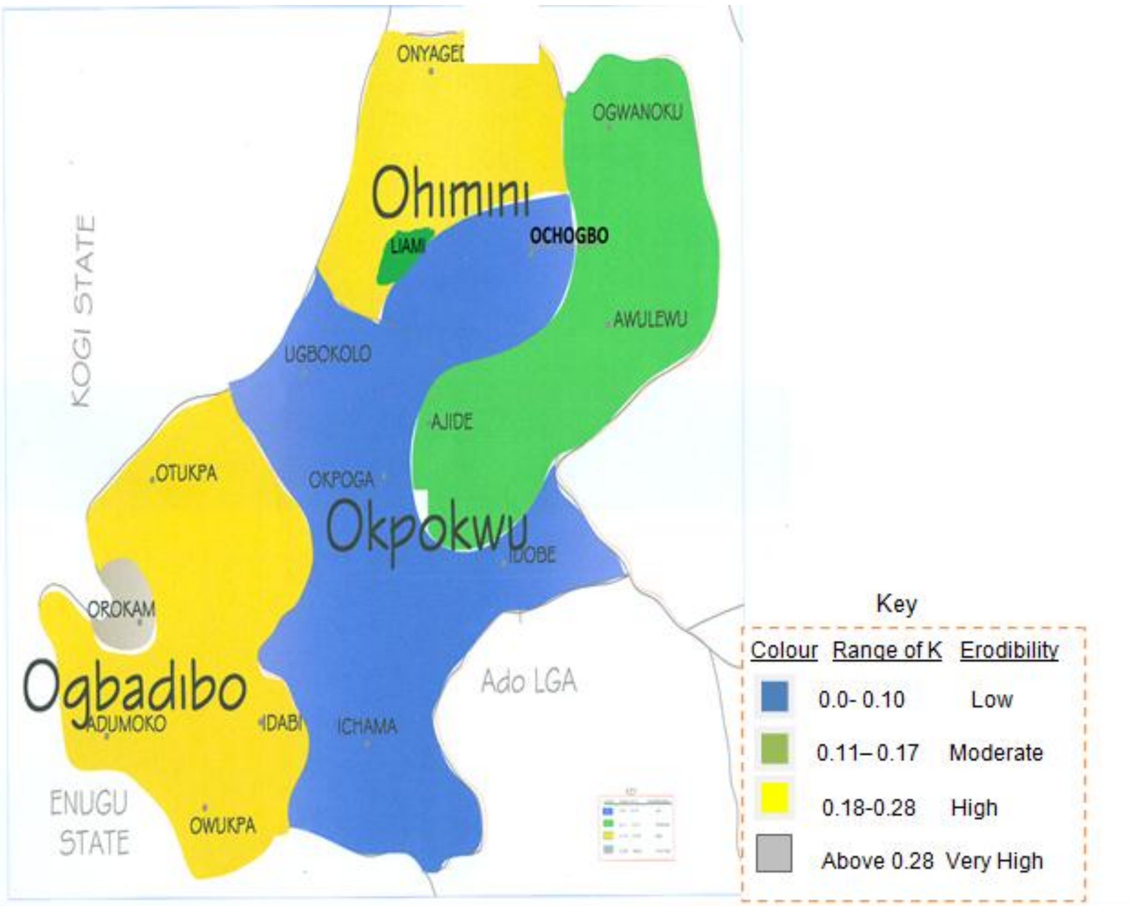

Figure 5: Erodibility Map of Soils of the SW Benue state (Ogbadigbo, Okpokwu and Ohimini).

The low moisture reduces the cohesiveness between the particles hence making them easily dispersible by erosive agents such as water, thus increasing its susceptibility to erosion. This result agrees with Andreassian, et al. (2004) who reported that a drier soil is generally more susceptible to wind and water erosion than a wet soil.

ii. Permeability

The permeability of the study area ranges from 0.0034 cm/s - 0.012cm/s (Table 1). This is relatively high according to Bell (1983) classification. This high rate of permeability suggests high pore-pressure and agrees with Manyatsi (1998) that high permeability reduces the shear strength of the soil and consequently makes the soil more susceptible to erosion.

iii. Porosity

The porosity of soils ranged from 2.0% to 40%. The highest porosity is observed in Ochobo (40%) and the lowest at Orokam (2.0%) (Table1). The soil samples from Adumoko, Orokam, Okpoga and Liami have porosity less that 10%. This low porosity is an indication that the soil is dense and contains low volume of voids relative to the volume of solids. Sandy soil which is mostly the predominant soil class of the area are more porous and less cohesive due to their divided individual soil particles. This lack of cohesion within the soil particles make them prone to the effect of erosive forces.

iv. Specific Gravity

The specific gravity of a soil is influenced by the structure, texture and compactness. It is an important soil physical property, considering its influence on the water holding capacity and hydraulic conductivity. This result could be as a result of the high organic matter present in the area where the soil sample was collected. This could have encouraged infiltration and reduced surface run-off and soil loss.

v. Particle Size

From Table 1, results from the particle size analysis indicate that most of the particles obtained from the study area belong to the category of fine sand and silt (0.2mm – 0.0002mm). This suggests that very little force is required to detach and transport the soil particles therefore making then more susceptible to erosion.

vi. Bulk Density

The bulk density ranged from 1.70 g/cm^3 – 2.26 g/cm^3 (Table 1). This is high compared to the average standard value of 1.33gm/cm^3 as given by Esu (1999) and agrees with Wyle and Ray (1999) that, where the bulk density is high, plant roots find it difficult to penetrate the soils, and this reduces infiltration and increases overland flow and results to erosion.

The high bulk density experienced in the study zone can be attributed to the long intense tillage of soils in the area which depletes soil organic matter and weakens soil structure thereby making it vulnerable to the forces of erosion.

vii. Shear Strength

It was observed that soils from Adumoko, Orokam, Otukpa, Idabi, and Owukpa areas have the least shear strength of 6.10kN/m^2, 4.10kN/m^2, 12.10KN/m^2, 6.10KN/m^2 and 6.10KN/m^2, respectively. The predicted soil loss were the highest in these areas. The low shear strength observed in these areas could be attributed to the looseness of the soil particles which have little or no aggregates capable of providing much resistance to the forces of erosion This agrees with experimental studies by Hong, et al. (2006) 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 the erosion rate.

viii. Clay Content

Most of the soil samples showed very little percentage of clay content with the highest being 24% and the lowest 3% (Table 1).

Since the presence of clay material provides the required bondage between the varying soil particles resulting to the formation of more stable aggregates which makes them less susceptible to erosion, the absence reduces the tendency of the soil particles to bind together and form aggregates that are resistible to the shearing force of flowing water thus making the soils vulnerable to soil erosion. This agrees with Parfitt, et al. (2000), who indicated that there was a positive correlation between aggregate stability and clay content of soils.

ix. Soil pH

pH values ranged from 5.05 - 7.85 with an average value of 5.8 (Table 1). This result indicates that the soils have low concentration of salts which can increase its risk of being erodible. For high silt soils, decreased pH increases erodibility probably due to the effect of surface crusting which can result to low infiltration and increase run off and consequently soil erosion. This agrees with studies carried out by Mehta, (1998) and Arulanandan, (2003) among others on the effect of salt concentration on erodibility of soils. Arulanandan (2003) concluded from erosion tests that the erodibility of soil decreases with increasing salt concentration.

Erodibility Indices

i. Dispersion Ratio (DR)

Results obtained from the calculation of the Dispersion Ratio (DR) showed values ranging from 0.52 to 0.74 with average value of 0.58. While the lowest value of 0.52 (Table 2) was found in soil samples from Ajide and Ochobo, the highest value of 0.74 was found from Idabi. According to Middleton (1930) soils having dispersion ratio greater than 0.15 are erodible in nature. In soils of eastern Nepal, Chakrabarti (1990) reported that susceptibility to erosion is significantly related to the dispersion ratio. This result therefore indicates that the soils from the study area are susceptible to erosion. From statistical analysis, dispersion ratio is positively related with soil loss showing coefficient of correlation (coefficient of dependence) of 65% (Figure 1).

ii. Modified Clay Ratio (MCR)

The Modified Clay Ratio (MCR) was found to range from 3.10 at Okpoga to 15.84 at Idabi respectively, with an average value of 8.92 (Table 2). These results are considered low when compared with values obtained from stable soils like loamy soils. Low values of MCR are an indication of the low clay content of the soils in the study area. The graphical plot of soil loss and MCR (figure 2) showed a positive relationship with a coefficient of correlation (high coefficient of dependence) of 95%.

iii. Erosion Ratio (ER)

The Erosion Ratio (ER) of the soil samples was calculated and found to range between 0.26 at Otukpa to 0.72 at Okpoga with an average of 0.36 (Table 2). These values can be considered as high compared to standard values given by Khera and Kahlon (2005) that soils having erosion ratio > 0.10 are erodible in nature. Figure 3 shows that dependence of soil loss on erosion dispersion is very low as the coefficient of dependence is 34% (Figure 3).

iv. Water Stable Aggregates (WSA)

Erosion by water and wind is also related to the number and stability of aggregates against abrasive effects of running water or blowing wind. Results obtained from the determination of water stable aggregates (soil aggregates > 2mm) showed that while the soil samples considered had as low as 2%, soil samples obtained from Idobe and Ochobo had the maximum 18% and16 % (Table 2) of water stable aggregates respectively. With this low value of WSA the resistance of soils from the study area is considerably reduced thus increasing their vulnerability to erosion. Figure 4 shows a very high negative coefficient of dependence of 85%. This shows that the higher the water stable aggregates the lower the resistance to erosive forces.

Determination of Erodibility Factor (K)

From Table 3, it can be observed that the soils in Orokam are most erodible having erodibility factor (K) of value of 0.32. The least predicted losses were found in soils at Idobe and Okpoga with both having K values of 0.03, respectively. This low erodibility factor value could be attributed to the more clay content present in the soils which has provided higher binding and inter binding forces which increases cohesion of soil particles and helps in resisting detachability of soil by water.

Erosion Prediction

From the results of the predicted soil losses in the various communities under the study area (Table 3) and using the standard erodibility indices as given by Chouliaras (2000), Orokam having the highest value of K factor has the highest predicted soil losses of 65 tons/ha/yr.

This could be as a result of the highly silty nature of the soils from this area, and silty soils are known to lack cohesion as their particles are loose therefore require little drag force to be transported by the force of moving water.

These results agree with findings of Chouliaras (2000) that most erodible soils are silts and fine grain sands. High erodibility of silty soils is due to small size and weight of the grains and to their low (in some cases almost zero) cohesion, since grain surface is not electrically charged. As a consequence, sandy and silty grains are easily detached and transported by overland flood.

Soil Erodibility Mapping

The erodibility map (Figure 5) of the South-West Benue was produced based on the estimated values of the soil erodibility factor K and the corresponding soil losses which were determined based on the Revised Universal Soil Loss Equation (RUSLE).

From the erodibility map, it can be observed that Orokam which has the highest Erodibility factor K has the highest predicted soil loss of 65 tons/ha/yr. The area made up of Ochobo, Ugbokolo, Okpoga, Ichama and Idobe with K factor ranging from 0.0- 0.10 has low erodibility. Moderate susceptibility of soils to erosion is noticed on the map for areas like Ajide, Awulewu and Ogwanoku. While Onyagede, Otukpa, Adumoko, Idabi and Owukpa with K factor values ranging from 0.18 – 0.28 are observed to be highly prone to erosion.

Generally the South-West Area of Benue State erosion problem is basically socio-economic and ecological in nature. The socio-economic factors that greatly influence human activities detrimental to soil resources in the area include among others poverty and ignorance. The ecological factors that affect soil erosion are physical and biological. The interaction of these physical and biological factors determined by the state of the soil play important role in dictating the degree and extent of soil erosion.

CONCLUSION

This study has looked at the various soil properties in relation to their degree of influence on soil's susceptibility to erosion and concludes that:

(i) Most of the soil samples were predominantly of sand and silt making the soil to be classified as silty sand soil;

(ii) Permeability results showed that the soils were highly permeable, making them vulnerable to shear stress of water;

(iii) The shear strength of the soil samples in some of the areas was averagely low. This suggests that the resistance of the soils from these areas was also low. Results of the moisture content and clay content were also found to be low which also is an indication that the soil is dry and loose, has little or no binding properties to make the soil particles cohesive and less vulnerable to the forces of erosion;

(iv) Dispersion Ratio (DR), Modified Clay Ratio (MCR) and Erosion Ratio (ER) were high , while Water Stable Aggregates (WSA) which can offer resistance to the shearing force of water was low suggesting that soils from the study area are vulnerable to erosion (with various degree of susceptibility);

(v) Erodibility factor (K) results and annual soil losses in this areas where predicted showed that Orokam, have the highest value of erodibility factor (K) of (0.32) and the highest predicted soil loss of (65 ton/ha/yr) while areas like Okpoga, Ochobo and Idobe had the lowest (K) values and lowest predicted soil loses too;

(vi) A strong positive correlation was found to exist between soil loss, Dispersion Ratio, Modified Clay Ratio, while a negative correlation existed between soil loss, ER and WSA;

(vii) The high correlation coefficient noted between MCR, DR, WSA and soil loss appears to indicate that MCR, DR, and WSA are better indices of soil erodibility;

(viii) An erodibility map made up of four classes was drawn showing low, medium, high and very high classes in terms of susceptibility to erosion. It thus implies that some of the areas are highly vulnerable to erosion, while some moderately vulnerable with some having little tendency to be eroded;

(ix) It was suggested that control measures be put in place in areas that are highly susceptible to erosion to avoid more soil losses and further development of gullies;

(x) Deforestation should be discouraged in this area as removing this natural soil cover which also provides organic matter and cohesion of soil particles leaves the soil more exposed to agents of erosion.

REFERENCES

1. Abah, B.S. 2000. "Investigation of Soil Erodibility Factor K for Okpokwu L.G.A.". Unpublished project thesis. Soil Sc. Dept. Uni-Agri, Makurdi, Nigeria.

2. Andreassian, C.K., C.R. Panabrokke, and J.P. Quirk. 2004. "Effect of Initial Water Content on Stability of Soil Aggregates in Water". *Soil Sc*. 83: 185-195.

3. Arulanandan, K. 2003. "Fundamental Aspects of Erosion of Cohesive Soil". *J. Hydr, Div ASCE*. 101 (5): 635-639.

4. Bryan, R.B. 1981. "Predicting Soil Losses due to Street and Rill Erosion". In: *FAO Conservation Guide*. FAO: Rome, Italy. 1:121 -149.

5. Bryan, R.B. 2000. "The Concept of Soil Erodibility and some problems of Assessment and Application". *Catena*.16:393-412.

6. Chakrabarti, D.C. 1990. “Investment on Erodibility and Water Stable Aggregates of Certain Soils of Eastern Nepal”. *J. Indian Soc. Soil Sci.* 17:465 470.

7. Chouliaras, I.G. 2000. “Erosion by Water: Study of the Erodibility of Cohesive Soil”. Ph.D. Thesis. A. Stotle University of Thessaloniki, Finland.

8. Hong, D.I., G.B. Miao, and D.S. Deng. 2005. “Relation of Starting Shear Stress and Physical and Mechanical Indexes of Cohesive Undisturbed Soil”. *Adv. Water Sci* (in Chinese). 17(b):774-779.

9. Hudson, N.W. 1995. *Soil Conservation. 3rd Ed.* Iowa State University Press: Ames, IA,.

10. Kahlon, M.S. and K.L. Khera. 2000. “Evaluation of Soil Erodibility in Relation to Soil Physical Properties”. *Journal of Indian Society of Soil Science.* 48:205 -206.

11. Lal, R. 2001. “Soil Degradation by Erosion”. *Land Degradation and Development*.12:519-539.

12. Manyatsi, A.M. 1998. *Soil Erosion and Control Training Manual*. Environmental Consulting Services: Mbabane, Swaziland. 1-13.

13. Morgan, R.P. 2001. “A Simple Approach to Soil Loss Prediction: A Revised Morgan-Finney Model”. *Catena*. 44(4):305-322.

14. Ogban, B.U. 2005. “Soil Properties in Relation to Gully Erosion in Ogbadibo local Government Area of Benue State, Nigeria”. Unpublished M.Eng. Thesis. Agriculture & Environmental Engineering Department. University of Agriculture, Makurdi, Nigeria.

15. Relf, D. 2001. “Reducing Erosion and Runoff”. Virginia Cooperative Extension Publication No. 426-722. Virginia Polytechnic Institute and State University. Blacksburg, VA.

16. Wyle and Ray. 1999. “Interrelationships between Soil Structure/Texture, Soil Biota/Soil Organic Matter and Crop Production”. *Geoderma*. 57:3-30 (151).

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SUGGESTED CITATION

Isikwue, M.O., C. Abutu, and S.B. Onoja. 2012. “Erodibility of Soils of the South West Benue State, Nigeria”. *Pacific Journal of Science and Technology*. 13(2):437-447.

Pacific Journal of Science and Technology