Journal of Forestry Research and Management. Vol. 18(1).141-150; 2021, ISSN 0189-8418

www.jfrm.org.ng

EVALUATION OF SOIL PHYSICAL PROPERTIES IN RELATION TO TOPOGRAPHY ON AN AGRARIAN LANDSCAPE

Ayodele Owonubi[a], Ezekiel Oiganji[b] and Maram Julius Isaiah[b]

[a] Forestry Research Institute of Nigeria; Federal College of Forestry, Jos; Department of Horticulture and Landscape Technology

[b] Department of Crop Science, Faculty of Agriculture, University of Jos, Nigeria

ABSTRACT

Variation in topographic characteristics across the landscape can significantly affect soil physical properties. The objective of the study is to assess the physical properties of soils of the study area with respect to topography with the view to estimate their productivity. The study area was stratified based on slope position. Soil samples were collected at random from each slope class at depths of 0 – 15, 15 – 30 and 30 – 45cm. Soil samples were analyzed in the laboratory using standard procedures. The findings show that soil depth across the entire landscape were shallow (15 to 50cm).Mean color development equivalent and Hurst index values were within the range 10 to 54 and 15 to 22.5 respectively, indicating that these soils have undergone low development and are therefore considered young soils. Bulk density of the soils were within the range 1.43-1.87 g/cm^3.Soils of the study area have high inherent susceptibility to erosion. Values for potential erosion risk are very high and range from 88 to 444 tons/hectare/year and as such adequate conservation practices are required to curtail soil erosion. Also, soil productivity indices ranged from moderate to high (0.19-0.46).However, variation in soil properties with respect to topography seemed to have been obscured by intense agricultural activities ongoing in the area which has resulted in a great deal of anthropogenic-pedoturbation. The soils of the study area are however classified as Entisols with respect to data from soil depth.

Keywords: physical properties, topography, agrarian, productivity, erosion

Introduction

A good knowledge of soil physical properties as it relates to topography is essential for good land evaluation, which is a prerequisite for sound land use planning and the design of appropriate soil conservation measures especially on agrarian landscapes. Soil properties have been reported to change systematically with respect to topography (Norton *et al*, 2003). Topography affects drainage, runoff, soil erosion, deposition, thermal regime of the soil, as the direction of slope influence the amount and intensity of solar radiation which is absorbed by the soil (Brady and Weil, 1999). Consequently, topography influences infiltration rates and degree of evapo-transpiration by modifying the soil moisture content and consequently influencing the yield plant litter and production and decomposition. Agbenin and Tiessen (1995) studied a toposequence of soils derived from syenetic rocks and observed that total P increased with decreasing particle size and decreased down slope while Ca-bound phosphate decreased down slope in all particle size fractions. Norton et. al. (2003) in a study observed that the relatively large aerial extent of back slopes suggests that dynamic erosion and deposition are important factors in the

Journal of Forestry Research and Management. Vol. 18(1).141-150; 2021, ISSN 0189-8418
www.jfrm.org.ng

development of soils on the landscape. It was noted that surface disturbance in the form of erosion and deposition mixes, sorts, and transports soils and forest litter downslope.

Physical properties in most cases affects the productivity of soils for crop production within a given lithology and climate condition.Many soil physical properties change with changes in topography due to erosional and depositional processes. The improvements in soil's physical properties have been noted to lead to yield improvement (Brady and Weil, 1999). However, no soil studies have been performed on the selected area of study. Hence, the objectives are to evaluate soil physical characteristics with respect to topography of the study area. Understanding the influence of topography on physical properties of the soil will help to predict the behaviors of soils, identify their best uses, estimate their productivity provide baseline for further research and for extending and extrapolating research results.

Materials and Method

Field Work

The study area was stratified based on slope position with the aid of 90m resolution Shuttle Radar Topography Mission (SRTM)elevation data. This was facilitated with the aid of Geographic Information System software. The slope position classes are as shown in Figure 1.Soil samples were collected from each slope strata at depth of 0 – 15cm, 15 – 30cm and 30 – 45cm. A total number of 57 composite samples were collected with the aid of soil auger. Hand trowel was used for collecting surface clods or aggregates for laboratory analysis.

Laboratory Analysis

Soil samples were air-dried in the laboratory, crushed with porcelain pestle and mortar and sieved to remove material greater than 2mm (gravel and other coarse fragments). Percentage gravel with reference to total soil was calculated. Particle size analysis was determined by dispersing soil samples in 5% calgon (sodium hexametaphosphate) solution by shaking on a reciprocating shaker. The particle size distribution was determined by the hydrometer method as described by Gee and Bauder (1986).Bulk density was determined using the clod method, particle density determined by the graduated cylinder method and water holding capacity was determined as described by Estefan *et al*(2013).Aggregate stability was conducted using water drop test as described by (Mbagwu and Bazzoffi, 1995) whereas, geometric mean weight diameter and soil erodibility was determined using the procedure of van der Knijff*et al* (200). Soil color and consistence were described using procedures in the guidelines for soil description (FAO, 2006). Consequently,air-dried and moist soil consistencies were rated from 1 to 6, whereas wet consistency was rated from 1 to 4.Furthermore, the classification for color indices as presented in Table 1 was used to rate the degree of soil development.Potential soil erosion risk (Ap) and productivity indix (PI) was assessed with equation 1 and 2 respectively (van der Knijff*et al* (2000) and Delgado (2003)):

$$Ap = R*K*LS \quad (1)$$

$$PI = \sum_{i=1}^{n}(Ai \ x \ Bi \ x \ Ci \ x \ Ki) \quad (2)$$

Where: R = Rainfall erosivity factor (MJ.mm/ha.h.y), K = Soil erodibility factor (t.ha.h/MJ.mm), LS = Topographic factor. Also, A = conditions that regulate the air-water relations of horizon i, B = conditions that determine mechanical resistances (impedances) to the croproot exploration in horizon i, C = conditions that regulate the potential fertility of horizon i, K = evaluates the relative importance of horizon i in the soil profile. Data from laboratory analysis was analyzed using one-way analysis of variance.

Table 1: Classification for color indices

Class	Color Development Equivalent (CDE)	Hurst Index (HI)
Very Low	< 10	> 22.5
Low	10-54	15-22.5
Moderate	54-108	7.5-15
High	> 108	< 7.5

Source: adapted from Schaetzl and Thompson (2015)

Results and Discussion

The Environment of study

A terrain characteristic of the study area is presented in Figure 1 and 2. The study area is located within the Jos metropolis at the Experimental farm of the Faculty of Agriculture, University of Jos. The elevation of the study area ranges from 1120 to 1087m above sea level with a relative elevation range of 23m. On the other hand, the topographic factor ranges from 5.9 to 2.1 with a mean of 2.9. Consequently, the influence of topography on erosional processes is low to moderate. Furthermore, soils of the area have developed from granite gneiss. The area has a tropical continental climate. Average annual rainfall over the study area is 1260mm (Olowolafe, 2002). Consequently rainfall erosivity (Yu and Rosewell, 1996) was calculated as 4737.44 (MJ.mm/ha.h.y) which is rated as very high.

The predominant land use activities in the study area are farming. The crops grown are; grains (Maize, Rice, Cowpea, sorghum, groundnut, soybeans, Barbara nut and sesame), vegetables (Lettuce, Carrot, Cabbage, spinach and tomatoes), root crops (Cocoyam) and tuber crops (Sweet potato and Cassava). The cropping systems adopted in cultivating these crops are mono-cropping and mixed cropping while farming systems adopted is continuous cropping. The types of mixed cropping used by some farmers are alternate mixed cropping and ley cropping system. Perennials crops such as Banana, Pawpaw and Moringa are also planted. As farmers are harvesting crops that have attained physiological maturity, farms are cleared in preparation for the next growing season. Nurseries raised for semi dry season farming are Cabbage, tomatoes, pepper. River Dilimi is the only source of irrigation water and it is to the North of the study area. About two to three cropping cycles takes place on farmlands adjacent to the river.

Journal of Forestry Research and Management. Vol. 18(1).141-150; 2021, ISSN 0189-8418

www.jfrm.org.ng

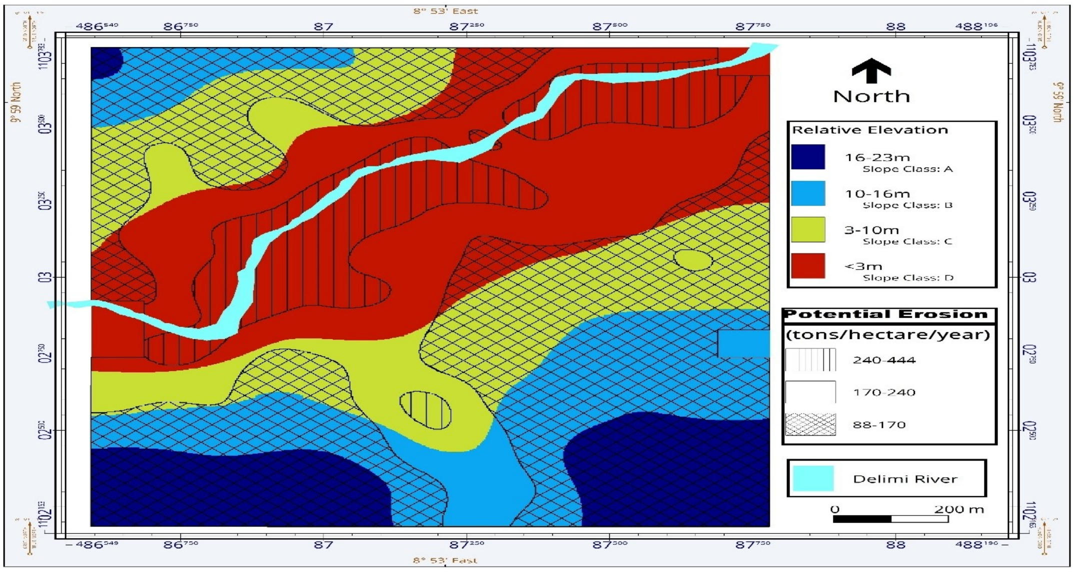

Figure 1: Elevation and erosion characteristics of the study area

Particle Size Distribution and Color Indices

The color characteristics of soils have been used as a valuable tool to study soil development (Schaetzl and Thompson, 2015) Hence, color indices used to evaluate soil development in this study are presented in Table 2 and 3. There were no significant differences in color indices across soil depth and slope positions ($p > 0.05$). However, mean CDE and HI values were within the range 10 to 54 and 15 to 22.5 respectively, indicating that these soils have undergone low development and are therefore considered young soils. This is further underscored by depth of soil in the area which range from 15 to 50cm. Soil are coarse in texture especially within 0 to 15cm depth. This is not unlikely as soils of the study area has developed from granite gneiss (Directorate of Overseas Surveys, 1977). Gitas *et al* (2009) has associated the development of coarse soil textures with similar geology. There were generally no significant differences in sand and silt fractions across soil depth and slope positions. However significant difference ($p < 0.05$) was observed in the distribution of clay fractions across soil depths. Consequently, clay content increased with increase in depth. This is most likely due to increased weathering at deeper depths. Furthermore, clay content seemed to influence water holding capacity of soils in the study area. Hence, water holding capacity increased with increase in soil depth; and also increase from upper slope to lower slope positions.

Soil Consistence

The distribution of soil consistence was similar across slope positions as was observed for soil texture. However, there was significant difference in consistencies across soil depths. Consequently, air dried consistency for 0 - 15, 15 - 30 and 30 - 45cm depths were slightly hard, hard and very hard in consistency respectively. Similar trends were observed for moist consistency. Moist consistency at depths of 15 to 45cm were firm and indicates that some restriction to root growth may be experienced by plants at these soil depths. Furthermore, for wet consistency, stickiness and plasticity increased with increase in soil depth.

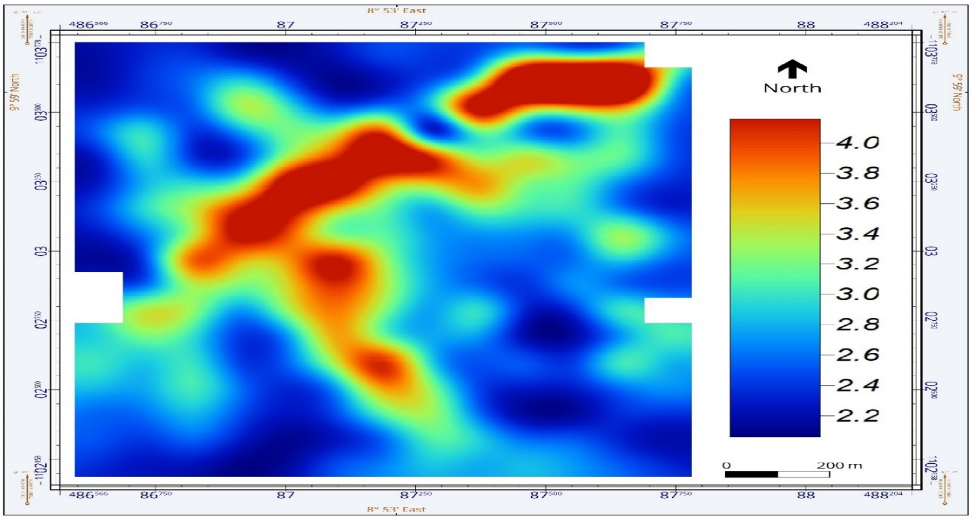

Figure 2: Topographic factor (LS) over the study area

Soil Density and Stability

Soil particle density generally ranged from 2.4 to 2.6 g/cm^3 and is an indication that the soils have undergone substantial weathering with respect to the parent material (Brady and Weil, 1999). Soil bulk density values(Table 4)in surface soils are within normal range ideal for plant growth for these soil types. Consequently, porosity of the soils is high. The soils are however highly susceptible to erosion as observed by their very high erodibility (>0.04) and very low macro aggregate stability values (3 to 14 J/g). Aggregate stability affects several aspects of soil physical behavior, such as infiltration rate, crusting and susceptibility to erosion. Aggregate stability values obtained in this study were low and in addition, much lower than that recorded by Mbagwu and Bazzoffi (1995) for Italian soils. This further underscores the susceptibility of these soils to erosion. Consequently, appropriate management practices are required to protect the soil from erosion.

Table 2: Soil properties across soil depths of the study area

Variable	soil depth (cm)	Mean	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Sand (%)	0-15	81a	78	85	0.0001
	15-30	78a	74	81	
	30-45	70b	65	74	
Silt (%)	0-15	13a	10	16	0.505
	15-30	13a	10	16	
	30-45	14a	10	17	
Clay (%)	0-15	6b	4	9	0.009
	15-30	9ab	7	12	
	30-45	17a	14	20	
Gravel (%)	0-15	33a	23	43	0.013
	15-30	40a	30	50	

	30-45	21b	9	33	
Water Holding capacity (ml/L)	0-15	4.59ab	4.301	4.886	0.033
	15-30	4.87a	4.578	5.163	
	30-45	4.795b	4.435	5.154	
Particle Density (g/cm^3)	0-15	2.444a	2.336	2.552	0.022
	15-30	2.435a	2.327	2.543	
	30-45	2.424b	2.292	2.557	
Geometric mean weight diameter (mm)	0-15	.440a	.373	.507	0.201
	15-30	.369a	.302	.436	
	30-45	.216a	.134	.298	

Table 2 (continued): Soil properties across soil depths of the study area

Variable	soil depth (cm)	Mean	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Color Development Equivalent (wet)	0-15	16a	13	18	0.576
	15-30	18a	15	21	
	30-45	22a	18	25	
HURST INDEX (wet)	0-15	17a	13	21	0.943
	15-30	17a	13	21	
	30-45	16a	11	21	
Consistency (air dry)	0-15	3c	2	4	0.0001
	15-30	4b	4	5	
	30-45	5a	4	6	
Consistency (moist)	0-15	3b	2	4	0.020
	15-30	4ab	3	4	
	30-45	4a	4	5	
Wet Consistency (stickiness)	0-15	2a	1	2	0.001
	15-30	3b	2	3	
	30-45	3c	3	4	
Wet Consistency (Plasticity)	0-15	2b	1	2	0.007
	15-30	2ab	2	3	
	30-45	3a	2	4	

Soil Erosion and Productivity

Soil erosion is a major phenomenon affecting productivity of soils especially in tropical climates. A recent study conducted by Thapa and Yila (2010) showed that nearly 90 percent of farmers on the Jos Plateau acknowledged that their farmlands are undergoing soil erosion, despite an array of land management practices they have adopted. In the study area sheet and rill erosion are prevalent although observations by Olowolafe and Nyagba (1999) in volcanic areas of the Jos Plateau indicated that rills are more prominent on the escarpments and upper foot slopes; sheet erosion is wide spread over the entire terrain whereas gully erosion was observed in areas of massive laterites and occasionally along the boundaries between volcanic and non-volcanic soils.

Journal of Forestry Research and Management. Vol. 18(1).141-150; 2021, ISSN 0189-8418

www.jfrm.org.ng

Table 3: Soil properties across slope positions of the study area

Dependent Variable	slope Position Class	Mean	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Sand (%)	A	74.761bc	70.755	78.767	0.009
	B	80.086a	77.213	82.959	
	C	78.967ab	75.166	82.767	
	D	70.967c	64.760	77.173	
Silt (%)	A	13.286a	9.909	16.662	0.743
	B	12.038a	9.616	14.460	
	C	10.450a	7.246	13.654	
	D	16.833a	11.602	22.065	
Clay (%)	A	11.759a	9.027	14.491	0.492
	B	7.829a	5.869	9.788	
	C	10.583a	7.992	13.175	
	D	12.200a	7.968	16.432	
Gravel (%)	A	18.125b	6.925	29.325	0.0001
	B	30.095b	22.063	38.127	
	C	52.700a	42.075	63.325	
	D	24.950b	7.599	42.301	
Water Holding capacity (ml/L)	A	4.617a	4.283	4.950	0.390
	B	4.795a	4.556	5.034	
	C	4.533a	4.217	4.849	
	D	5.067a	4.550	5.583	
Particle Density (g/cm^3)	A	2.543a	2.420	2.666	0.110
	B	2.499a	2.411	2.588	
	C	2.381a	2.264	2.498	
	D	2.315a	2.124	2.505	
Geometric mean weight diameter (mm)	A	.296a	.220	.372	0.812
	B	.404a	.349	.458	
	C	.369a	.296	.441	
	D	.298a	.180	.416	

Potential soil erosion risk estimated in this study is presented in Figure 1. Values for potential erosion risk are very high and range from 88 to 444 tons/hectare/year. This underscores the need to engage appropriate management practices to conserve the soils against losses to erosion. The current productivity status of soils of the study area is presented in Table 5. The class range from moderate to high. However, this may decline over time if concert efforts are not directed into appropriate conservation measures.

Table 3 (continued): Soil properties across slope positions of the study area

Variable	Slope Position Class	Mean	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Color Development Equivalent	A	18a	15	21	0.758
	B	19a	16	21	

	C	17a	14	20	
	D	20a	15	25	
HURST INDEX	A	17a	13	21	0.132
	B	15a	12	18	
	C	21a	17	25	
	D	14a	7	21	
Consistency (air dry)	A	5a	4	6	0.035
	B	4b	3	4	
	C	3b	3	4	
	D	5ab	4	6	
Consistency (moist)	A	4a	3	5	0.271
	B	3a	3	4	
	C	3a	3	4	
	D	4a	3	5	
Wet Consistency (stickiness)	A	3a	2	3	0.185
	B	3a	2	3	
	C	2a	2	3	
	D	3a	2	4	
Wet Consistency (plasticity)	A	3a	2	3	0.098
	B	2a	2	2	
	C	2a	1	2	
	D	3a	2	4	

Table 4: Soil compaction and macro aggregate stability indices of surface soil (0 – 15cm) across slope positions of the study area

Dependent Variable	Relative elevation (m)	Mean	95% Confidence Interval		P value
			Lower Bound	Upper Bound	
Bulk Density (g/cm^3)	A	1.483	1.377	1.588	0.778
	B	1.510	1.435	1.584	
	C	1.657	1.528	1.786	
	D	1.430	1.248	1.612	
Porosity (%)	A	43.173	35.852	50.494	0.725
	B	40.963	35.787	46.140	
	C	31.560	22.594	40.526	
	D	42.800	30.120	55.480	
Kinetic Energy (J/g)	A	11.671	9.407	13.935	0.245
	B	11.780	10.179	13.381	
	C	12.000	9.227	14.773	
	D	7.331	3.410	11.252	
K factor	A	0.01156	0.01139	0.01174	0.532
	B	0.01032	0.00860	0.01204	
	C	0.01125	0.00707	0.01544	
	D	0.01317	-0.04057	0.06692	

Table 5: Soil Productivity Index for the Study area

Slope Class	Depth	Structure	Clay (%)	Sub-factor A	Gravel (%)	Bulk Density	Sub-factor B	Sub-factor C*	Sub-factor K	PI
A	0-15	Weak	5.2	0.95	23	1.48	0.95	0.95	0.15	0.13

	15-30	Weak	11.7	0.89	25	1.65	0.90	1.00	0.25	0.20
	30-45	Weak	14.0	0.85	5	1.81	0.82	1.00	0.15	0.10
									High:	0.46
B	0-15	Weak	4.0	0.96	28	1.51	0.95	0.95	0.15	0.13
	15-30	Weak	8.8	0.91	33	1.66	0.70	1.00	0.25	0.16
	30-45	Weak	10.7	0.9	29	1.85	0.80	1.00	0.15	0.11
						1.86			High:	0.40
C	0-15	Weak	7.6	0.93	50	1.66	0.45	0.95	0.15	0.06
	15-30	Weak	7.8	0.93	69	1.6	0.25	1.00	0.25	0.06
	30-45	Weak	16.4	0.85	39	1.88	0.60	1.00	0.15	0.08
									Moderate:	0.19
D	0-15	Weak	7.7	0.93	32	1.43	0.70	0.95	0.15	0.09
	15-30	Weak	8.1	0.92	33	1.61	0.70	1.00	0.25	0.16
	30-45	Weak	10.4	0.9	5	1.87	0.80	1.00	0.15	0.11
									High:	0.36

*adapted from Owonubi and George (2019).

Conclusion

Soil physical properties studied in this research showed no significant variation with respect to slope position. This is most likely as a result of ongoing intense agricultural activities in the area which might have obscured the effect of topographical factors on the soil properties. However, there were significant variation in soil properties with respect to soil depth across slope positions. The soils in the study area are therefore classified as Entisols with respect to data from soil depth. Soils of the study area have high inherent susceptibility to erosion and as such adequate conservation practices are required to curtail soil erosion. Such conservation measures should include conservation tillage. This is more so as the plow layer has a friable consistency when moist.

Reference

Agbenin, J. O. and Tiessen, H. (1995). Soil properties and their variations on two contiguous hillslopes in Northeast Brazil. Catena 24: 147-161.

Brady, N. C. and Weil, R. R. (1999). The Nature and Properties of soils. 12th edition. Prentice-Hall, Inc. New Jersey. Pp 1 – 850.

Delgado, F. (2003). Soil Physical Properties on Venezuelan Steep Lands: Applications to Soil Conservation Planning. CDIAT, University of Los Andes, Merida, Venezuela. LNS0418011. pp 95 - 110

Directorate of Overseas Surveys. (1977). Jos Plateau (lands Systems). Published for the Nigerian Government by the British Government's Ministry of Overseas Development (Land Resouces Division). Map 1.

Estefan, G Sommer, R., and John, R. (2013). Methods of soil, plant, and water analysis: A manual for the west Asia and north Africa region. (3rd edition). International Center for Agricultural Research in the Dry Areas (ICARDA), Beirut.Pp 26 – 135.

FAO. (2006). Guidelines for soil description. FAO (Food and Agriculture Organisation), Rome. Pp 21 – 82.

Gitas, I. Z. Douros, K. Minakou, C, Silleos, G. N. andKarydas, C. G. (2009). Multi-Temporal Soil Erosion Risk Assessment in N. Chalkidiki using a Modified USLE Raster Model. EARSeLeProceedings 8 (1), 40 – 52.

Gee, G. W. and Bauder, J. W. (1986). Particle size analysis. In: A. Klute (Ed) Methods of soil analysis (part 1): physical and mineralogical methods. Agronomy Monograph no. 9 (second edition). Pp 1-2000

Norton, J. B., Sandor, J. A. and White, C. S. (2003). Hillslope soils and organic matter dynamics within a native American Agroecosystem on the Colorado Plateau. Soil Sci. Soc. Am. J. 67: 225-234.

Mbagwu, J. S. C. and Bazzoffi, P.(1995). Predicting the water-drop energy required to breakdown dry soil aggregates. International Atomic Energy Agency and United Nations Educational Scientific and Cultural Organization. IC/95/49, pp 1-16.

Olowolafe, E. A. (2002). Soil parent materials and soil properties in two separate catchment areas on the Jos Plateau, Nigeria.GeoJournal 56, 201-212. 15.

Owonubi, A, and Vincent Agbo George. 2019. Assessment of Soil Salinity under Irrigation Farming Along the Delimi River of the Jos Plateau. International Journal of Recent Innovations in Academic Research Volume-3, Issue-8, August-2019: 108-113.

Schaetzl, R. J., and Thompson, M. L. (2015). Soils: genesis and geomorphology. Cambridge University Press, New York.Pp 1 – 700.

Van der Knijff, J. M., Jones, J. A., andMontanarella, L. (2000). Erosion Risk Assessment in Europe. European Soil Bureau, European Commission; Joint Research Centre, Eoropean Commission; Space Research Centre. Pp 1 – 31.

Yu, B. andRosewell, C. J. (1996). A robust estimator of the R-factor for the universal soil loss equation. Transactions of the ASAE, 39 (2): 559-561.