Prediction of Soil Erosion of Imo State Soils by Their Infiltration Rates

Gregory C. Obiechefu[1], Precious N. Egbuikwem[2], Kodak U. Emerson[3*]

[1,2]*Lecturer, Department of Agricultural and Bio-Environmental Engineering, Imo State Polytechnic, Umuagwo, Owerri, Nigeria*

[2]*Researcher, Department of Civil Engineering, Surrey University, United Kingdom*

[3]*Researcher, Department of Civil Engineering and Geosciences, Newcastle University, United Kingdom*

*Corresponding author: kemerson@hotmail.co.uk

***Abstract*: The soil erosion and infiltration rates/capacities of five different soil groups in Imo State Nigeria namely: Rhodic ferrasols, Eutric nitosols, Lithosols, Eutric gleysols and Dystric ferrasols were investigated / measured. The final infiltration rates of these soils after prolonged wetting were determined. The amount of soil erosion from these soil groups under known rainfall intensities and runoff rates were also measured. Some soil physical properties of the soils (bulk density, porosity, permeability and grain size distribution) were also measured. The infiltration capacities of the soil groups and the amount of soil erosion from the soil groups were compared. The infiltration rates from these five soil groups ranged from 132mm/hr to 820mm/hr for the Rhodic ferrasols, while that of Eutric nitosols ranged from 5.64mm/hr to 450mm/hr. The infiltration rates for the Dystric ferrasols ranged from 82.8 mm/hr to 192mm/hr. The infiltration rates for the Lithosols ranged from 43.2 mm/hr to 180mm/hr. The range for the Eutric gleysols was from 46mm/hr to 276mm/hr. The erosion from the soils (sediment concentration) were in the average of 150g/l, 280g/l, 750g/l, 1008g/l, and 1250g/l for the Rhodic ferrasols, Eutric nitosols, Lithosols, Eutric gleysols and Dystric ferrasols respectively. From this study, the soils of Imo State with higher infiltration capacities had lower soil erosion. Therefore, the infiltration capacities of these soils may be used to assess or predict the erosion rates of Imo State soils.**

***Keywords*: Erosion, Dystric, Eutric, Infiltration rates, Lithosols. nitosols, Sediment concentration.**

1. Introduction

Soil erosion is a natural process of soil material removal and transportation through the action of erosive agents such as water, wind, glacier, gravity, and human disturbance [1]. The problem of soil erosion has really aided in the declining quality of arable land for production of food crops for human consumption and export, thus preventing guaranteed food security in the country. Erosion affects the soil adversely. Some of the negative impact of soil erosion includes: loss of soil structure, nutrient degradation and soil salinity. It also leads to pollution and sedimentation in streams and rivers, clogging these waterways and causing declines in fishes and other aquatic species.

Erosion (particularly by water) is a serious problem in Imo State Nigeria and indeed all over the world. Rills dissect arable lands. Flooding contributes its own quota. Lives and properties are lost and remedial measures are very costly. However, this menace has to be solved. To be able to do this, [2] stated that all erosion sub-processes (splash, sheet, overland flow, inter-rill, rill, gullies, stream bank, etc), including factors affecting erosion (e.g. infiltration, soil types, soil erodibility, soil shear strength, rainfall erosivity, soil erodibility, etc.) have to be adequately delineated, understood and impact of each sub-process integrated, including the appropriate application of various erosion models to predict or determine the total soil erosion on a landscape or watershed area.

If soil erosion in agricultural land is unchecked, it could lead to loss in productivity through loss of land and nutrients. That ultimately have an economic consequence - the soil will not be able to provide good crop yield, which in turn will lead to poor yield, food scarcity and hunger.

The above mentioned problems caused by erosion can be reduced by increasing the rate of infiltration. Infiltration is the downwards entry of water into the soil, and has been recognized as an important factor that affects soil erosion.

A measure of infiltration rate is usually determined in the field by flooding areas or basins of furrows or measuring water entry into the soil by using cylinder infiltrometer. Infiltration is affected by diverse factors which include: rainfall, rainfall intensity, runoff, temperature, soil type, soil structure, soil compaction, soil slope, soil moisture condition (including antecedent soil moisture conditions), cultivation practices, surface cover, etc. Increased or high infiltration rate is assumed to decrease erosion by the increase of the volume of water into the soil and by so doing increase the time before overland flow process kicks in.

The objectives of this study are to carry out infiltration and soil erosion tests in order to determine how infiltration rates affect soil erosion rates of selected Imo State soils, to determine the impact of rainfall intensity and infiltration rates on the erosion / erosion rates of some Imo State soils, and to determine the soil group of Imo State with the highest erosion rate.

2. Infiltration Models

Infiltration models have been developed for many soils and locations / regions so that they can be easily used to obtain quick values of infiltration rates of soils for those locations when urgent erosion control, conservation works or irrigation projects designs are needed to be developed. It is important to know the infiltration model that fits a soil or particular location so that the value can be used immediately for erosion control design or irrigation development projects without the need to embark on fresh field studies to determine the infiltration capacity of the soil where the control measure is intended to be carried out. This saves time.

Some of the more popular infiltration models include:

A. Horton equation

The Horton's equation (1940) [10] is expressed as:

$f = fc + (fo - fc)\, e^{-kt}$ (1)

where f = infiltration rate or capacity (L/T) at time, t,

fc = final steady state infiltration rate or capacity at large times (L/T)

fo = initial infiltration rate or capacity at t = 0

k = Horton's constant, **-** a constant for a given soil and initial condition (1/T).

It represents the rate of decease of infiltration rate / capacity.

t = time in hrs.

For this equation, the infiltration rate is measured in mm/hr.

2.1 Kostiakov Equation

The Kostiakov (1932) [11] equation is expressed as:

$f = at^b$ (2)

where f = cumulative depth of infiltration at time, t, a and b are constants. The constants are measured or obtained from infiltration data and have no particular physical meaning.

A Modified Kostiakov 's equation is given as:

$f = at^b + C$ (3)

where f = cumulative infiltration at any time a, b, and C are constants depending on soil type

t = time in minutes

B. Green – Ampt equation

The Green-Ampt (1911) [7] equation was developed by applying the Darcy equation (see equation 6 below) to the wetted soil zone and assuming vertical flow, uniform water content, and uniform soil hydraulic conductivity (near saturation) and given as:-

$F = K_e.t = F - N_s.\ln(1 + F/N_s)$ (4)

where F = cumulative infiltration depth (L)

K_e = effective hydraulic conductivity (L/T)

t = time (T)

N_s = effective matric potential (L).

$N_s = (\eta_e - \Theta).\ \psi$ (5)

Where Θ = soil water content (L^3/L^3), η_e is effective porosity (L^3/L^3)and ψ is matric potential (L).

Darcy's equation used is:

$(q = A.K.(\partial h/\partial s) = A.K.(\Delta h/L)$ (6)

where q is flow rate L^3/T, A is cross-sectional area of the soil through which water is flowing (L^2), K is saturated hydraulic conductivity of the flow medium (L/T) $\partial h/\partial s$ is hydraulic gradient (L/L) in the flow direction s, and Δh is total change in pressure head or potential causing flow for a distance L). Hydraulic conductivity is determined from field or laboratory measurements.

The parameters of the Green and Ampt model (effective porosity, capillary potential, and hydraulic conductivity) can be estimated from readily measured soil properties, using equations developed by [3], [4].

C. Philip equation

The Philip's equation (1957) [12] is given as:

$f = St^{0.5} + At$ (7)

where f = depth of infiltration or cumulative infiltration

t = time of infiltration

S = a Sorptivity term ($L/T^{1/2}$) and

A = a conductivity term (L/T)

D. Holtan equation

The Holtan's equation (1961) [8] is given as:

$F = a(S_t - F)^n + f_c$ (8)

where F = cumulative infiltration or infiltration rate in mm/hr,

S_t = storage potential of the soil above the impending strata (i.e. total porosity minus the antecedent soil moisture in units of length (L).

a and n = constants dependent on soil type, surface and cropping conditions.

n = 1.4 (Holtan and Creitz, 1967) [9]

fc = final infiltration rate or capacity.

The use of F instead of t as the independent variable offers advantage in watershed hydrology simulations.

3. Soils of Imo State, Nigeria

Imo State, Nigeria is located approximately at latitude 5° 18 12.60 N and longitude 6° 56 26.39 E, and at altitude of 211m above mean sea level. Soils of Imo State are classified according to [5] as Acrisols, Lithosols Ferrasols, Nitosols etc. But for the sake of this project, we will be looking at the following soils: Rhodic ferrasols, Eutric nitosols, Lithosol, Eutric gleysols and Dystric ferrasols.

Rhodic Ferrasols are ferrasols of the warm tropical regions which have no acrylic property and they are mainly formed on basin rocks such as basalt, diorites, and are found in Ideato North, Ideato South and Ngor Okpala area of Imo State, while Eutric Nitosol are nitosols with a base saturation of 50% or more, meaning that calcium, magnesium and potassium are relatively abundant. They are formed on almost flat to sloping terrain in the highland. They undergo moderate leaching. Nitosols are part of Alfisols which is formed in semi-arid to

International Journal of Research in Engineering, Science and Management
Volume-3, Issue-6, June-2020
www.ijresm.com | ISSN (Online): 2581-5792

humid areas, typically under a hardwood forest cover. They are mostly found in Umuna-Orlu, Imo State.

Lithosol are group of shallow soil lacking a well-defined horizon, especially on entisols consisting of partially weathered rock fragments usually on steep slopes. They are also called skeletal soil. They are mostly found in very steep, mountainous region where erodible materials are so rapidly removed by erosion that a permanent covering of deep soil cannot establish itself. The flora typically supported on them is generally of very poor nutritive value for grazing, while Eutric gleysols are gleysols of a histic H horizon. They are always drained or saturated with groundwater. They are greenish-blue grey in color. They occur in a wide range of unconsolidated materials, mainly fluvial marine with basic to acidic mineralogy. They are found in depression areas and low landscape position with shallow groundwater. On exposure, as the iron in the soil oxidizes and color changes to reddish yellow or orange patches. They are found in Umuna-Orlu in Imo State. Dystric ferrasol are ferrasols having a phithite within 125cm of the surface. They are mostly found in Umuagwo – Ohaji in Imo State. Soils with base saturation of 50% or more tends to have erosion problems. For these types of soils infiltration capacity needs to be improved.

4. Materials and Methods

A. Soil physical properties and infiltration test

The soil physical properties of bulk density, textural classification, porosity, permeability, moisture content at start and finish of infiltration tests of the soil groups were measured and as well compared with [6].

The infiltration data were collected by running insitu infiltration tests in specified locations of the five soil groups of Imo State using the double ring infiltrometer. The infiltration data collected were fitted to some infiltration models and the coefficient of determination R2 obtained.

B. Erosion tests

In order to measure the erosion of the different soil groups of Imo State, soil samples were collected from the different locations (Umuagwo, Umuna, Ideato North, Ngor Okpala) where the infiltration tests were conducted. The samples were placed in respective soil erosion rigs with length of 1.5m, width of 0.6m and depth of 0.2m. Figure1 is a photo of the erosion rig. The soils were prepared in the box and compacted to the insitu bulk densities and moisture conditions when the infiltration tests were conducted. The rigs were slanted at an angle of 20 slope so that water can easily flow without additional pressure added to it. 20 slope was chosen because this is the threshold slope at which rills begin to form on landscapes from literature [2].

The prepared soils in the 4 different rigs were exposed to the same rainfall event (rainfall intensity) at the same time. Three different rainfall intensities of 92mm/hr, 73.5mm/hr and 68mm/hr were used to monitor soil erosion of the four soil groups. The rainfall intensities of the rainfall events were measured using rain gauges installed by the side of the soil rigs.

Fig. 1. Setup of the erosion rigs for the erosion investigation

C. Soil loss and sediment collection and separation

The erosion rig has an outlet where eroded soil and sediment was collected from. The water collected was further separated by decanting using funnel and filter to get the actual soil that was eroded. The erosion boxes were surrounded with splash boards to collect splash loss. The separated soil was weighed and dried to determine the weight of the soil that was eroded by splash as well as by rainfall and runoff. These experiments were conducted for all the four (4) soils with similar rainfall intensities to monitor the soil loss from each soil group under the same rain condition (same rainfall intensity). The soil loss (erosion rate), runoff volume and splash losses were measured after each rainfall events.

5. Results and Discussions

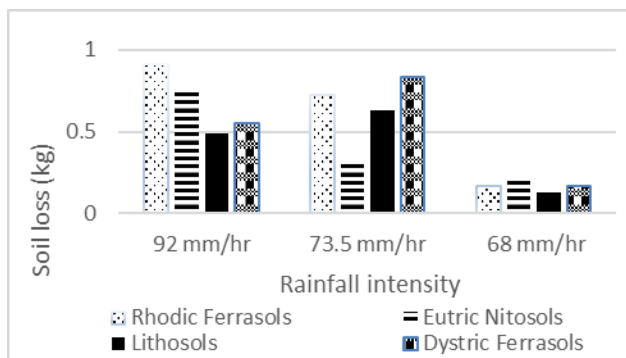

Fig. 2. Soil loss for varying rainfall intensities for various soil types

The results of soil physical properties - soil type, particle size distribution, bulk density, permeability and infiltration rates of the soil groups are shown in Table 1, while the result of soil loss corresponding to various rainfall intensities for the various soil groups is shown in Figure 2. After the experiments the data collected were analysed for infiltration, infiltration model fitting, erosion loss, splash loss, sediment and volumetric sediment discharge at the outlet. The average final infiltration rates ranged from 43.2 to 132 mm/hr; while the infiltration capacity ranged from 45.6mm/hr for the Eutric nitosols to 820 mm/hr for the Rhodic ferrasols.

Table 1
Physical characteristics of the five soil types of Imo State, Nigeria

Soil type	Specific gravity (G_s)	Bulk density Kg/m^3	m.c. initial %	m.c. final %	Porosity %	Sand %	Silt %	Clay %	Perm-eability (K) (m/day)	Avg final infiltration rate (mm/hr)	Infiltration capacity (mm/hr)
Rhodic Ferrasols	2.64	1509	6.81	60.62	42.84	87.92	3.86	8.22	12.909	132.0	820.0
Eutric Nitosols	2.65	1691	11.70	61.68	36.20	69.79	9.05	21.16	7.649	56.40	45.6
Lithosols	2.70	1836	18.22	68.30	34.00	66.89	9.11	24.00	4.821	43.20	180.0
Dystric Ferrasols	2.67	1746	16.51	63.41	34.61	73.67	3.43	22.90	6.682	82.80	192.0
Eutric Gleysols	2.66	1717	13.09	63.67	33.44	64.52	6.02	29.46	3.531	40.60	276.0

A. Bulk density

From Table 1, it can be seen that, the densities of the soils ranged from 1509 kg/m^3 for the Rhodic ferrasols to 1836 kg/m^3 for the Lithosols. The Rhodic ferrasols with lower bulk density had higher erosion / soil loss, while lithosols with higher bulk density had lower erosion rate. Bulk density have an effect on the erodibility of the soil. Soils with higher bulk densities were expected to offer more resistance to soil loss (if density alone is considered).

The Rhodic Ferrasols have the lowest bulk density of 1509 kg/m^3 and a corresponding highest infiltration capacity of 820 mm/hr. The high infiltration rate of this soil group could be due to their low amount of clay and high percentage of sand. Similarly, the highest bulk density was found in the Lithosols and they also recorded a relatively low infiltration capacity which could be attributed to their high bulk density and relatively high percentage of fines.

B. Rainfall intensity and soil loss

From Table 1, it can be seen that erosion increased with increase in rainfall intensity. For the Rhodic Ferrasols and Eutric Nitosols, soil loss decreased with decrease in rainfall intensities. Higher rainfall intensities produce greater kinetic energy and higher runoff volumes leading to greater soil loss. This is also obvious from previous studies, expectation and personal experiences of the authors. At intensity of 92 mm/hr the erosion for the Rhodic ferrasols was highest (0.91kg), while that for Lithosols was smallest (0.49 kg). For intensity of 73.5 mm/hr soil erosion for the Dystric nitosols was highest (0.83kg), while Eutric nitosols was smallest (0.30kg). For the lowest intensity, soil losses for all soil losses for all the soils groups were generally low. Eutric nitosol had the highest of 0.20 kg.

C. Infiltration rate

From the result obtained, Rhodic ferrasols had higher infiltration rates, while Lithosols had lower infiltration rates. It was observed that the infiltration capacities of the soil indicate their ability to resist erosion.

Soil with high infiltration capacity for example the Rhodic ferrasols are more porous and generally susceptible to erosion, while the soils with low infiltration capacity can induce flooding and puddling problems.

6. Conclusion

The following conclusions were reached on the basis of the results from this study:

- The infiltration capacities of Imo State soil fall within the high, medium and low infiltration rates.
- The variations in infiltration rates can be accounted for by the differences in the initial moisture condition of the soils.
- The rainfall intensity affected soil loss with higher intensity resulting in more soil erosion of which splash loss was significant.
- The infiltration rates obtained from this study predicted favourably the erosion rates of the Imo state soils studied, whereby lower rates indicate more soil resistance and less erosion.

References

[1] O. O. Okoroafor, C. O. Akinbile and A. J. Adeyemo, 'Determination of soil erodibility factors (k) for selected sites in Imo State.' *Journal of Resources and Environment*, vol 8 (1), pp. 6 -13, 2018.
[2] G. C. Obiechefu, 'Rill initiation and evolution: An integrated study of the rill erosion sub-processes and the development of a gully erosion model,' *Unpublished PhD thesis*, Cranfield University, Bedford, United Kingdom, 1997.
[3] W. J. Rawls and D. L. Brakensiek, 'Estimation of soil water retention and hydraulic properties.: in H.J. Morel Seytoux edited: Unsaturated flow in hydrologic modelling. Theory and Practice NATO series C,' *Mathematical and Physical Science*, vol 275, pp.275 – 300; London, Kluwen Academeics, 1989.
[4] W. J. Rawls, D. L. Brakensiek, and K. E. Saxton, 'Estimation of soil water properties'. *ASAE Transaction*, 25, pp. 1316 -1320, 1982.
[5] FAO, 'The state of Food and Agriculture for rural non-farm insurance in developing countries', Rome, 1998.
[6] G. C. Obiechefu, 'Evaluation of infiltration models for Imo State soils'. Paper presented at the 15th annual conference of the Nigerian Society of Agricultural Engineers at Maiduguri, Borno State, Nigeria. From 10 – 13 September 1991.
[7] W. H. Green and G. A. Ampt, 'Studies in soil physics 1, the flow of air and water through soils,' *Journal of Agricultural Science,* Vol. 4, p1 -24, 1911.
[8] H. N. Holtan, 'A concept for infiltration estimates in watershed engineering,' *ARS Papers*, pp. 41 – 51, 1961.
[9] H. N. Holtan and N. R. Creitz, 'Influence of soils, vegetation and geomorphology on elements of the flood hydrograph,' *Proceedings of the Sympsiumon flood and their computations. Leningrad*, Russia, 1967.
[10] R.E. Horton, 'An approach toward a physical interpretation of infiltration capacity,' *Soil science society of America proceeding*, Vol 5, p399 – 417, 1940.

[11] A. N. Kostiakov, 'On the dynamics of the coefficient of water percolation in soils and the necessity of studying it from a dynamic view for the purposes of ameriolation,' *Transaction of the 6th congress of the international society of soil science Russia*, Part A: 17 – 21.
[12] J. R. Philip, The theory of infiltration: 4. Sorptivity and algebraic infiltration equation, *Soil science* 84, pp. 257 – 278, 1957.