Agr. Foo. Nat. Res. J. Volume 3, Issue 1, Page 147 - 153

ISSN: 3043-5420

Agriculture, Food and Natural Resources Journal

The Official Journal of the Faculty of Agriculture, Nnamdi Azikkiwe University, Nigeria

Journal homepage: https://journals.unizik.edu.ng/afnrj

Original Article

Evaluation of Kostiakov and Philip infiltration models: application to the coastal plain soils of Owerri, Southeastern, Nigeria

OPEN ACCESS

Michael Akaninyene OKON* & Goodness Chiamaka NKWOR

Department of Soil Science and Technology, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria

DOI: https://www.doi.org/10.5281/zenodo.13981475

Editor: *Dr Onyekachi Chukwu, Nnamdi Azikiwe University, NIGERIA*

Received: *January 12, 2024*
Accepted: *March 24, 2024*
Available online: *March 31, 2024*

Peer-review: *Externally peer-reviewed*

Conflict of Interest: The authors have no conflicts of interest to declare

Financial Disclosure: *The authors declared that this study has received no financial support*

ABSTRACT

Infiltration experiment involve the use of large volumes of water with heavy infiltrometer. This study evaluated Kostiakov and Phillip infiltration models on the coastal plain soils of Owerri, Imo State. Four land use types; Plantain Plantation (PP), Forestry Botanical Garden (FBG), Fallow Land (FL) and Vegetable Farm (VF) were selected for the study, and two infiltration tests were carried out in situ using a double ring infiltrometer method. Kostiakov and Phillip infiltration equations were fitted based on data generated from field measurements. Basic infiltration rates for the four land uses were also determined, and they were in this order: PP > FL > FBG > VF. Plantain Plantation had the highest basic infiltration rate with a mean value of 3.95 cm/min, followed by Fallow Land (3.93 cm/min) and Forestry Botanical Garden (2.38 cm/min), while Vegetable Farm (1.40 cm/min) had the lowest basic infiltration rate. Kostiakov model generated these equations: $I = 0.06t^{1.3}$,$I = 0.30t^{1.2}$, $I = 0.21t^{1.3}$ and $I = 0.05t^{1.3}$ for PP, VF, FBG and FL while Philip model gave these equations: $I = -0.90t^{1/2} + 7.56t$, $I = -0.95t^{1/2} + 7.56t$, $I = -2.76t^{1/2} + 9.84t$, $I = -1.96t^{1/2} + 7.05t$ for FL, PP,FBG and VF respectively. Philip model recorded high negative sorptive values. Root Mean Square Error (RMSE) and Coefficient of determination (R^2) were computed for each model to determine the best fit. The Kostiakov model gave higher R^2 values and the least RMSE values; therefore, it is selected as the best fit model for the soils of the study area.

KEYWORDS: *Infiltration models, Infiltration rate, Land use types, Soil properties.*

INTRODUCTION

Water infiltration into soils has become a very important topic of discussion in soil water conservative practices and soil water management (Adindu *et al.*, 2014). Infiltration is a major component of the general mass hydrologic budget. It plays a crucial role in the hydrology of both soil surface and subsurface (Amin *et al.*, 2017). It has gained the interest of many field workers and researchers in the plant and earth sciences (Adindu *et al.*, 2014; Okon & Osuji, 2014 & Henry *et al.*, 2016).

Due to shortage in annual rainfall in many geographical areas, most farmers rely on irrigation for dry season crop production. Therefore, it becomes very necessary to quantify soil infiltration in order to determine water availability for crop growth and to calculate the irrigation water requirement (Zolfaghari *et al.*, 2012).

*Corresponding author: michaelaokon@gmail.com

Infiltration is the movement of water into the soil from the soil surface (Dagadu & Nimbalker, 2012). The velocity at which water enters the soil at any given time is the infiltration rate and it is the capacity of the soil to absorb water (Adindu *et al.,* 2014). Land use types and soil types are some of the factors that can influence the infiltration rate of soil depending on the condition of the surface of the soil and its physical and chemical properties (Siyal *et al*., 2002). When lands are put into different uses, it results in a change in the soil's intrinsic properties which also affects the hydrologic equilibrium of the soils (Osuji *et al.*, 2010). Parent materials also profoundly influences the properties of soils formed from them (Okon *et al.,* 2014), as they affect their physical, chemical and mineralogical properties.

The infiltration characteristics of soils are quantified when data of infiltration measurements in the field are fitted into infiltration models mathematically (Oku & Aiyelari, 2011). These models can then be used in designing and optimizing irrigation projects (Adindu *et al.,* 2014). Some of the benefits of using infiltration models are substantial reduction in time and cost of field measurement of field infiltration when designing and optimizing irrigation projects. The models are adequate in predicting water infiltration to a reasonable of level of accuracy (Adindu *et al.*, 2014).

Numerous infiltration models are available for the estimation of infiltration rates (Mohammad *et al.*, 2016) and they are classified as; empirical, semi-empirical and physical based (Mishra *et al.*, 1999). Infiltration models can be used to estimate final soil infiltration rate though the values for each model parameter have been observed to be different due to the fact that parameters are soil dependent (Adindu *et al.,* 2015). Different researchers have evaluated different infiltration models to get the best fit infiltration model for different locations (Oku &Aiyelari, 2011; Adindu *et al.,* 2014; Henry *et al.*, 2016). This research work therefore evaluated Kostiakov and Philip infiltration models on the coastal plain soils of Owerri to get the better fit model for the area.

MATERIALS AND METHODS

Study Area

This study was carried out in the Federal University of Technology Owerri Teaching and Research Farm, Southeastern Nigeria which is located between Latitude 5◦25'N and 5◦30'N and Longitude 7◦00'E and 7◦10'E. The area has a maximum and minimum temperature of 32◦C and 20◦C respectively with mean annual rainfall of 2500mm (Okon & Osuji, 2014). The rainy season starts from the month of March and ends in November with a bimodal distribution having two prominent seasons; the rain/wet season and the dry/harmattan season, the rainy season lasts from March to November while the dry/harmattan season lasts from December to February. Vegetation type of the area is a typical lowland rainforest nd the climate is humid tropics (Okon *et al*., 2021)Soils of the study area are derived from Coastal plain sands (Onweremadu *et al.,* 2012).

Sampling procedure and Data collection

Reconnaissance visit was made to the study area and four land use types were selected for this study. They were; Plantain plantation (PP), Forestry Botanical Garden (FBG), Fallow land (FL) and Vegetable farm (VF). Infiltration rates and cumulative infiltration of these soils were determined in-situ randomly in different land use types and this was replicated twice.

Determination of infiltration rate

Infiltration rates were determined in situ using a double ring infiltrometer as described by Bertrand (1965). Two infiltration tests were carried out on each of the four land use types. The double ring infiltrometer measuring 30 cm and 60 cm respectively for inner and outer ring were driven into the ground to a depth of 7cm. Dried grasses and leaves were spread at the bottom of the rings to a depth of 5 cm to minimize soil surface disturbance when pouring water into the compartments.

To ensure that water inside the inner ring flows vertically, water was first filled in the outer ring before filling the inner ring. This was done to ensure that the soil profile around the inner ring would be wet. Water intake or infiltrations of soils were read off with the help of a ruler attached. Water levels of the outer and the inner rings were maintained at same level and repeated readings of the water in the inner ring were taken at the interval of 2 minutes and each experiment lasted for 20 minutes. (Brady & Weil, 1999)

Kostiakov model equation

Kostiakov infiltration model (Kostiakov, 1932) can be estimated using data derived from the field measurements or laboratory. The model proposes a simplified empirical equation of infiltration using the field data curve fitting. The relationship between I (cumulative infiltration), and t (time), is given by the equation

$$I = Kt^{a} \qquad (1)$$

Where I = cumulative infiltration, t = time from the start of infiltration, 'K' and 'a' are empirical constants which are to be estimated.

To determine the parameters 'K' and 'a', the log of both sides of equation (1) were taken. The slope of this graph gave the value of a, while log K gave the intercept. The value of K was obtained from the antilog K (Henry *et al.*, 2016).

Phillip model equation

The mathematical and physical analysis of the infiltration process developed by Philip (1957) separated the process into two components which are; that caused by sorptivity factors and that influenced by gravity. The Philip model takes the form of a power series but in practice an adequate description is given by the two-parameter equation.

$$I = St^{1/2} + At \qquad (2)$$

Where I = Cumulative infiltration, S = Sorptivity, A = Transmissivity or permeability co-efficient (Henry *et al.*, 2016).

The constant values A and S were determined by plotting a graph of i against $t^{1/2}$.

Model Evaluation

Best fit Infiltration model for the soils of the study area was ascertained through Testing the Goodness of fit. Root Mean Square Error (RMSE) and Co-efficient of determination (R^2) were calculated and the model with least RMSE value and highest R^2 was selected as best model.

$$RMSE = \sqrt{(\sum(\text{actual} - \text{predicted})^2/n)} \qquad (3)$$

Where: Actual = actual values, Predicted=predicted values, n= number of data points

$$R^2 = \text{Regression SS} \div \text{Total SS} \qquad (4)$$

Where, R^2 = Coefficient of determination, SS= sum of squares.

RESULTS AND DISCUSSION

Infiltration Rate

Table 1 shows the field measurements of infiltration rates (i) and cumulative infiltration (I) for replications 1 and 2 respectively for the different land use types studied. The results showed that infiltration rates were highest at the onset of irrigation as shown in Figure 2 and started to reduce till it got to a constant or near constant state called steady state or basic infiltration rate (Brady & Weil, 1999), while the cumulative infiltration increased as the water continued to accumulate as shown in Figure 1. The infiltration rates were high which can be due to the sandy nature of the soils since the soils were formed from coastal plain sands (Okon *et al*., 2017).

The highest infiltration rate at the onset of irrigation was recorded in the Fallow Land (6.50cm/min) followed by Plantain Plantation (6.00cm/min), then Forestry Botanical Garden (3.00cm/min) and the least was in the Vegetable Farm (2.40cm/min). The least infiltration rate recorded in the Vegetable Farm could be attributed to soil compaction due to anthropogenic activities. The Run 2 also had similar result as the Vegetable Farm also had the least infiltration rate at the onset of irrigation (1.25cm/min) but the highest was recorded in the Plantain Plantation 97.75cm/min).

Cumulative infiltration at the onset of irrigation was also highest in Fallow Land (13.00cm), followed by Plantain Plantation (12.00cm) and then Forestry Botanical Garden (6.00cm) while the least was seen in Vegetable Farm (4.80cm) for Run 1.

Run 2 had the highest cumulative infiltration in Plantain Plantation (15.50cm) at the onset of irrigation, followed by Fallow Land (11.90cm) then Forestry Botanical Garden (9.30cm) and the least in Vegetable Farm (2.50cm). The low cumulative infiltration of the Vegetable Farm suggests compaction of the area.

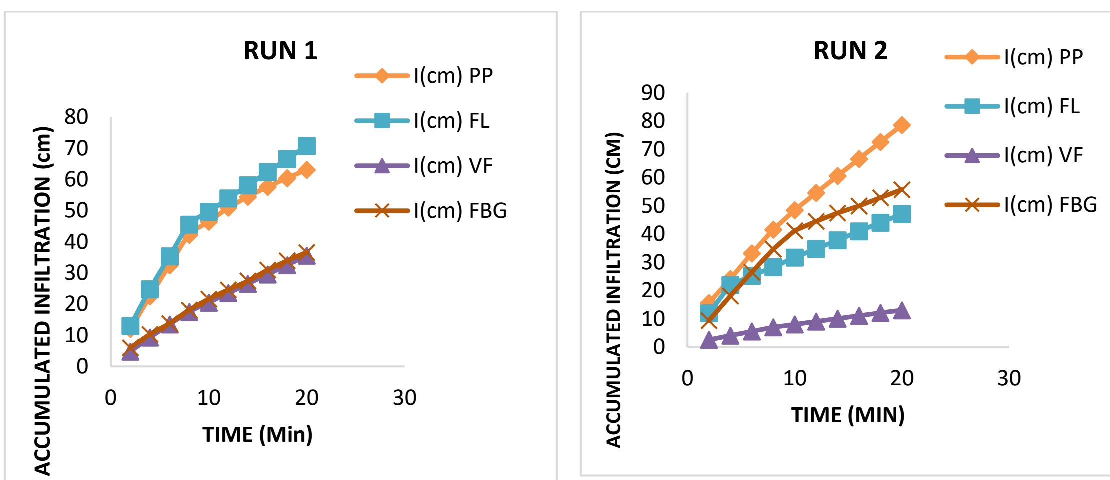
Kostiakov Infiltration Model

Table 2 shows the summary of Kostiakov parameters, Kostiakov equations, R^2 and RMSE obtained for the various land uses. From the result, the K (a constant signifying initial infiltration rate) values obtained ranged from 0.05 - 0.3 and 0.02 - 0.56 for Runs 1 and 2 respectively. The 'a' values (infiltration decay constants) obtained were all positive indicating that the soils were not saturated at the time of the experiment. This result obtained is in contrast with that of Adindu *et al.* (2014) who obtained negative (a) values and attributed it to the fact that the soils were saturated at the time when the experiment was conducted. Ahaneku, (2011) also reported that the figures obtained for the calculated infiltration in his work were negative under the Kostiakov equation and attributed it to the fact that water was being given off in his experimental farm during the rainy season. The different soils studied showed high R^2 values and low RMSE values for both replications showing that Kostiakov equation was an appropriate equation for predicting infiltration rate in the area as the values of R^2 ranged from 0.969 to 0.999 for replication 1 and 0.974 to 0.9993 for replication 2 while the values of RMSE ranged from 0.3225 to 0.9965 for replication 1 and 0.4729 to 3.7872 for replication 2 indicating an excellent model. This corroborated with the findings of (Adindu *et al*., 2014) who also discovered that Kostiakov infiltration model was a good model for coastal plain soils in Southeastern Nigeria.

Table 1. Field measured cumulative infiltration (I) and infiltration rate (i)

Run	t (min)	I PP (cm)	i PP (cm/min)	I FL (cm)	i FL (cm/min)	I VF (cm)	i VF (cm/min)	I FBG (cm)	i FBG (cm/min)
1	2	12.00	6.00	13.00	6.50	4.80	2.40	6.00	3.00
	4	22.50	5.63	24.80	6.20	9.30	2.33	10.30	2.58
	6	32.50	5.42	35.30	5.88	13.50	2.3	13.80	2.30
	8	42.20	5.23	45.50	5.69	17.50	2.19	18.10	2.26
	10	46.40	4.64	49.60	4.96	20.50	2.05	21.60	2.16
	12	50.90	4.24	53.90	4.49	23.50	1.96	24.60	2.05
	14	54.40	3.89	58.10	4.15	26.50	1.89	27.40	1.96
	16	57.60	3.60	62.30	3.89	29.50	1.84	30.90	1.93
	18	60.40	3.36	66.50	3.69	32.50	1.81	33.90	1.88
	20	63.10	3.16	70.70	3.54	35.50	1.78	36.60	1.83
2	2	15.50	7.75	11.90	5.95	2.50	1.25	9.30	4.65
	4	24.00	6.00	21.90	5.48	4.00	1.00	18.10	4.53
	6	33.10	5.52	25.20	4.20	5.50	0.917	26.40	4.40
	8	41.50	5.19	28.30	3.54	6.90	0.863	34.60	4.33
	10	48.40	4.84	31.60	3.16	8.00	0.800	41.20	4.12
	12	54.50	4.54	34.70	2.89	9.00	0.750	44.40	3.70
	14	60.50	4.32	37.80	2.70	10.00	0.714	47.40	3.39
	16	66.50	4.16	40.90	2.56	11.00	0.688	49.90	3.12
	18	72.50	4.03	44.00	2.44	12.00	0.667	52.80	2.93
	20	78.50	3.93	47.10	2.36	13.00	0.650	55.70	2.79

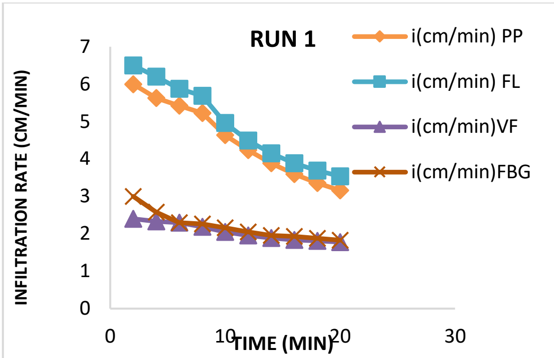
Where: t = Time, I PP = Cumulative infiltration of Plantain Plantation, i PP = Infiltration rate of Plantain Plantation, I FL = Cumulative infiltration of Fallow Land, i FL = Infiltration rate of Fallow Land, I VF = Cumulative infiltration of Vegetable Farm, i VF = Infiltration rate of Vegetable Farm, I FBG = Cumulative infiltration of Forestry Botanical Garden, i FBG = Infiltration of Forestry Botanical Garden. Run 1=first replication



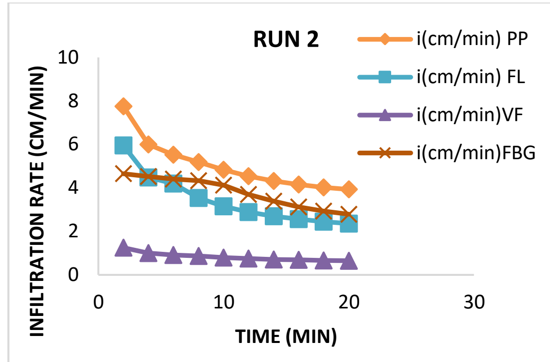
A B

Figure 1: Graph of accumulated infiltration against time for Run1 and Run 2

Where: *I(cm) PP =Cumulative infiltration of Plantain Plantation, I(cm) FL =Cumulative infiltration of Fallow Land, I(cm) VF =Cumulative infiltration of Vegetable Farm, I(cm) FBG =Cumulative infiltration of Forestry Botanical Garden.*



A



B

Figure 2: Graph of infiltration rate against time for Run1and Run 2

Where: *i(cm/min) PP =Infiltration rate of Plantain Plantation, i(cm/min) FL =Infiltration rate of Fallow Land, i(cm/min) VF =Infiltration rate of Vegetable Farm, i(cm/min) FBG =Infiltration rate of Forestry Botanical Garden.*

Table 2: Summary of Kostiakov parameters equations, R^2 and RMSE

Rep.	Land use	K	a	Kostiakov equation ($I = Kt^a$)	R^2	RMSE	Ranking of R^2	Ranking of RMSE
1	PP	0.06	1.3	$I = 0.06t^{1.3}$	0.969	0.3701	4	2
	FL	0.05	1.3	$I = 0.05t^{1.3}$	0.975	0.3225	3	1
	VF	0.30	1.2	$I = 0.30t^{1.2}$	0.997	0.9969	2	4
	FBG	0.21	1.3	$I = 0.21t^{1.3}$	0.999	0.9408	1	3
2	PP	0.04	1.4	$I = 0.04t^{1.4}$	0.998	0.3044	2	1
	FL	0.02	1.8	$I = 0.02t^{1.8}$	0.980	0.4633	3	2
	VF	0.56	1.4	$I = 0.56t^{1.4}$	0.9993	3.7872	1	4
	FBG	0.10	1.3	$I = 0.10t^{1.3}$	0.974	0.4729	4	3

PP = Plantain Plantation, FL = Fallow Land, VF = Vegetable Farm, FBG = Forestry Botanical Garden, I = Cumulative Infiltration, K and a are Kostiakov empirical constants that were estimated, R^2 = Co-efficient of determination, RMSE = Root Mean Square Error

Phillip's Infiltration Model

Table 3 shows the summary of Philip parameters, equations, R^2 and RMSE obtained for the various land uses. Results of the experiment shows that S (sorptivity which embodies the influence of soil water relation, that is, matric suction and conductivity in the wetting process) values ranged from (-0.90) to (-2.78) and (-0.75) to (-5.18) for Reps 1 and 2 respectively. The A (Transmissivity, that is, hydraulic conductivity which represents the effect of gravity) ranged from 7.05 to 9.32 and 5.84 to 8.37 in Reps 1 and 2 respectively. Sorptive forces of the soil largely govern the initial water infiltration rate (Oku & Aiyelari, 2011). The sorptive values obtained in this study were all negative. The high negative values recorded could be attributed to the fact that the soils were unsaturated at the onset of irrigation and had high matric potential gradient and also due to their sandy nature. This result is in contrast to that obtained by Oku & Aiyelari (2011) who obtained positive sorptive values that are high with low transmissivity values that ranged from 0.14 to 1.29 which invariably put the soil conductivity class between "very slow" and "slow" (FAO, 1963; Oku & Aiyelari, 2011). The values of R^2 and RMSE for Philip infiltration model showed that the model had high R^2 values but not as high as that of Kostiakov model. High R^2 values reveals better fit model. The model predicted R^2 values ranging from 0.4967 to 0.967 for the first replication and 0.906 to 0.9335 for the second replication which showed that Philip model was also a good model to measure infiltration rate in the area. This corroborated with the findings of Adindu *et al.*, (2015) who also got similar results of R^2 values greater than 0.8. The RMSE values were moderate showing that it was also a good fit model for use in the area but the Kostiakov model was a better model since it had lower RMSE values. The RMSE values for Philip model ranged from 12.8959 to 17.0016 for the first replication and 10.9464 to 15.5952 for the second replication. It was observed that Kostiakov model gave the lowest RMSE values and the highest R^2 values; therefore, it is selected as the best fit model.

Table 3: Summary of Philip parameters equations, R^2 and RMSE

Run	Land use	S	A	Philip equation ($I = St^{1/2} + At$)	R^2	RMSE	Ranking of R^2	Ranking of RMSE
1	PP	-0.95	7.56	$I = -0.95t^{1/2} + 7.56t$	0.885	14.1642	3	2
	FL	-0.90	7.56	$I = -0.90t^{1/2} + 7.56t$	0.967	14.2034	1	3
	VF	-1.96	7.05	$I = -1.96t^{1/2} + 7.05t$	0.4967	12.8956	4	1
	FBG	-2.78	9.32	$I = -2.78t^{1/2} + 9.32t$	0.932	17.0016	2	4
2	PP	-0.81	7.22	$I = -0.81t^{1/2} + 7.22t$	0.906	13.5669	4	3
	FL	-0.75	5.84	$I = -0.75t^{1/2} + 5.84t$	0.929	10.9465	2	1
	VF	-5.18	7.48	$I = -5.18t^{1/2} + 7.48t$	0.9335	12.7000	1	2
	FBG	-1.37	8.37	$I = -1.37t^{1/2} + 8.37t$	0.913	15.5952	3	4

PP = Plantain Plantation, FL = Fallow Land, VF = Vegetable Farm, FBG = Forestry Botanical Garden, I = Cumulative infiltration, S = Sorptivity, A = Transmissivity or permeability co-efficient, R^2 = Co-efficient of determination, RMSE = Root Mean Square Error

CONCLUSION AND RECOMMENDATION

The study revealed that Kostiakov model gave the highest R^2 values and the least RMSE values, From the results of this research work, Kostiakov infiltration model was more suitable than Philip infiltration model for predicting water infiltration in the Coastal plain soils of Owerri, Imo State, Southeastern Nigeria.

Acknowledgements: We want to acknowledge FUTO for giving us the platform and environment to carry out this work. Finally, we acknowledge God Almighty for His divine wisdom and direction.

Authors' contributions: MAO. contributed to the conceptualization of the work, generation of topic, supervising the research work, writing, editing and financing of the article, GCN contributed to the implementation of the research work, writing and discussing of the project and financing of the article publication.

Ethics Committee Approval

Not Applicable

REFERENCES

Adindu R. U, Igbokwe K. K & Dike I. I. (2015). Phillip Model Capability to Estimate Infiltration for soils of Aba, Abia State. *Journal of Earth sciences and Geotechnical Engineering* 5: 63-68. http://www.sciencepress.com/upload/GEO/vol%205_2_4.pdf

Adindu R. U, Igbokwe K. K, Chigbu T. O. & Ike-Amadi C. A. (2014). Application of Kostiakov's Infiltration model on the soils of Umudike, Abia State, Nigeria. *American Journal of Environmental Engineering* 4 (1): 1-6. http://article.sapub.org/10.5923.j.ajee.20140401.01.html

Ahaneku, I. E. (2011). Infiltration Characteristics of Two Major Agricultural Soils in North Central Nigeria. Agricultural *Science Resourcees Journal*, 1(7): 166–171.

Amin. S. A, Abubakar, N. A, Unman, D. D, Abdullahi, A. S. & Yakub, M. A. (2017). Comparative Evaluation of Infiltration models for estimating soil cumulative infiltration. *Global Scientific Journal*, 5 (12): 1-8.

Bertrand, A.R., (1965). Rate of water intake in the field. In: Methods of Soil Analysis. Part I, 1 ed. Eds., st C.A. Black *et al*. *Monograph of agonomy*. 9. ASA-SSSA, Madison, W.I., pp: 197-209. https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/agronmonogr9.1.c12

Brady, N.C & Weil, R.R. (1999) soil water characteristics and behaviour, *The Nature and properties of soil fifth edition* 171-212

Dagadu J. S. & Nimbalkar P. T. (2012). Infiltratioen Studies of Different Soils under Different Soil Conditions and Comparison of Infiltration Models with Field Data. *International Journal of Advanced Engineering Technology*. 3 (3): 154-157. https://www.scirp.org/reference/referencespapers?referenceid=2683837

Food and Agriculture Organization (FAO), (1963). High Dam Soil Surveys Project Deb BC. Rome. 63 pp. https://journals.indexcopernicus.com/search/article?articleId=1740340

Henry, U. I., Ibrahim, Iro I., Habib, L. I. & Henry, M. U., (2016). Evaluation of Water Infiltration Equations on Fadama Soils of Jos – North, Plateau State, Nigeria. *Journal of Biology, Agriculture and Healthcare*. 6 (16): 1-8. https://www.iiste.org/journals/index.php/JBAH/article/download/32513/33405

Kostiakov A. N., (1932). On the dynamics of the coefficient of water percolation in soils and on the necessity of studying it from a dynamic point of view for the purposes of amelioration. Moscow, Russia: Transactions 6th *Congress of International Society of Soil Science*. pp.17–21.

Mishra, S.K., Kumar S.R. & Singh, V.P. (1999). Calibration and validation of a general infiltration model. *Hydrological Processes*, 13: 1691-1718.

Mohammad Z., Mohammad M. & Javed A., (2016). Application of spreadsheet to estimate infiltration parameters. *Perspectives in Science*. 8: 702—704. https://doi.org/10.1016/j.pisc.2016.06.064

Okon, M. A. & Osuji, G. E., (2014). Differences in infiltration rate under a catenary landscape in Owerri, Southeastern Nigeria. *International Journal of Research in Agriculture and Forestry*.1(2):1-6. *www.ijraf.org/pdf/v1-i2/1.pdf*

Okon, M.A., Osuji, G.E., Onweremadu, E.U., Agim, L.C., Uzoho, B.U., Osuaku, S.K., & Ahukaemere, C.M. (2014) Differences in soil physicochemical properties on a catenary landscape in Owerri, Southeastern Nigeria. *International Journal of Applied Research and Technology* 3(10): 11-15.

Okon, M.A, Nwachukwu, M.N., & Osujieke, D.N (2017) Differences in physicochemical properties of soils under oil palm plantations of different ages in Ohaji/Egbema, Imo State. *International journal of research in agriculture and forestry* 4 (1) 1-5 https://dx.doi.org/10.22259/ijraf.0401001

Okon M.A., Eneje, R.C., Oguike P.C., Egboka N.T. & Onwuasoeze, E.N (2021) Assessment of climate variability in Owerri area of Imo State, Southeastern Nigeria. *Journal of Erosion and Environmental Degradation*, 5 (1) 11-14.

Oku, E. & Aiyelari, A. (2011). Predictability of Philip and Kostiakov's infiltration models under Inceptisols in the Humid Forest zone, Nigeria. In: *Kasetart Journal (Natural Sciences)*,45:594-602. https://www.thaiscience.info/journals/article/TKJN/10898346.pdf

Onweremadu, E.U., Ndukwu, B.N., Osuji, G.E. & Okon, M.A. (2012) Rheological properties of soil groups in Central south-eastern Nigeria in relation to other physical properties. *Nigerian Journal of soil science*, 22 (1): 161 – 164.

Osuji, G.E., Okon, M.A., Chukwuma M.C. & Nwarie, I.I. (2010). Infiltration Characteristics of Soils under Selected Land Use Practices in Owerri, Southeastern Nigeria. *World Journal of Agricultural Sciences,* 6 (3): 322-326.

Philip, J. R. (1957). The theory of Infiltration: Sorptivity and algebraic infiltration equations. Soil Science 84: 257-264. https://www.soilphysics.okstate.edu/teaching/soil-6583/references-folder/philip%201957.pdf

Siyal, A.G., Oad, F.C., Samo, M.A., Hassan, Z. & Oad, N.L. (2002). Effect of compactions on infiltration characteristics of soil. *Asian Journal of Plant Scieence,* 1: 3-4. https://scialert.net/fulltext/?doi=ajps.20023.4

Zolfaghari, A.A, Mirzaee S. & Gorji, M. (2012). Comparison of Different Models for Estimating Cumulative Infiltration. *International Journal of Soil Science.* 7 (3): 108-115. https://scialert.net/abstract/amp.php?doi=ijss.2012.108.115