

AN EMPIRICAL EVALUATION OF HORTON, GREEN-AMPT AND PHILIP INFILTRATION MODELS IN A HUMID TROPICAL ENVIRONMENT: A CASE STUDY OF ORLU, IMO STATE NIGERIA

I.L. Duruanyim¹, O.O Okorafor¹, G.U. Asonye¹, T.A. Ihedioha¹, N.A.A. Okereke¹
C.I. Obineche^{2*}

¹Department of Agricultural and Biosystems Engineering, Federal University of Technology
Owerri, Imo State, Nigeria.

²Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic
Nekede Owerri, Imo State, Nigeria.

Article Received: 26 February 2026, Article Revised: 16 March 2026, Published on: 06 April 2026

*Corresponding Author: C.I. Obineche

Department of Agricultural and Biosystems Engineering, Federal University of Technology Owerri, Imo State, Nigeria.

DOI: <https://doi-10.1555/ijrpa.4353>

ABSTRACT

Accurate estimation of soil infiltration characteristics is essential for effective irrigation design, water resource management, and soil conservation practices. This study evaluates the performance of three widely used infiltration models Horton, Green–Ampt, and Philip in predicting infiltration rates in a humid tropical environment using Orlu, Imo State, Nigeria, as a case study. Field infiltration tests were conducted using a double-ring infiltrometer, while laboratory analyses were performed to determine relevant soil properties including particle size distribution, moisture content, and specific gravity. Model parameters were derived and used to simulate infiltration rates, which were then compared with observed field data using statistical performance indices such as coefficient of determination (R^2), root mean square error (RMSE), and t-test analysis. Results revealed that the Horton model exhibited the highest correlation ($R^2 = 0.87$) but significantly overestimated infiltration rates. The Green–Ampt model provided the most reliable predictions with minimal deviation from observed values, while the Philip model showed moderate performance. The study concludes that the Green–Ampt model is most suitable for infiltration prediction in the study area.

KEYWORDS: Infiltration models, Horton model, Green–Ampt model, Philip model, soil properties, irrigation management.

INTRODUCTION

Efficiency in the application of irrigation water is of great economic importance especially to countries with limited water supplies (Akinbile and Ogedengbe,2006).Infiltration is key to soil and water conservation and irrigation management because it helps in determining the amount of runoff over the soil surface during rainfall or irrigation (Oku and Aiyeleri, 2011).

Infiltration capacity is very important amongst parameters to be determined during design of irrigation system especially surface irrigation system. The water infiltration process through surface soil is a complex interaction between rainfall and irrigation intensities, soil type and surface condition. These factors govern the ability at which water passes through the soil (Barcarolle, 1997).Basically, Infiltration occurs in three stages. Stage one is when water enters the soil as rapidly as it is being applied. Stage two occurs as soon as ponding initiates. The final stage is the steady-state in which infiltration is controlled by hydraulic conductivity of soil (Hillel, 1998).

Several researchers were able to successfully compare and evaluate those available soil-infiltration models in different frameworks under field conditions (Mbagwu,1995; Mishra and Singh,1999; Shukla et al.,2003; Chahinian et al.,2005 and Dashtaki et al.,2009).

Mirzaee et al. (2013) evaluated the capacity of eight diverse infiltration models (Green and Ampt, Philip, Horton, Kostiakov, Modified Kostiakov, Swartzendruber, Revised Modified Kostiakov models and SCS (US-Soil Conservation Service)) which he assessed using least squares fitting to measured soil infiltration. Sihag et al. (2017a) compared various infiltration models (Kostiakov, SCS, Novel model and Modified Kostiakov) for the NIT Kurukshetra campus. Novel model was most suited *as* compared to others using field infiltration data.

Infiltration models are used to estimate the infiltration rates and infiltration potentials of soil. Different models are best applied to certain soil types and certain site conditions (Mazloom and

Foladmand, 2013). The wide variety of sites and soil conditions makes it difficult to determine what model will give the best estimate of the infiltration rate and infiltration capacity. Prediction of soil infiltration poses a challenge due to its variability and adequate selection of the technique used in determining the parameters of the models which depend on the local soil characteristics (Ogbe *et al.*, 2011). Horton (1940), showed that during a period of constant precipitation, the rate of infiltration de-creases with time. When there is plenty of water available, infiltration rates follow the limiting function, until a constant rate is reached. Knowledge of the infiltration characteristics of soils plays a significant role in the choice of appropriate soil management practices that is capable of alleviating the production constraints

of soils. Onyegbule *et al.* (2018) did a research on the infiltration characteristics of soils in Imo State under four different land uses namely: secondary forest, plantain plantation, continuously cultivated land and the grazing land and they were investigated using a double ring infiltrometer. Results showed that they all recorded low infiltration rates. The study considers the various soil groups within the specified study area to determine infiltration parameters for the three selected infiltration models. All the experiment and sample collections were made only within the study area. The main objective of this work is to comparatively evaluate three infiltration models namely, Philips, Green-Ampt and Hortons, for estimating soil infiltration rates in Orlu, Imo State Nigeria.

MATERIALS AND METHODS

MATERIALS

Geological records of Orlu in Imo State of Southeastern Nigeria indicate that the study location is within a sedimentary rock formation and lies within the Awka-Orlu uplands in a zone of sandy lateritic soil. It is bounded in the east by Ideato LGA, West by Orsu LGA, North by Anambra State and South by Njaba LGA (figure. 1). It has a population of 143, 17 persons (National Population commission, 2006). The climate is a typical humid climate, the same in the southeastern region of Nigeria. Two distinctive seasons are familiar with the climate of the area. The rainy season that begins in April and ends in October, with higher intensity in June and July and late September and dry season which begins in November and ends in March. The annual amounts of rainfall vary between 1990 mm and 2200mm. Temperature characterizes are generally high with little variations during the year. The mean daily maximum air temperature ranges from 23 °C – 28 °C, while the mean daily minimum values range from 20 °C - 26 °C. This shows that Orlu receives abundant relatively constant solar radiation because of its latitudinal location being bisected by the 50 parallel (Okorie and Ezedike, 2014)

hot and dry season which begins in November and

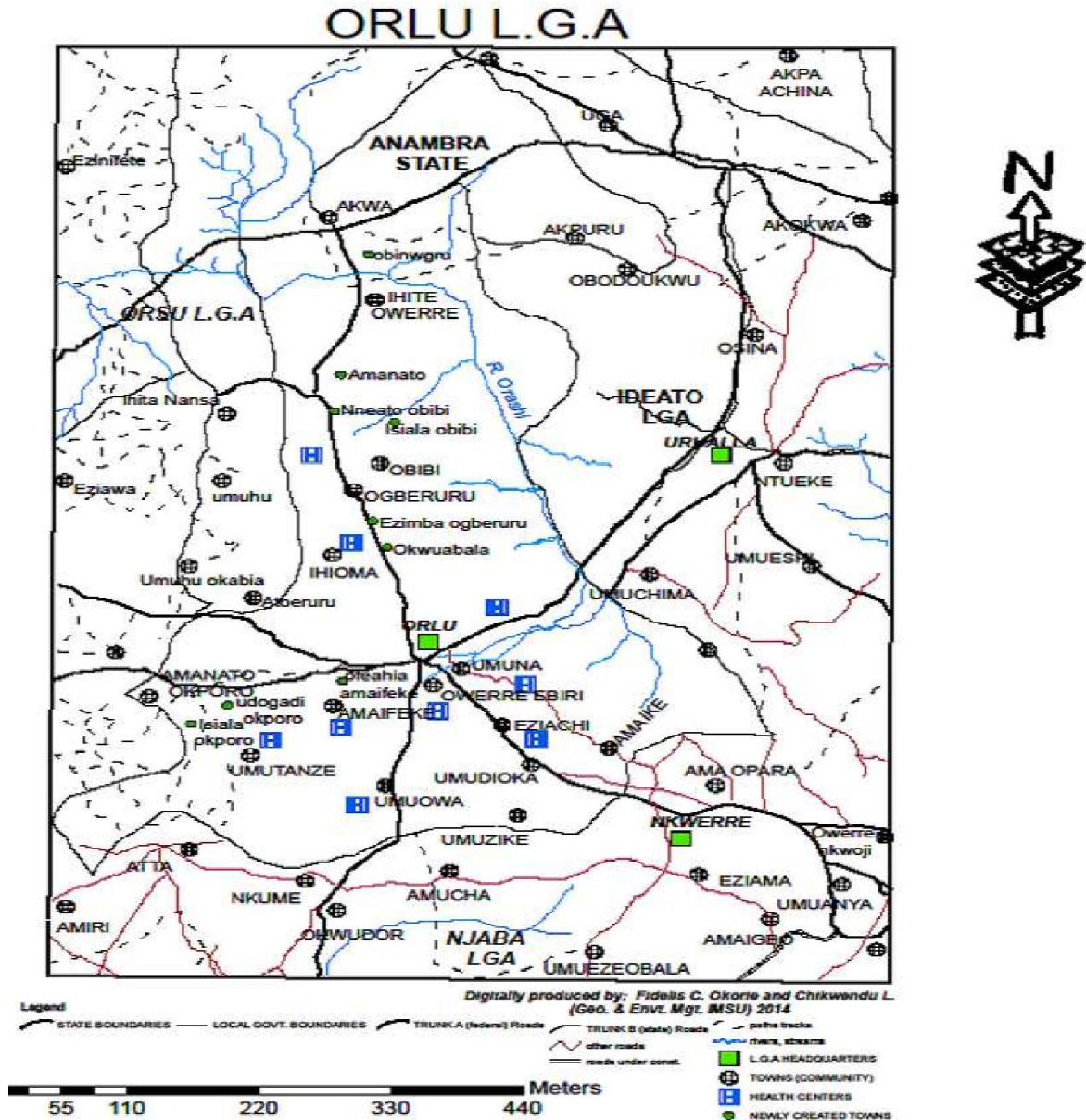


Figure 1. Map of Orlu in Imo State, Nigeria.

Soil Sampling and Analysis

Three samples were collected randomly from the sites and a total of six (6) soil samples was collected, using soil auger at a depth of 10 to 25 cm. Adequate care was taken in the collection of soil samples, making sure the points were uncultivated, non-compacted, non-eroded and having minimum presence of vegetation so as to guarantee viable soil samples. The samples were conveyed in labeled sampling bags to the laboratory and subjected to the following soil test namely; particle size analysis (grain size distribution) and proctor test (dry bulk density and optimum moisture content test). The soil tests were required to generate data required for the determination of sorptivity (S) factor in Philips Model; capillary suction and soil moisture capacity factors in Green-Ampt Model.

Hydrometer Analysis

The equivalent particle diameter was obtained thus;

$$D = K \sqrt{\frac{L}{t}} \quad 1$$

Where, t is in minutes, and D is given in mm.

The corrected hydrometer reading was obtained as follows;

$$R_C = R_{ACTUAL} - \text{Zero Correction} + C_T \quad 2$$

Where, R_C = Corrected hydrometer reading

R_A = Actual hydrometer reading

C_T = Temperature correction factor

The percent finer was obtained also using the following relationship;

$$P = \frac{a \times R_C}{W_S} \times 100 \quad 3$$

Where; W_S = Weight of the soil sample in grams.

The adjusted percent fine was obtained using the equation below;

$$\text{Adjusted percent fines as follows: } P_A = \frac{P \times F_{200}}{100} \quad 4$$

Where; F_{200} = % finer of #200 sieve as a percent

Hence, a plot of the grain size D versus the adjusted percent finer was plotted on a semi-logarithmic sheet to obtain the curve of variation in grain-size

Determination of Optimum Moisture Content of Soil (Oven Dry Method)

The moisture content of the soil samples was determined before and after infiltration. The moisture content is required for the computation of the void ratio and porosity which are needed for calculating the cumulative infiltration in the Green-Ampt Model. It is also required for the determination of sorptivity factor in the Philips Model.

Determination of Specific Gravity (Density Bottle Method)

Specific gravity is an important factor which was used in computing void ratio of the soil.

$$G_s = \frac{G_L (M_2 - M_3)}{(M_4 - M_1) - (M_3 - M_2)} \quad 5$$

Where,

G_s = specific gravity of soil

M_1 = weight of bottle + stopper (g)

M_2 = weight of bottle + stopper + soil (g)

M_3 = weight of bottle + stopper + soil + water (g)

M_4 = weight of bottle + stopper + water (g)

G_L = Specific gravity of water

Infiltration Test and Determination of Model Parameters

A double ring infiltrometer was used to carry-out in-situ infiltration experiments on the selected sites to determine parameters for the models used in the study vis-à-vis Hortons, Philips and Green-Ampt models.

Determination of parameters for Horton's infiltration model

(Horton, 1940)

$$F(t) = f_c t + \frac{(f_0 - f_c)}{k} (1 - e^{-kt}) \quad 6$$

Where, $F(t)$ = Total Infiltration at time t

f_0 = Initial infiltration rate or maximum infiltration rate

f_c = Constant or equilibrium infiltration rate after the soil has been saturated or minimum infiltration rate

k = the decay constant specific to the soil.

To determine the values of f_0 and f_c , a graph was plotted for experimental values obtained from each site with the time values on the x-axis and infiltrated rate values on the y-axis using excel. The y-intercept of a tangent to the infiltration curves gives the f_0 values while the constant infiltrated rate value gives the f_c .

Determination of parameters for the Philip's model

The Philip's model uses Richard's equation as its basis (Philip, 1957). It applies an infinite series solution that is a function of time. It has initial ponded conditions as assumptions where the ponding height remains constant. The infiltration rate (f) is described with the following equation:

$$f = \frac{1}{2} S_p t^{-\frac{1}{2}} + C_a$$

Where, C_a is the gravity factor and S_p is the sorptivity. The infiltration potential (F) can be calculated directly from integrating the infiltration rate.

The Philips model is given by the equation below as

$$F = S t^{1/2} + C_a t \quad 7$$

Where, S = Sorptivity ($L t^{-1/2}$), a function of initial and final soil water content, θ_1 and θ_n

C_a = Constant that depends on both soil properties and on θ_1 and θ_n

t = The elapsed time

Where, Φ = final moisture content of the soil

θ_0 = Initial moisture content of the soil

Determination of parameters for Green-Ampt Model

The Green-Ampt model is a model that provides many variables that reflect the soil's in-situ conditions. It is a function of the following soil properties: saturated hydraulic conductivity, field and saturated moisture contents, soil suction head, and time. It is derived from Richard's equation which describes the equality between the change in soil water content over time and the change in hydraulic conductivity and diffusivity through the depth of the soil profile (Putte, *et al.*, 2013).

$$f = \frac{K_s(H_0 + \psi_f + L_f)}{L_f} \tag{8}$$

Where, K_s = the saturated hydraulic conductivity,

H_0 = the ponding depth that creates a head above the soil,

ψ_f = the suction head below the wetting front, and

L_f = the length of the wetting front.

The ponding depth (H_0) is assumed to be zero considering that the ponding depth is usually too small to make a significant impact on the infiltration rate (Gupta, 2008).

$$F = \Delta\theta L_f \tag{9}$$

Where, $\Delta\theta$ is the difference between the saturated and field moisture contents. Substituting the value of F into equation 8, we arrive at equation 10, for infiltration rate that uses variables.

$$f = K_s + \frac{K_s \psi_f \Delta\theta}{F} \tag{10}$$

Hence, The Green-Ampt equation was derived by Green and Ampt in 1911 as;

$$F(t) = Kt + \psi\Delta\theta \ln\left(1 + \frac{f(t)}{\psi\Delta\theta}\right) \tag{11}$$

Where, $F(t)$ = Cumulative infiltration against time (L)

K = Soil hydraulic conductivity (LT^{-1})

t = Elapsed time

ψ = Capillary suction of soil (L)

$\Delta\theta$ = Soil moisture capacity (Dimensionless)

n or θ_s = Effective porosity of soil (dimensionless)

θ_i = Initial soil moisture (Dimensionless)

$f(t)$ = Infiltration rate

The Infiltration was calculated using the relationship below;

$$f(t) = K \left[\frac{\psi \Delta \theta}{F} + 1 \right] \quad 12$$

Where, θ = Water content of the soil

F = the total volume already infiltrated

The soil moisture capacity ($\Delta \theta$) is the difference between the effective porosity (n) of soil and the initial soil moisture (θ_i).

$$\text{That is, } \Delta \theta = n - \theta_i \quad 13$$

Data analysis using coefficient of determination, R^2

The coefficient of determination, R^2 , is used in analysis to show how the differences in one variable can be explained by a difference in the second variable. That is, R-squared gives you the percentage variation in y explained by x -variables. The range is 0 to 1 that is 0% to 100% of the variation in y can be explained by the x -variables. The coefficient of determination (R^2) is comparable to the correlation coefficient (R). The R Squared (R^2) is the square of the correlation coefficient R (hence the term R squared). It is given by the equation below

$$R^2 = \frac{\text{Explained Variation}}{\text{Total Variation}} \quad 14$$

$$R^2 = \frac{\sum(\hat{Y} - \bar{Y})^2}{\sum(Y - \bar{Y})^2} \quad 15$$

Where: \hat{Y} = Predicted value

Y = Actual value

\bar{Y} = Mean of the actual value

RESULTS AND DISCUSSION

Classification of Soil

The outcome of the grain size distribution analysis of the soil samples from different locations were given in table 1.

Table 1: Grain size distribution result for Orlu.

M = 48.3g

Sieve size (mm)	Mass retained(g)	Mass passing (g)	%passing
2.0	6.5	41.8	86.5
1.18	6.3	35.5	73.5
0.85	8.3	27.2	56.3
0.600	12.1	15.1	31.3
0.425	10.5	4.6	9.5
0.300	1.3	3.3	6.8
0.150	1.7	1.6	3.3
0.075	1.0	0.6	1.2
Pan	0.3	0.3	0.0

The values of the sieve size (mm) were plotted against the values of percentage of soil passing using grain size distribution graphs for each location.

Determination of Moisture Content by Oven Dry Method

The result of the test carried out to determine the Optimum moisture content of the soil samples is shown in Table 2 and Table 3

Table 2: Optimum moisture content (Before and after Infiltration) of the soil samples from all the locations.

Tools	Orlu (before)	Orlu (after)	
Can id	C	11	
Can + Ws	35.2	31.7	
Can + d.s	33.8	29.6	
Can	19.2	21.1	
d.s	14.6	8.5	
W	1.4	2.1	
W%	9.6	24.7	

The values of optimum moisture content before infiltration in Table 2 were used in computing for void ratios needed for the calculation of porosity in equation 2. The difference in values of optimum content (both before and after infiltration) were used in figure 2; to determine the sorptivity values needed for calculating infiltration using Philip's model.

The values of Specific gravity used in equation 5; for all the locations were calculated using equation 5; and the results shown in table 3.

Table 3: Determination of Specific Gravity. (Density Bottle Method)

Tools	Orlu	
M ₁	150.4	

M₂	160.2	
M₃	652.3	
M₄	646.3	
GL	1.00	
G_s	2.58	

Table 4. Results of Void Ratio and Porosity.

Tools	Orlu		
M%	9.6		
G_s	2.58		
E	0.25		
N	0.20		

Determination of the infiltrometer test

The double-ring infiltrometer was used during the test as recommended by (Ogbe et al., 2011, Duruanyim et al., 2025a, Duruanyim et al., 2025b) which gave the values for observed infiltration which was utilized during the analysis of the predicted values.

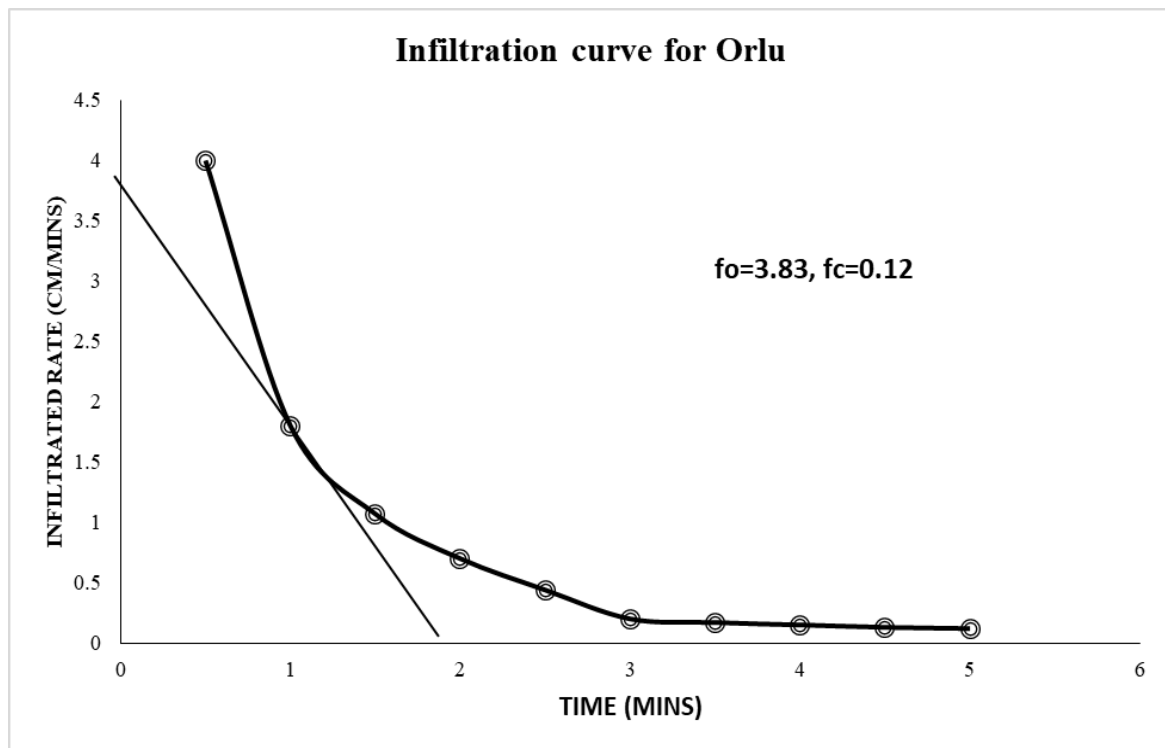


Figure 2: A graph showing the infiltration rate model curve for Orlu.

Determination of Infiltration Parameters for Horton’s Model

The infiltration test by means of double ring infiltrometer as described by (Ogbe et al., 2011, Duruanyim et al., 2025a) gave the values for observed infiltration which was used for all the

analysis with the predicted values. It also gave the values needed for computation of Horton's equation for calculating infiltration per time.

Infiltration rates predicted by models compared with measured values for all the locations

The result of the infiltration rates predicted by models compared with measured values for the locations under study indicates that at 5 cm/mins Green-Ampt, Horton and Philip models recorded 2.03, 4.07, and 1.30 cm/mins respectively.

Analysis Comparison

The values of the analysis using the T-test, Coefficient of Determination and Root Mean Square are shown in Table 5.

Table 5: Value of performance indices between predicted and measured values for all the locations.

Models	Green-Ampt	Horton	Philip
R ²	0.42	0.85	0.42
RMSE	0.29	5.32	2.33
T-TEST	2.56	305.42	139.68
Correction Factor	1.075	0.536	1.683

The correction factors for the models in all the location shows that Philip model has the highest value of 1.683, followed by Green-Ampt (1.075) and Horton (0.536) respectively.

DISCUSSION

The results obtained from this study provide important insights into the infiltration characteristics of sandy lateritic soils in Orlu, Imo State, and the applicability of three widely used infiltration models: Horton, Green–Ampt, and Philip.

The grain size distribution analysis revealed that the soil is predominantly sandy with minimal fines, as indicated by the high percentage passing through larger sieve sizes. This soil texture typically promotes relatively high infiltration rates due to larger pore spaces and reduced resistance to water movement. However, the measured infiltration rates in this study were moderate rather than excessively high, suggesting the influence of other controlling factors such as soil compaction, initial moisture content, and structural stability.

The increase in moisture content from 9.6% before infiltration to 24.7% after infiltration confirms active water intake and validates the reliability of the field measurements. This

change also reflects the soil's capacity to store water, which is critical for plant growth and groundwater recharge. The computed porosity (0.20) and void ratio (0.25) further support the moderate infiltration behavior observed, as these values indicate a soil structure with limited but effective pore connectivity.

The comparative evaluation of the infiltration models showed significant variation in predictive performance. The Horton model exhibited the highest coefficient of determination ($R^2 = 0.85$), indicating a strong correlation with observed data trends. However, despite this high correlation, the model substantially overpredicted infiltration rates by approximately 86.7%. This overestimation can be attributed to the empirical nature of the Horton model, which assumes an exponential decay of infiltration without explicitly accounting for soil physical properties such as suction head and moisture gradients. As a result, the model tends to perform well in curve fitting but may lack physical realism under certain field conditions.

The Green–Ampt model demonstrated the most reliable predictive capability among the three models. Although its coefficient of determination ($R^2 = 0.42$) was lower than that of the Horton model, it produced the lowest RMSE (0.28) and minimal deviation from observed values, underestimating infiltration by only 7.0%. This relatively high accuracy is due to the physically based nature of the Green–Ampt model, which incorporates key soil parameters such as hydraulic conductivity, wetting front suction, and moisture content differences. These parameters allow the model to better represent the actual infiltration process in the soil. This is in agreement with Duruanyim et al.(2025) which noted that Green-Ampt model made the best prediction because in the derivation of its model, the assumptions made were similar to the in-situ soil conditions where the experiments were conducted.

The Philip model also underestimated infiltration rates, with a deviation of about 40.6%. Its moderate performance can be linked to its reliance on sorptivity as a dominant parameter. While sorptivity effectively captures early-time infiltration dominated by capillary forces, it becomes less accurate over longer periods when gravitational effects become more significant. This limitation explains the model's reduced performance compared to the Green–Ampt model. The statistical performance indices further reinforce these observations. While Horton recorded the highest R^2 value, its RMSE and T-test values were significantly higher, indicating poor predictive reliability. In contrast, the Green–Ampt model achieved a better balance between statistical accuracy and physical representation of the infiltration process.

The correction factors obtained (1.075 for Green–Ampt, 0.536 for Horton, and 1.683 for Philip) suggest that all models require calibration for local conditions. The relatively small

correction factor for Green–Ampt indicates that it is inherently closer to the observed field behavior compared to the other models. The outcome of the results according to Machiwele et al., 2006; Oku and Aiyeleri, 2011 posited that very few of the infiltration models are better and for an exact site conditions which suggest that not all models are applicable in all soils.

CONCLUSION

This study evaluated the performance of Horton, Green–Ampt, and Philip infiltration models in predicting soil infiltration characteristics in a humid tropical environment in Orlu, Imo State, Nigeria. The results demonstrate that soil in the study area is predominantly sandy lateritic with moderate infiltration capacity influenced by its porosity, moisture content, and structural properties. Among the three models evaluated, significant differences were observed in their predictive performance. The Horton model showed a strong statistical correlation with observed data but significantly overestimated infiltration rates, limiting its practical applicability. The Philip model provided moderate predictions but underestimated infiltration due to its limitation in representing long-term infiltration behavior. The Green–Ampt model emerged as the most reliable and suitable model for the study area. Its predictions closely matched observed values with minimal error, owing to its incorporation of key soil physical parameters that govern infiltration processes. In conclusion, while empirical models like Horton may offer good curve-fitting capabilities, physically based models such as Green–Ampt provide more accurate and dependable predictions for infiltration in humid tropical soils. Therefore, the Green–Ampt model is recommended for hydrological modeling, irrigation planning, and soil water management in Orlu and similar environments.

REFERENCE

1. Akinbile, C. O. and Ogedengbe, K. (2006). On The Dynamics of Advance Wetting Front in Furrow Irrigation in Nigeria. *Journal of Applied Irrigation Science*, 41(2): 203-222.
2. Barcarolle, C. B. (1997). Influence of Well Preparation on Field Saturated Hydraulic Conductivity Measure with Guelph Parameter, *Gendarme*, 80(1 and 2): 169-180.
3. Chahinian, N., Moussa, R., Andrieux, P. and Voltz, M. (2005). Comparison of Infiltration
4. Models to Simulate Flood Events at the Field Scale. *Journal of Hydrology*, 306(1):191–214.

5. Dashtaki, S. G., Homae, M., Mahdian, M. H. and Kouchakzadeh, M. (2009). Site-dependence Performance of Infiltration Models. *Water Resources Management*, 23(13):2777–2790.
6. Duruanyim I.L, Egwuonwu C.C, Okorafor O.O, A.N Ofoma (2025). Prediction Efficiency of Philip Infiltration Model in Okigwe Zone Imo State, Nigeria. *Umudike Journal of Engineering and Technology (UJET)* ; Vol. 11, no 2, pp.11-17. Print ISSN : 25367404, Electronic ISSN : 2545-5257
7. Duruanyim I.L., O.O Okorafor, A.N. Ofoma, C.U. Ukaoha, C.C Egwuonwu, and C.I. Obineche. (2025).
8. Modeling Soil Infiltration Dynamics in Owerri, Nigeria: A Relative Study of Three Classical Infiltration Models”. *Journal of Global Agriculture and Ecology* 17 (4):78–93. <https://doi.org/10.56557/jogae/2025/v17i49982>
9. Green, W. H. and Ampt, G. A. (1911). *Studies in Soil Physics*. *Journal of Agricultural Science* 4:1–24.
10. Horton, R.E. (1940). An Approach towards a Physical Interpretation of Infiltration Capacity. *Soil Science Society of America Proceedings*, 5: 399-417.
11. Gupta, R. S., (2008). *Hydrology and Hydraulic Systems*, 3rd Edition, Waveland Press, Long Grove, IL.
12. Hillel, D. (1998). *Evaporation from Bare-surface Soils and Wind Erosion*. In *Environmental Soil Physics*. San Diego, CA: Academic Press, 508–522.
13. Machiwal, D., Jha, M.K., Mal, B.C. (2006). Modeling infiltration and Quantifying Spatial Soil Variability in Wasteland of Kharagpur India. *Biosystems Engineering*, 95: 569-582
14. Mazloom, H. and Foladmand, H. (2013). Evaluation and Determination of the Coefficients of
15. Infiltration Models in Marvdasht Regions, Fars province. *International Journal of Advanced Biological and Biomedical Research*, 1(8), 822-829.
16. Mbagwu, J. S. C. (1995). Testing the Goodness of Fit of Infiltration Models for Highly Permeable Soils under Different Tropical Soil Management Systems. *Soil Tillage Research*,34(3):199–205
17. Mirzaee, S., Zolfaghari, A. A., Gorji, M., Dyck, M. and Ghorbani, D. S. (2013). Evaluation of Infiltration Models with Different Numbers of Fitting in Different Soil Texture Classes. *Arch Agronomic Soil Science*, 1–13

18. Mishra, S. K. and Singh, V. P. (1999). Another Look at SCS-CN Method. *Journal of Hydrology Engineering*, 4(3):257–264
19. Ogbe, V. B., Jayeoba, O. J. and Ode, S. O. (2011). Comparison of Four Soil Infiltration Models on A Sandy Soil in Lafia, Southern Guinea Savanna Zone of Nigeria. *Publication of Nasarawa State University, Keffi*, 7(2): 116-126.
20. Oku, E. and Aiyelari, A. (2011). Predictability of Philip and Kostiakov Infiltration Model under Inceptisols in the Humid Forest Zone, Nigeria. *Kasetsart Journal (Natural Science)*, 45:594 - 602.
21. Okorie, Fidelis Chinazor, and Cyprain Ezedike (2014). Influence of Climate Variability on Mosquitoes Bite in Orlu Area of Imo state Nigeria. *Social Sciences*. Vol. 3, No. 6, pp. 183-188. doi: 10.11648/j.ss.20140306.11
22. Onyegbule, U. O., Azu, E. O., Donatus, O. and Akagha, U. N.(2018). Infiltration Characteristics of Soils in Owerri, Imo State, Southern Nigeria under Four Selected Land Uses. *Asian Soil Research Journal*, 1(3): 1-8.
23. Philip, J. R. (1957).The Theory of Infiltration: 2. The Profile at Infinity. *Soil Science*, 83: 435-448.
24. Philips, J. R. (1957). The Theory of Infiltration: The Infiltration Equation and its Solution. *Soil Science*, 83(5):345-358.
25. Putte, A. P., Covers, G., Leys, A., Langhans, C., Clymans, W. and Diels, J., (2013). Estimating the Parameters of the Green-Ampt Infiltration Equation from Rainfall Simulation Data: why simpler is better.*Journal of Hydrology*, 476: 332-334.
26. Shukla, M. K., Lal, R. and Unkefer, P. (2003). Experimental Evaluation of Infiltration Models for Different Land Use and Soil Management Systems. *Soil Science*, 168(3):178–191.
27. Sihag, P., Tiwari, N. K. and Ranjan, S. (2017a) Estimation and inter-comparison of infiltration models. *Water Science*, 31(1):34–43