The Pharma Innovation Journal 2023; 12(9): 2742-2747

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(9): 2742-2747
© 2023 TPI
www.thepharmajournal.com
Received: 15-07-2023
Accepted: 23-08-2023

Shubham Kindo
M. Tech Student, Department of Soil and Water Engineering, SVCAET&RS, FAE, IGKV, Raipur, Chhattisgarh, India

Narendra Agrawal
Assistant Professor, Department of Soil and Water Engineering, SVCAET&RS, FAE, IGKV, Raipur, Chhattisgarh, India

A Shori
Assistant Professor, Department of Soil and Water Engineering, SVCAET&RS, FAE, IGKV, Raipur, Chhattisgarh, India

MP Tripathi
Professor, SWE, Department of Soil and Water Engineering, SVCAET&RS, FAE, IGKV, Raipur, Chhattisgarh, India

Corresponding Author:
Shubham Kindo
M. Tech Student, Department of Soil and Water Engineering, SVCAET&RS, FAE, IGKV, Raipur, Chhattisgarh, India

Comparison and estimation of four infiltration models in Chhattisgarh plains

Shubham Kindo, Narendra Agrawal, A Shori and MP Tripathi

Abstract

An important component of the hydrological cycle is infiltration. In order to support the growth of plants, it contains soil moisture within the vadose zone. In this work, the validity of four infiltration models was compared to actual results obtained from a double-ring infiltrometer. The infiltration rate in the Chhattisgarh plains was measured at eight separate sites. The effectiveness of the models was evaluated by employing various established infiltration models, such as Horton's, Philip's, Kostiakov's, and Green-Ampt. Subsequent to fitting these models, their performance was assessed using the Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2), and root mean square error (RMSE). Comparing RMSE, NSE, and R^2 among the models, Philip's model shows the highest precision with RMSE values from 0.8433 to 1.8642, R^2 values between 0.935 and 0.981, and NSE values from 0.9347 to 0.9814 (measured in Cm/h). This outperforms Green-Ampt, Horton's, and Kostiakov's models. Philip's model's estimation of the infiltration rate is crucial for the planning and construction of irrigation systems. Therefore, Philip's model might be utilized to generate infiltration information in Chhattisgarh plains soils in the absence of measured infiltration data.

Keywords: Double ring infiltrometer, infiltration models, infiltration rate, Chhattisgarh plains soils

Introduction

Water infiltration through soils occurs naturally. It plays a significant role in the hydrological cycle. Through a process known as infiltration, water enters the soil through the top surface. The infiltration rate is the percentage of water that actually enters the soil at any given time. Infiltration, which is a critical factor for soil and water conservation, determines the amount of runoff that takes place on the surface of the land during irrigation and precipitation. The rate at which the soil is penetrating as well as other factors are important to determine if it can cope with too much rainfall or irrigation. Erosion and high water flows have an impact on the quantity of water held in plant root zones, which are indicators of poor infiltration rates. In view of this, it is therefore difficult for the land to fulfil its water requirement in order to produce crops.

Surface runoff and groundwater recharge are related to infiltration. It also aids in the design of flood management, landslide prevention, irrigation, drainage, and water delivery systems, among many other natural and artificial processes (Dagadu *et al.* 2012) [2]. The design, operation and maintenance of surface irrigation systems are strongly influenced by soil infiltration behaviour or characteristics to a large extent because these directly influence major factors such as inflow rate, cycle duration, application time and productivity depth. When quantitatively fitted into infiltration models, these soil properties related to infiltration are identified. However, not all soil types may be used with all infiltration models. The accuracy of individual models has been assessed by a range of researchers, as they compare the observed and measured rate of infiltration. Under different circumstances, a certain model provides better forecasts than other models. But as of now, it is not clear which model makes the better prediction (Turner, E.R. 2006) [17].

In order to assess the hydrologic processes, a number of infiltration models have been developed. Williams *et al.* (1998) [19] systematically and comprehensively presented and summarized these models. In various field conditions, researchers have been successful in the comparison and evaluation of these soil infiltration models. Eight different models of infiltration were evaluated in 2013 by Mirzaee and al. 2013 [8], using the least square sizes that would be taken into account for measured soil infiltration. Sihag *et al.* (2017a) [15] analyzed multiple infiltration models (Kostiakov, SCS, Novel model, and Modified Kostiakov) for the NIT Kurukshetra campus.

Compared to other models in which field infiltration data was used, the novel model showed greater suitability with respect to Singh's different soft computing techniques for predicting soil infiltration rates. Model parameters are to be identified in this study with a view to determining which model best fits the specific area of research.

Materials and Methods

Study area

On November 1, 2000, Chhattisgarh, the 26th state of the Indian Union, was created. The Chhattisgarh Plains, the Bastar Plateau, and the Northern Hills make up the three agro-climatic zones of the state of Chhattisgarh in East Central India. With an average annual rainfall of 1200 mm, Chhattisgarh is situated between 17°46' and 24°5' North Latitude and 80°15' and 84°20' East Longitude. 4.67 MHA of net sown land, or 34% of the state's total land area, makes up the state's estimated 13.78 MHA of total land area. The objective of the current inquiry is to determine the approximate location of the Chhattisgarh plains, which are located around 21°30' North and 81°45' East.

Sample Collection

A core cutter with a diameter of 10 cm and a height of 130 mm has been used to collect soil samples. In order to obtain the soil fractions for the determination of soil texture, disturbed soil samples were taken from the field at different sites and air-dried ground and were passed through a 2 mm sieve.

Measurement of Infiltration Rates

The tool utilized to calculate infiltration rates was a double-ring infiltrometer (ASTM 2003) [1]. The 600 mm inner ring and 300 mm outer ring make up the two components of the double-ring infiltrometer. The infiltrometer rings penetrated 700 mm of dirt. Without causing any damage to the topsoil surface, the hammer should strike the steel plate in an evenly balanced manner that is positioned on top of the ring. The water level in each circle remained unchanged until a consistent infiltration rate had been reached and the depth of water on an infiltrometer was monitored regularly. A sample of soil from a site close to the experimental area selected was collected for moisture content calculation at approximately 100 or 150 g.

Infiltration Models and Parameter

Four well-known infiltration models were chosen for this investigation, and model parameters were determined by data gathered from field measurements. The following infiltration models were assessed to find the best-fitting model for observed field infiltration rate data.

Horton's Model

In Horton's semi-empirical model, the decrease of infiltration capacity with time was stated as an exponential decay given by (Horton, R. E., 1940) [5].

$$I = f_c + (f_o - f_c)e^{-kt}$$

Where,
I is Infiltration capacity or potential infiltration rate [cm/h],
f_c is final constant infiltration rate [cm/h],
f_o is initial infiltration capacity [cm/h],
k is Horton's decay coefficient, which is dependent on soil characteristics and vegetation cover, and
t is the time after the start of infiltration (h).

The Horton model's parameter was established by plotting a graph of ln(I-f_c) against time (t) and identifying the optimal straight line that fits the plotted data points. The intercept of this line corresponds to ln(I-f_c), while the slope represents the k_h value.

Kostiakov's Model

Kostiakov's model expresses the cumulative infiltration equation as

$$F_p = at^b$$

Where,
F_p is cumulative infiltration capacity (cm/h)
t is time after infiltration starts, and
a and b are constants that depend on the soil and initial conditions.
Plotting ln(F_p) against ln(t) provides the parameter values for a and b. If the Kostiakov equation is applied to the data, the result is a straight line. The slope of the equation is b and the intercept is log an (infiltration rate at time t: l). The values of a and b range from 0 to l.

Philip's Model

Philip's two-term model is derived from the Taylor power series solution, as introduced by Philip in 1957 [12-13]. The relationship shown below represents the Philip two-term model:

$$f_p = \frac{1}{2}st^{-\frac{1}{2}} + k$$

Where,
f_p is infiltration capacity at any time step from the beginning
s is infiltration capacity at any time step from sorptivity of soil water,
k is the hydraulic conductivity of Darcy.

Green-Ampt Model

Green Ampt (Green, W.H. and Ampt, G.A. 1911) [3] proposed an infiltration capacity model based on Darcy's law, which is expressed as where m and n are Green Ampt's infiltration model parameters.

$$f = m + \frac{n}{F}$$

Where,
f is infiltration capacity
F is cumulative infiltration
m and n are Green-Ampt parameters of infiltration
Values of infiltration capacity, f are plotted against 1/F on an arithmetic graph. When considering the best-fitting straight line, the intercept on the vertical axis corresponds to the value of "m," while "n" represents the slope.

Comparison and validation of models

Root Mean Square Error (RMSE)

The root means square error is abbreviated as RMSE. When using a statistical model to predict a numerical outcome, predicted values rarely match actual outcomes completely.

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\left(\sum_{i=1}^{n}(a_i - b_i)^2\right)}$$

Where,
a is the calculated value of the infiltration rate
b is observed values of the infiltration rate
N is the number of observations

Nash-Sutcliffe Model Efficiency Coefficient

The Nash-Sutcliffe efficiency (NSE) is a standardized statistic that measures the proportion of residual variance to the variance of observed data, as introduced by Nash and Sutcliffe in 1970 [9].

An NSE value of 90% or more signifies excellent performance, a range of 80-90% indicates reasonably good performance, and a value below 80% indicates a poor fit.

$$\text{Model efficiency} = 1.0 - \frac{\sum_{i=1}^{n}(x-y)^2}{\sum_{i=1}^{n}(x-\bar{x})^2}$$

Coefficient of Determination (R^2)

A statistical models capacity to explain and predict future events is determined and evaluated using the coefficient of determination, often known as R^2. It describes how the observed and estimated infiltration rate data are related to each other.

The mathematical formula for computing R^2 is

$$R^2 = \left(\frac{z\sum ab - (\sum a)(\sum b)}{\sqrt{z(\sum a^2) - (\sum a)^2}\sqrt{z(\sum b^2) - (\sum b)^2}}\right)^2$$

Results and Discussions

Initial and Final Infiltration Rate and Mc (%) of Different Locations

The results of field infiltrations are summarised in Figure 2, together with an estimated computed rate of infiltration. Based on the results of field tests carried out at 8 different sites.Values obtained from various sampling sites show a range of 16.8 to 25.2 cm/h for the initial infiltration rate, 1.2 to 3.7 cm/h for the final infiltration rate, and 14.28 to 22.12% for soil moisture content.

From the result, the final infiltration rate in vertisols with a minimum value of 1.2 cm/h (at site-1) and higher values of 3.7 cm/h (at site-8). Extensive root systems, animals digging into the soil, inadequate presentation and disturbance of land caused by an infiltration ring facilitate variation in penetration rates. (Thomas *et al.* 2020) [18] The findings of this study's concluding infiltration results align with the outcomes of Zemke *et al.* (2019) [20], who assessed both undisturbed and disturbed sections within a pine forest. They reported infiltration rates of 2,622 and 935 mm h-1, respectively. Moreover, the vertisols displayed a notable moisture content of 22.12%.

Table 1: Details of initial and final infiltration rates and moisture contents of eight locations

Test Site	Soil type	Initial	Final	Mc (%)
1	Vertisols	20.4	1.2	22.12
2	Inceptisols	21.6	2.7	19.88
3	Alfisols	16.8	1.3	19.50
4	Entisols	25.2	3.4	14.28
5	Vertisols	22.8	1.8	21.08
6	Inceptisols	22.8	3.3	18.58
7	Alfisols	18.0	1.5	20.18
8	Entisols	21.6	3.7	16.19

Estimation of Infiltration Models parameter

Table 2 displays the values of several infiltration model parameters for various soil conditions for the infiltration models by Horton, Philip, Kostiakov, and Green-Ampt applied to clay loam soil under field conditions. For Horton's model, the empirical constant 'k' has values that vary from 2.25-3.16. In the Kostiakov infiltration model, the empirical constants 'a' have values that vary from 5.7-9.0, while 'b' has values that vary from 0.48- 0.60, respectively. In Philip's model, the constants 's' has values that vary from 12.5-17.27, and 'k' has values that vary from -5.23 to -1.58. and In the Green-Ampt model, the constants 'm' have estimated values that vary from -3.28 to 0.75 and 'n' has values of 29.44-53.76.

For determining the numerical values of the model parameters, the infiltration equation has been evaluated using experimental results from the study area. Based on this study, it was observed that the parameter values of infiltration models differ in terms of soil type and soil. (Dagadu *et al.*, 2012 [2] The estimated values of the parameter "b" for Kostiakov's model varied between 0.48 and 0.60 (as shown in Table 2). This observation aligns with infiltration theory, which dictates that the value of "b" should be positive and consistently less than one, as indicated by Ogbe *et al.* (2011) [10]. Several researchers have also reported negative values for k in literature studies, such as Shukla *et al.*, 2003 [14], and Machiwal *et al.*, 2006 [7] when using the Philip TwoTerm model to identify infiltration data taken from observed infiltration.

Table 2: Estimation of Infiltration Models parameter

Test site	Hortan's model	Kostiakov model		Philip's model		Green-Ampt model	
	k	a	b	s	k	m	n
1	2.68	6.56	0.48	14.85	-4.52	-3.28	43.76
2	3.16	8.37	0.55	15.69	-3.38	-0.31	45.24
3	2.57	5.70	0.49	12.50	-3.62	-2.04	29.44
4	3.13	8.95	0.53	17.08	-3.80	-0.76	50.84
5	2.72	7.58	0.48	17.27	-5.23	-2.57	53.76
6	2.25	9.00	0.60	13.81	-1.58	0.75	42.67
7	2.80	6.06	0.48	13.42	-3.90	-2.26	34.02
8	2.89	8.53	0.58	13.94	-1.95	0.41	42.91

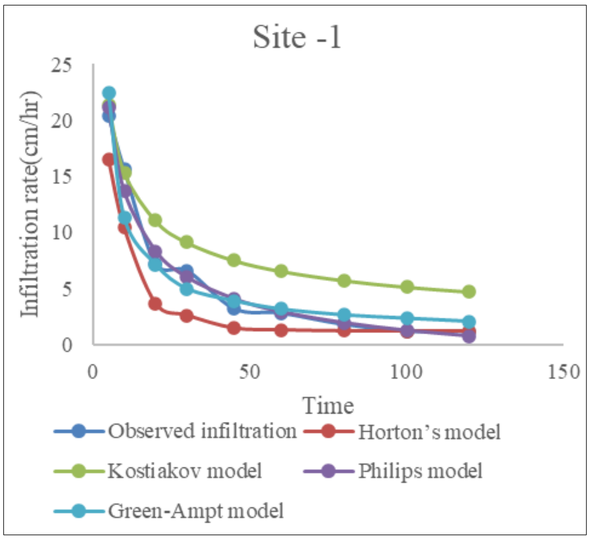
Performance Evaluation of the Infiltration Model

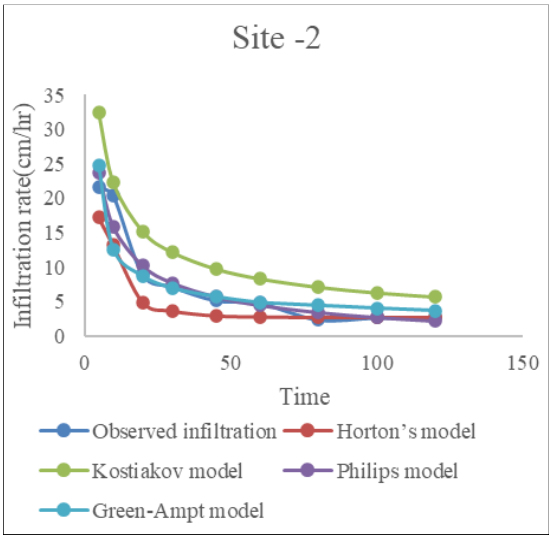
RMSE, NSE, and R^2 techniques were employed to assess infiltration models. The optimal model selection relied on the highest R^2, NSE, and RMSE values. Table 3 summarizes the results, showing average R2 values of 0.9568, 0.9635, 0.9638, and 0.8962, NSE values of 0.8085, 0.5453, 0.9645, and 0.878, and RMSE values of 2.9307, 4.8530, 1.2030, and 2.0917 cm/h for Philip's, Horton's, Green-Ampt, and Kostiakov models respectively.

Comparing the values of R2, NSE, and RMSE, it is evident that Philip's model outperforms the Green-Ampt, Horton, and Kostiakov models. As a result of this comparison, Philip's model was selected for evaluating infiltration rates in this study area due to its superior performance when compared to similar models used in the region. This outcome aligns with the findings of Thomas *et al*. (2020) [18], who examined four infiltration equations on both silt and sandy soils, highlighting Philip's model as a highly accurate representation of infiltration. The capability of these models to precisely estimate infiltration rates for specific sites was emphasized by Haghighi *et al*. (2010) [4], and Machiwal *et al*. (2006) [7] demonstrated that certain infiltration models are more suitable than others depending on site conditions. Oku *et al*. (2011) [11] reinforced this idea, indicating that not all models are universally applicable to all types of soils. Thus, the application of these models under validated field conditions has yielded insights into appropriate infiltration characteristics for equations, enhancing simulation and irrigation efficiency to reduce water losses, as indicated by Kankam *et al*. (1997) [6].

Table 3: Performance evaluation parameters of infiltration models

Test site	Hortan's	Kostiakov	Philip's	Green-Ampt
Root means square error (RMSE)				
1	2.8993	3.3039	0.8841	1.7837
2	3.5015	5.4331	1.7959	2.9510
3	2.4067	2.9758	1.1079	1.9905
4	3.3116	5.1352	1.0177	2.0903
5	3.3642	4.1880	1.8642	3.1746
6	2.6655	7.9811	0.8433	1.0025
7	2.5807	3.1382	1.2411	2.1875
8	2.7161	6.6693	0.8700	1.5539
Average	2.9307	4.8530	1.2030	2.0917
Nash-Sutcliffe model efficiency (NSE)				
1	0.800	0.741	0.981	0.924
2	0.752	0.402	0.935	0.823
3	0.881	0.709	0.960	0.870
4	0.803	0.527	0.981	0.822
5	0.814	0.711	0.943	0.834
6	0.805	0.748	0.980	0.983
7	0.811	0.721	0.956	0.804
8	0.802	-0.196	0.980	0.964
Average	0.8085	0.5453	0.9645	0.878
Coefficient of determination (R^2)				
1	0.9576	0.9818	0.9814	0.9245
2	0.9460	0.9312	0.9347	0.8236
3	0.9585	0.9602	0.9597	0.8701
4	0.9580	0.9818	0.9814	0.9216
5	0.9625	0.9374	0.9364	0.8287
6	0.9566	0.9809	0.9805	0.9724
7	0.9633	0.9567	0.9563	0.8644
8	0.9521	0.9781	0.9796	0.9642
Average	0.9568	0.9635	0.9638	0.8962





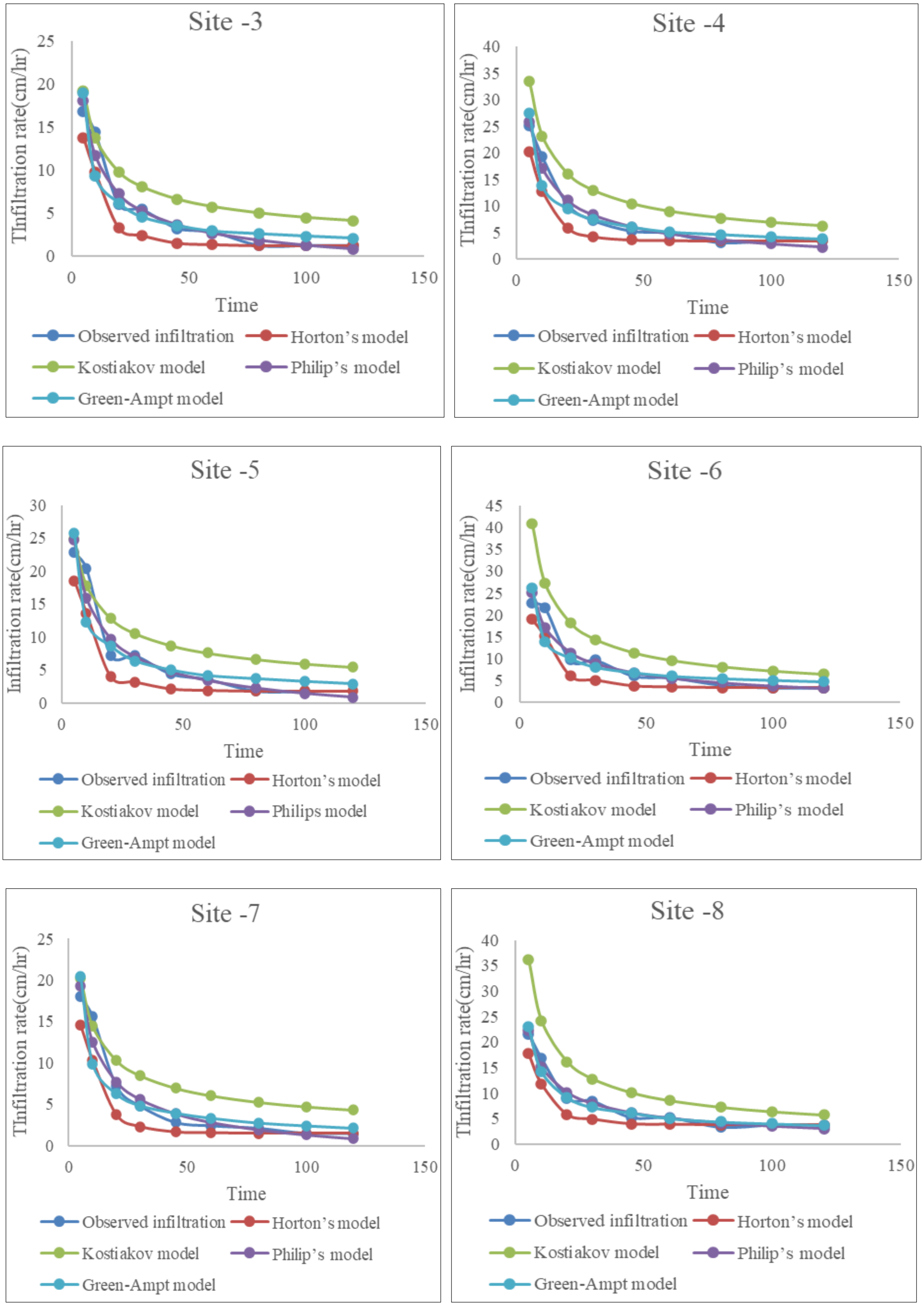


Fig 2: Comparison of observed infiltration rate with various models estimated infiltration rate for the study area.

Conclusions

Infiltration plays a significant role in the hydrological cycle and constitutes a focal point in the field of hydrology. The infiltration rate data for different types of soil are particularly important in planning and building water supply schemes, as well as understanding the rainfall process. The prediction accuracy of four infiltration models has been validated through the use of two overlapping infiltrometer measurements. When the field and predicted rate of infiltration were compared, it was found to be much more similar to the observed data by Philip's model.

The rate of infiltration in this order may be predicted on the basis of a performance evaluation based upon Philip's, Green Ampt, Horton and Kostiakov models. Philip's model came up with the lowest values, and based on RMSE, R2 and NSE average values it can be inferred that this model accurately captured an infiltration rate. Using this model, it will be important to quantify the amount of infiltration in order to plan and schedule irrigation. If there were no obvious evidence of infiltration, Philip's approach would be a suitable one to artificially generate the data on infiltration.

References

1. ASTM Standards. Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer. D; c2003. p. 3385-9403
2. Dagadu JS, Nimbalkar PT. Infiltration Studies of Different Soils under Different Soil Conditions and Comparison of Infiltration Models with Field Data. International. Journal of Advance Engineering Technology. 2012;3:154-157.
3. Green WH, Ampt GA. Studies on Soil Physics, 1: The Flow of Air and Water through Soils. The Journal of Agricultural Science. 1911;4:1-24. https://doi.org/10.1017/S0021859600001441
4. Haghighi F, Gorji M, Shorafa M, Sarmadian F. Evaluation of Some Infiltration Models and Hydraulic Parameters. Spanish Journal of Agricultural Research. 2010;8:210-216. https://doi.org/10.5424/sjar/2010081-1160
5. Horton RE. Approach toward a Physical Interpretation of Infiltration Capacity. Soil Science Society of America Journal. 1940;5:339-417.
6. Kankam Yeboah K, Duah AA, Mensah FK. Design and Construction of Hund Dug Wells at Besease Technical Report. Water Research Institute (CSIR), Accra, Ghana; c1997. p. 16.
7. Machiwal D, Jha MK, Mal BC. Modelling infiltration and quantifying spatial soil variability in a watershed of Kharagpur, India. Biosystems Engineering. 2006;95(4):569-582. https://doi.org/10.1016/j.biosystemseng.2006.08.007
8. Mirzaee S, Zolfaghari AA, Gorji M, Dyck M, Ghorbani Dashtaki S. Evaluation of infiltration models with different numbers of fitting in different soil texture classes. Arch Agron Soil Science; c2013. p. 1-13.
9. Nash JE, Sutcliffe JV. River flow forecasting through conceptual models part I—a discussion of principles. 3 1970;10(3):282-290.
10. Ogbe VB, Jayeoba OJ, Ode SO. Comparison of Four Soil Infiltration Models on A Sandy Soil in Lafia, Southern Guinea Savanna Zone of Nigeria. Production Agriculture and Technology, Nasarawa State University Journal. 2011;7:116-126.
11. Oku E, Aiyelari A. Predictability of Philip and Kostiakov infiltration models under inceptisols in the humid forest zone, Nigeria. Agriculture and Natural Resources. 2011;45(4):594-602.
12. Philip JR. The theory of infiltration: 1. The infiltration equation and its solution. Soil science. 1957;83(5):345-358.
13. Philip JR. The Theory of Infiltration: 2. The Profile at Infinity. Soil Science. 1957;83:435-448. https://doi.org/10.1097/00010694-195706000-00003
14. Shukla MK, Lal R, Unkefer P. Experimental evaluation of infiltration models for different land use and soil management systems. Soil Science. 2003;168(3):178-191.
15. Sihag P, Tiwari NK, Ranjan S. Estimation and inter-comparison of infiltration models. Water Science. 2017a;31(1):34-43.
16. Sihag P, Tiwari NK, Ranjan S. Modelling of infiltration of sandy soil using gaussian process regression. Model Earth Syst Environment. 2017b;3(3):1091-1100.
17. Turner E. Comparison of infiltration equations and their field validation by rainfall simulation. University of Maryland, College Park; c2006.
18. Thomas AD, Of Osu AE, Emmanuel A, De-Graft AJ, Ayine AG, Asare A, *et al*. Comparison and estimation of four infiltration models. Open Journal of Soil Science. 2020;10(2):45-57.
19. Williams JR, Ying O, Chen JS, Ravi V. Estimation of infiltration rate in the vadose zone: application of selected mathematical models. vol 2 (No. PB–98-147317/XAB). ManTech Environmental Technology, Inc., Research Triangle Park, NC (United States); Dynamac Corp., Ada, OK (United States); National Risk Management Research Lab., Subsurface Protection and Remediation Div., Ada, OK (United States); c1998.
20. Zemke JJ, Enderling M, Klein A, Skubski M. The influence of soil compaction on runoff formation. A case study focusing on skid trails at forested andosol sites. Geosciences. 2019;9(5):204.