

Application of Horton's infiltration model for the soil of Dediapada (Gujarat), India

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Abstract

The design and evaluation of surface irrigation systems of a site requires reliable data of infiltration which could be provided by an infiltration model. In this study, Horton's infiltration model has been estimated for the soil located in a field of College of Agricultural Engineering and Technology, Dediapada, Gujarat using the infiltration data obtained from several locations in the field using double ring infiltrometer. The decay constant of the Horton's infiltration model was obtained using graphical method and also by using semi-log plot of t (time) vs. $(f - fc)$, where f is the infiltration rate (mm/hr) and fc is the initial rate of infiltration capacity (mm/hr). The potential of the Horton's infiltration model so obtained was evaluated by least square fitting with the observed infiltration data. The Horton's infiltration model was used to estimate infiltration rate (mm/hr) and cumulative infiltration (cm). The Horton's model for infiltration rate obtained by semi-log plot method was obtained as $i = 20 + 94 e^{-7.02t}$, where i = infiltration rate (mm/hr) and t = time (min). The coefficient of determination obtained when the infiltration model was applied to observation data taken at various points in the field were found to 0.96. Therefore, it could be inferred that the Horton's infiltration model could give a reliable estimate of infiltration for the soil of Dediapada.

Keywords: Cumulative infiltration, Double ring infiltrometer, Graphical method, Horton's Infiltration model, Infiltration rate

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INTRODUCTION

The flow of water through the surface of the soil is termed as infiltration. The water which is infiltrated replenishes the moisture deficiency in the soil while the excess water which moves downward by gravity force is responsible for building ground water table. Although a negligible proportion of soil water is present on earth compared to the total water present on earth surface, it is of paramount importance for plant life. The infiltration rates are necessary for estimation of groundwater recharge, effective rainfall and effective design of irrigation systems (Michael, 1978). The use of infiltration models in quantifying infiltration plays a major role in watershed management. Also, being one of the most important components of hydrologic cycle, it is becomes essential to estimate infiltration rate and cumulative infiltration for complex analysis of watershed. Efficiency in the application of irrigation water is of great economic importance especially to countries with limited water supplies (Akinbile *et al.*, 2006). The infiltration

process of a particular site can be assessed effectively using double ring infiltrometer, however, it becomes a tedious task to obtain infiltration data by this method which can otherwise be obtained in comparatively easier and reliable manner using infiltration model developed for the particular site of study. Therefore, infiltration models should be developed using the infiltration data available for different sites at various antecedent moisture conditions and suitable models should be developed or constants of existing infiltration models should be modified using standard methods. Numerous infiltration models have been used to estimate infiltration rates, however, in this study, only Horton's infiltration model has been evaluated.

Mishra *et al.* (2003) assessed Horton's infiltration model by conducting various infiltration tests in the laboratory and fields in USA and India. It was concluded from the study that Horton's infiltration model performed satisfactorily with an efficiency of 75% to 90%. Amin *et al.* (2006) used Horton's infiltration model to estimate cumulative infiltration at research farm sites of Agricultural and Biore-

source Engineering Department of Abubakar Tafawa Balewa University (ATBU), Bauchi, Nigeria. The parameters f_c , f_0 and k of the model were found to be 30, 65.97 and -1.73 respectively. When the cumulative infiltration was compared with observed infiltration, the coefficient of determination was found to be 0.893. T-test results also indicated that Horton's model performed satisfactorily. Zolfaghari *et al.* (2012) estimated cumulative infiltration for different provinces of Iran with different soils using Horton's infiltration model. The double ring infiltrometer was used to obtain the infiltration rate and cumulative infiltration. It was found that the coefficient of determination of Horton's infiltration model was found to be 0.960 which indicated that cumulative infiltration could be determined reliably by Horton's infiltration model. Sreejani *et al.* (2017) observed the evaluate infiltration characteristics at five different locations of Andhra University campus using a single and double ring infiltrometer and evaluated Horton's infiltration model. When the observed infiltration data was compared with the estimated infiltration data by Horton's model, it was found that the correlation coefficient was 0.96 and standard error was 2.0. Savasani *et al.* (2017) evaluated the performance of infiltration models on different soil types in Sangola region in solapur district of Maharashtra state and concluded that Horton's infiltration model performed better than other models like Kostiaikov and Green-ampt with a correlation coefficient of 0.98. The study was undertaken with the objective of obtaining the parameters of the Horton's infiltration model by graphical method and semi-log plot method. The performances of the infiltration equations were compared with the observed infiltration data to obtain the appropriate Horton's infiltration model.

MATERIALS AND METHODS

Study area: The study was conducted at various sites in a field of College of Agricultural Engineering and Technology, Dediapada Taluka of Narmada district in South Gujarat at 21°66" N latitude and 73°59" longitude with an elevation of 169 m above mean sea level.

The infiltration data was obtained from infiltration tests conducted by double ring infiltrometer at 10 different locations selected randomly in the field of 1hectare area adjacent to the Agricultural Engineering College building in Dedipada, Gujarat. The soil texture in the field was clay loam. The inner cylinder and outer cylinder used in the double ring infiltrometer test were 30 cm and 60 cm in diameter respectively. A buffer pond was created between the cylinders to reduce the loss due to lateral seepage. A hammer was used to drive the cylinders into the soil at 10 cm depth. The water was filled into the inner cylinder up to the point rod set at desired level and the time interval was not-

ed at various intervals as given in Table 1 to obtain the depth of infiltration. The observed infiltration data were used to evaluate the parameters of the Horton's infiltration model which was then used to estimate infiltration data.

Horton (1940) gave the following equation to obtain infiltration rate:

$$f = f_c + (f_0 - f_c)e^{-kt} \dots (1)$$

where,

f = infiltration rate at time t (mm/hr)

f_0 = initial rate of infiltration capacity (mm/hr)

f_c = final constant rate of infiltration at saturation (mm/hr)

k = a constant depending primarily upon soil and vegetation

e = base of the Napierian logarithm

t = time from beginning of the storm (hr)

Horton's model is empirical and it describes the familiar exponential decay of infiltration capacity evident during heavy storms. According to Horton's model, infiltration starts at a constant rate f_0 and decreases exponentially with time. After some time, when the soil saturation level reaches a certain value, the rate of infiltration becomes equivalent to f_c .

Infiltration capacity is the maximum rate at which the soil is capable of absorbing water. The term f_c denotes it in equation (1). It is also known as final constant rate of infiltration at saturation.

The parameters of Horton's infiltration model were determined in this study using two methods viz. (1) graphical method and (2) semi log plot method.

Graphical method: In this method, a linear graph plot of infiltration rate (mm/hr) vs. time t (min) was drawn and the area under the graph (F_c) where the infiltration rate becomes constant was taken. The value of F_c is used to obtain the value of the decay constant k in the Horton's equation.

$$k = \frac{f_0 - f_c}{F_c} \dots (2)$$

The value of f_c was obtained simply by observing the constant values of infiltration rate after a significant time had passed while the value of f_0 was obtained by projecting the graph on the y-axis (infiltration rate). The values of the parameters obtained for the Horton's infiltration model was used to estimate infiltration rate which were compared with the observed infiltration rate. The coefficient of determination was used as the measure of performance. As for accumulated infiltration depth (F), the Horton's equation was integrated using minimum and maximum time limits that were taken during the observation. The accumulated infiltration depth was evaluated using the following equation:

$$F = \int_0^t f_c + (f_0 - f_c)e^{-kt} dt \dots (3)$$

Semi-Log plot method: To obtain the parameters

of the Horton's model by this method, log is taken on both sides of equation (1).

$$\log(f - f_c) = \log(f_0 - f_c) - kt \log(e)$$

$$t = \frac{\log(f_0 - f_c)}{k \log(e)} - \frac{\log(f - f_c)}{k \log(e)} \dots (4)$$

Equation (4) is in form of a straight line $y=mx + c$ where,

$$m = - \frac{1}{k \log(e)}, y = t \text{ and } x = \log(f - f_c) \dots (5)$$

Semi-log plot of t vs. $(f-f_c)$ was used to obtain the required parameters of the Horton's infiltration model. The accumulated infiltration depth was obtained using equation (3) as given in the graphical method. The infiltration equations obtained by both the methods were compared with the observed infiltration data and the coefficient of determination was determined.

RESULTS AND DISCUSSION

The following average infiltration data were obtained by conducting double ring infiltrometer test at various locations in the field.

Graphical method: Time t (min) vs. f (mm/hr) was plotted on a natural graph paper as shown in Fig.2.

The value of f_c which is the constant infiltration rate was found to be 20 mm/hr and the value of f_0 was found to be 105 mm/hr after projecting the Horton's curve on the y-axis. The shaded area F_c was found to be 6120 sq. units. The value of F_c so obtained was appropriately converted into mm by multiplying the units of the axes. The final value of F_c was evaluated as 102 mm. After substituting the final value of F_c in equation, the value of k was found to be 0.93. Thus, the Horton's equation was obtained in the following form:

$$f = 20 + 95e^{-0.93t} \dots (6)$$

Where, t is in hours.

The equation was used to estimate the infiltration rate (mm/hr) and it was compared with the observed values taken at two different sites in the field as shown in Fig 3.

$$F = \int_0^{470} 20 + 95e^{-0.93t} dt \dots (7)$$

The accumulated infiltration F after t hours was obtained after integrating the above equation with limits $t=0$ to $t=470$. It was found that the estimated accumulated infiltration depth and observed infiltration depth were 258.6 mm and 304 mm respectively after 7.8 hours.

Semi-Log plot method: The Horton's model parameters were then estimated using semi-log of time (t) vs. $f-f_c$ as shown in Fig 4.

The slope of the best fitting line as shown in the Fig. was found to be 135 which was divided by 60 as the k value is to be obtained in hr^{-1} units. Since $f = f_0$ when $t = 0$, $f - f_c = f_0 - f_c$.

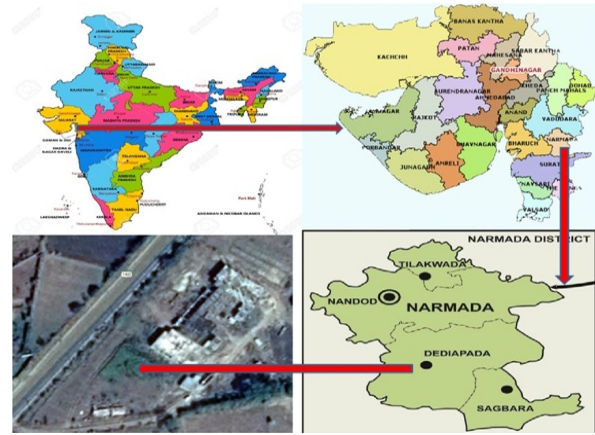


Fig. 1. Location of the study area.

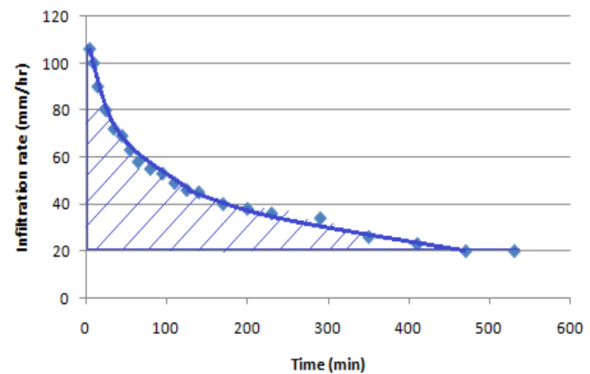


Fig. 2. Horton's infiltration curve showing infiltration rates at various times.

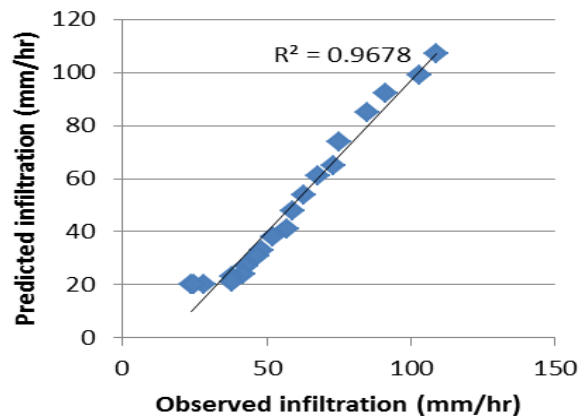
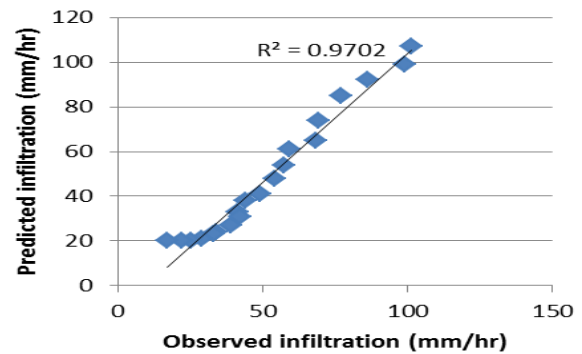


Fig. 3. Comparison of observed and predicted infiltration rate (Horton's graphical method).

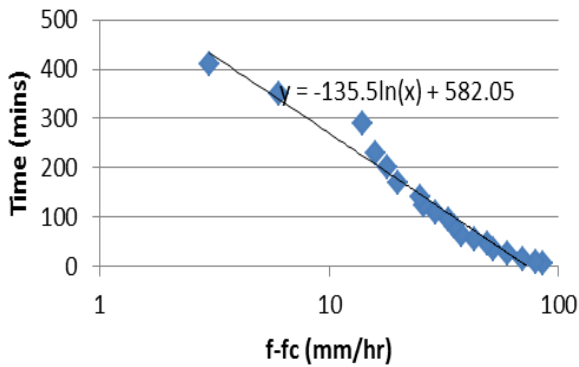


Fig. 4. Time t (min) vs. infiltration rate $f-f_c$ mm/hr.

$$m = -\frac{135}{60} = -\frac{1}{k \log(e)}$$

$$\therefore k = \frac{1}{2.25 \times 0.434} = 1.02 \quad \dots (8)$$

Also from the graph, when $t=0$, $f_0-f_c=74$.

$$f - f_c = 74 = f_0 - f_c$$

$$\therefore f_0 = 74 + f_c = 74 + 20 = 94$$

The following Horton's equation for infiltration rate is obtained.

$$f = 20 + 94 e^{-1.02t} \quad \dots (9)$$

The above equation was used to estimate the infiltration rate which was compared with the observed infiltration rate taken at two sites in the field as shown in Fig. 5.

$$F = \int_0^{470} 20 + 94 e^{-1.02t} dt \quad \dots (10)$$

The accumulated infiltration F after t hours was obtained after integrating the above equation with limits $t=0$ to $t=470$. It was found that the estimated

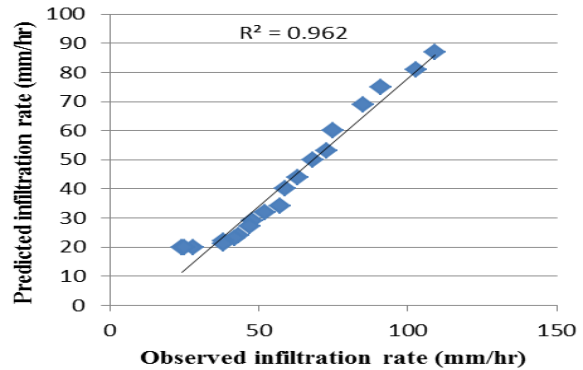
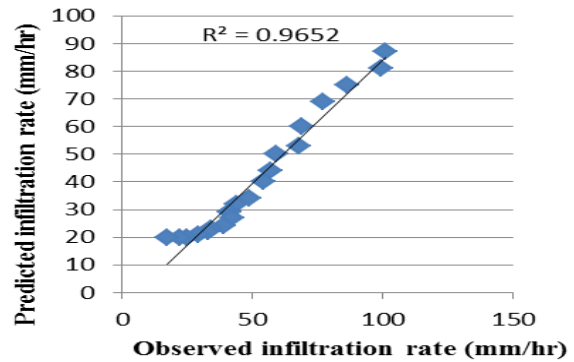


Fig. 5. Observed vs. predicted infiltration rate (log plot method).

accumulated infiltration depth and observed infiltration depth were 248.7 mm and 304 mm respectively after 7.8 hours.

It was observed from the study that the coefficient of determination obtained on comparison of observed and predicting infiltration rates was found to be 0.96 and therefore it can be concluded that the Horton's infiltration model could be used to

Table 1. Infiltration data obtained by double ring infiltrometer test.

Time t (min)	Before filling	After filling	Infiltration depth d (mm)	Infiltration rate f (mm/hr)	Cumulative infiltration F (mm)	$f-f_c$ (mm/hr)
5	141	150	9	106	9	86
10	142	150	8	100	17	80
15	143	150	8	90	25	70
25	137	150	13	80	38	60
35	138	150	12	72	50	52
45	139	150	12	69	61	49
55	140	150	11	63	72	43
65	140	150	10	58	82	38
80	136	150	14	55	95	35
95	137	150	13	53	109	33
110	138	150	12	49	121	29
125	139	150	12	46	133	26
140	139	150	11	45	144	25
170	130	150	20	40	164	20
200	131	150	19	38	183	18
230	132	150	18	36	201	16
290	116	150	34	34	235	14
350	124	150	26	26	261	6
410	127	150	23	23	284	3
470	130	150	20	20	304	0
530	130	150	20	20	324	0

estimate infiltration rate. However, the parameter of models are site specific and therefore the model should not used on other sites without making necessary modifications. Ajayi *et al.* (2016) also evaluated the decay constant k of the Horton's infiltration model and obtained different values for sandy soils at the Department of Agricultural Engineering experimental field, Samaru, Zaria, Nigeria. They concluded that the semi log plot method was less error prone compared to the graphical method. Sreejani *et al.* (2017) and Savasani *et al.* (2017) had also obtained high correlation coefficient of 0.96 and 0.98 respectively, for clay loam soils at Andhra University Campus, Visakhapatnam and Sangola region in solapur district of Maharashtra state respectively, after comparing estimated infiltration by Horton's model with the observed values. The results obtained in this study also revealed that high correlation coefficients were obtained when the Horton's model was used to simulate infiltration data and both method of obtaining parameters of the Horton's model could be successfully used for simulating infiltration rate as indicated by high coefficient of determination values.

Conclusion

The tedious task obtaining infiltration data on the same field for different experiments and analysis could be minimized by making use infiltration model such as Horton's infiltration model. In order to obtain the value of the decay constant in the Horton's infiltration model, two methods namely graphical and semi log method were used and it was concluded that the decay constant k was in both the methods were found to be close to each other. Also the Horton's infiltration model obtained by both the methods exhibited reliable perfor-

mance when compared with the observed infiltration data. The Horton's model for infiltration rate obtained by semi-log plot method was obtained as $i=20 + 94 e^{-1.02t}$, where i =infiltration rate (mm/hr) and t = time (min).

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