



A NOVEL METHODOLOGY FOR INFILTRATION MODEL STUDIES

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Abstract:

Infiltration is treated as one of the important parameter of the hydrological cycle as far as ground water recharge is concerned. It depends on soil characteristics such as soil texture, hydraulic conductivity, soil structure, vegetation cover, porosity, permeability, degree of saturation etc. Determination of infiltration rates is useful for mitigation of hydrological risk and reflects the future of ground water resources in the study area. Infiltration of water into the soil is determined by a simple instrument called Double ring infiltrometer. Infiltration models are the empirical formulae developed using infiltration concepts which is used to determine the infiltration rate of soil. One way ANOVA test was performed to find the significance of the infiltration models. In the present study an attempt is made to validate the Horton's model, Green ampt model and Kostiakov's infiltration model with observed field data for a residential area, Ernakulam. From the present study significant model for the particular site is determined by using decision factor analysis.

Keywords: *Infiltration; Double Ring Infiltrometer; Horton's Model; Kostiakov's Model; Green Ampt Model; One Way ANOVA; Correlation Coefficient.*

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1. Introduction

Soil infiltration refers to the soil's ability to allow water movement into and through the soil profile. Infiltration rates are a measure of how fast water enters the soil and are typically expressed in inches per hour. Infiltration capacity may be defined as the maximum rate at which a given soil at a given time can absorb water. It depends upon a large number of factors such as characteristics of the soil, vegetative cover, condition of the soil surface, soil temperature, water content of the soil, rainfall intensity, etc. Infiltration of water into the soil can be determined by a simple instrument called Double ring infiltrometer. The cylindrical ring made up of stainless steel are partially inserted into the soil and filled with water, after which the speed of infiltration is measured. Two cylinders of different diameter are taken for this experiment. The outer ring limits the lateral spread of water after infiltration. The field work for finding the infiltration rate is time consuming and is troublesome. There are certain infiltration models using which we can find the infiltration rate without any field work. The infiltration models selected for the present study are Horton's model, Green ampt model and Kostiakov's model.

2. Methodology

The double ring infiltrometer which consists of two concentric hollow rings or cylinders is driven into the soil uniformly without any tilt and disturbing the soil, to the least depth of 15 cm. The diameter of the inner ring is 30 cm and that of outer ring is 60 cm. Water is applied in both the inner and outer rings. The water depth in the outer ring should be kept the same during the observation period. The measurement includes the recording of volume of water added into the inner compartment, to maintain the constant water level and the corresponding elapsed time. As the purpose of the outer ring is to suppress the lateral percolation of water from the inner ring, the water added to it need not be measured though water is added to it to maintain the same depth as the inner ring. Observations are continued till constant infiltration rate is observed.



Figure 1: Double Ring Infiltrometer

2.1. Infiltration Models

2.1.1. Horton's Model

Horton expressed decrease of infiltration capacity with time as an exponential function.

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

- F → Infiltration capacity at any time
- f_c → Final steady state infiltration capacity
- f_o → Initial infiltration capacity
- t → Time in hours
- k → Horton's constant representing rate of decrease in infiltration capacity

2.1.2. Green Ampt's Model

Green Ampt presented an approach based on fundamental equation

$$F = K \left(\left(\frac{\Psi \Delta\theta}{F} \right) + 1 \right)$$

- F → Infiltration capacity
- K → Effective hydraulic conductivity
- Ψ → Suction head at wetting front
- $\Delta\theta$ → Increase in moisture content
- F → Cumulative infiltration

2.1.3. Kostiakov's Model

$$F = K_k t^{-\alpha}$$

- F → Infiltration capacity
- t → Time after infiltration starts
- K_k, α → Graphical parameters

2.2. Statistical Parameters

Three statistical parameters such as one way ANOVA test, correlation coefficient and standard error was used for comparing the observed values of infiltration rate with the infiltration models.

2.2.1. One Way Anova

The one-way analysis of variance (ANOVA) is used to determine whether there are any statistically significant differences between the means of an independent group and related dependent groups. The level of significance of various infiltration models with the observed infiltration rate from the field was found out using one way ANOVA test.

Total sum of squares = Sum of squares between groups + Sum of squares within groups

2.2.2. Correlation Coefficient

A correlation coefficient is a number that quantifies a type of correlation and dependence meaning statistical relationships between two or more values in fundamental statistics. Pearson's r , a measure of the strength and direction of the linear relationship between two variables that is defined as the covariance of the variables divided by the product of their standard deviations. The range of values for the correlation coefficient is from -1.0 to 1.0. A correlation of -1.0 indicates a perfect negative correlation, while a correlation of 1.0 indicates a perfect positive correlation. If the correlation is 0, this simply means there is no relationship between the two variables. The strength of the relationship varies in degree based on the value of the correlation coefficient.

2.2.3. Standard Error Of Correlation Coefficient

The standard error of the correlation coefficient is a parameter which measures how precisely the model estimates the coefficient's unknown value. The smaller the standard error, the more precise the estimate. The standard error of the coefficient is always positive. The standard error of correlation coefficient is given by

$$\sqrt{\frac{1 - R^2}{n - 2}}$$

R^2 → coefficient of determination

n → Number of observations

2.2.4. Decision Factor

Decision factor is the difference between correlation coefficient and standard error. The one with highest value of decision factor is said to be the best fitting one. Here, the model with highest value of decision factor will be the model best matching with the observed field data.

Decision factor (η) = Coefficient of determination (R^2) – Standard error (SE)

2.2.5. SPSS

SPSS Statistics is a software package used for logical batched and non-batched statistical analysis. The software name originally stands for Statistical Package for the Social Sciences. Bivariate statistics is also included in the base software. One way ANOVA test and Correlation Coefficient can be analyzed using this software.

3. Field Infiltration Data

The set of data were collected from a Residential area. The infiltration test was conducted at the site using double ring infiltrometer. The initial moisture content of the selected area was determined by adopting oven dry method and was found to be 13.11%. The soil was classified on the basis of USDA classification. The type of soil was identified as sand.

From the observed value the infiltration rate was determined as shown in the table 1

Table 1: Infiltration rate for the residential area

Time (min)	Volume of Water added (ml)	Infiltration rate (cm/hr)
5	2630	44.81
10	2000	33.97
15	2000	33.97
20	1500	25.54
25	1350	22.89
30	1375	23.37
35	2000	33.97
40	1200	20.36
45	1200	20.36
50	1350	22.89

55	1150	19.51
60	1320	22.4
65	1000	16.98
70	1330	22.65
75	1000	16.98
80	1000	16.98
85	1300	22.04
90	1275	21.68
95	800	13.61
100	900	15.3
105	900	15.3
110	900	15.3
115	900	15.3

The constant infiltration capacity of the Residential area was found to be 15.3 cm/hr. The infiltration capacity curve for the site was drawn by plotting infiltration rate(cm/hr) against time in minutes.

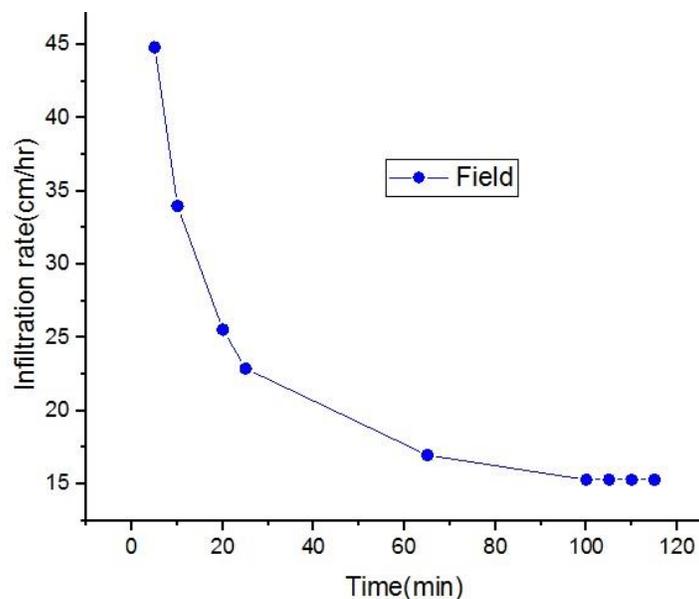


Figure 2: Infiltration Capacity Curve

4. Analysis of Results

Comparison of field infiltration data with horton’s model, Green ampt’s model and Kostiakov model was done. By making use of the parameters defined earlier, horton’s model values, Green ampt’s model values and Kostiakov’s model values are determined and is furnished in Table- 2

Table 2: Comparison of Infiltration Rates in cm/hr

Time (min)	Observed Infiltration rate	Horton's model	Green Ampt's model	Kostiakov's model
5	44.81	54.57	31.66	43.72
10	33.97	49.74	27.77	34.4
15	33.97	45.56	26.5	29.95
20	25.54	42.01	25.89	27.23
25	22.89	38.66	25.48	25.15
30	23.37	35.79	25.22	23.62
35	33.97	33.38	25.04	22.44
40	20.36	31.26	24.89	21.47
45	20.36	29.17	24.79	20.55
50	22.89	27.54	24.7	19.85
55	19.51	26	24.63	19.18
60	22.4	24.7	24.57	18.62
65	16.98	23.6	24.52	18.13
70	22.65	22.54	24.47	17.65
75	16.98	21.65	24.44	17.24
80	16.98	20.91	24.4	16.88
85	22.04	20.25	24.37	16.54
90	21.68	19.6	24.34	16.2
95	13.61	19.1	24.32	15.91
100	15.3	18.61	24.29	15.62
105	15.3	18.21	24.27	15.36
110	15.3	17.87	24.25	15.13
115	15.3	17.55	24.19	14.89

Figure 3 shows the comparison between observed infiltration rate and infiltration rate obtained from different models

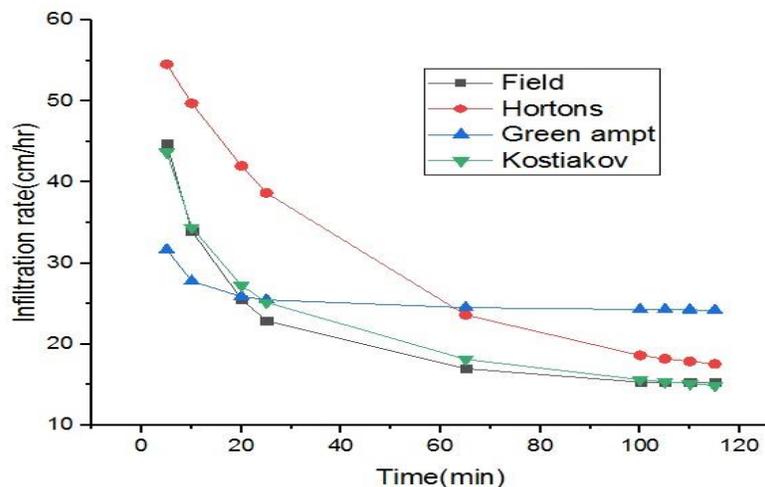


Figure 3: Comparison of infiltration rate

One way ANOVA test was performed to find the significance of the infiltration models. The permissible level of significance was 0.05 and all the data obtained were within the permissible limits. Therefore the data obtained was concluded to be significant for analysis. The value of significance level of the three models are shown below.

Table 3: Significance of Infiltration Models with Field data

Infiltration Models	Significance with field data
Horton's	0.002
Green ampt's	0.001
Kostiakov's	0.002

Various statistical parameters solved for the analysis is furnished in Table 4

Table 4: Statistical Parameters

Infiltration Models	Correlation Coefficient(R)	Coefficient of determination (R²)	Standard Error
Horton's	0.878	0.771	0.104
Green ampt's	0.862	0.744	0.110
Kostiakov's	0.905	0.819	0.105

Decision factor is the parameter which determines the best fitting model for the study area. Here, the model with highest value of decision factor will be the model best matching with the observed field data. The value of decision factor for various infiltration models are determined and furnished in Table 5

Table 5: Decision Factor for Infiltration Models

Infiltration Models	Decision Factor(η)
Horton's	0.667
Green ampt's	0.634
Kostiakov's	0.66

5. Results and Discussion

Best fit line for the models are plotted in SPSS and analyzed for the relationship between field data and various infiltration models.

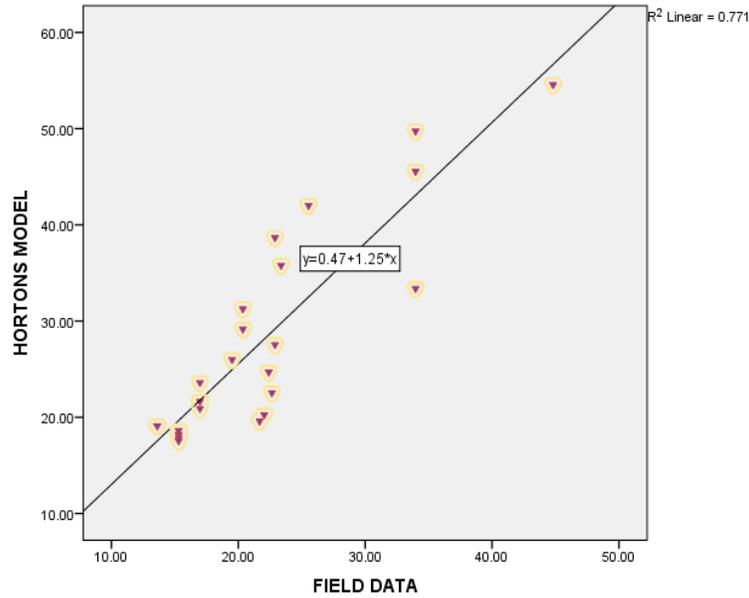


Figure 4: Horton’s Model vs Field Data

From the best fit line Field infiltration rate

$$x = \frac{y - 0.47}{1.25}$$

Where y is corresponding horton’s model value.

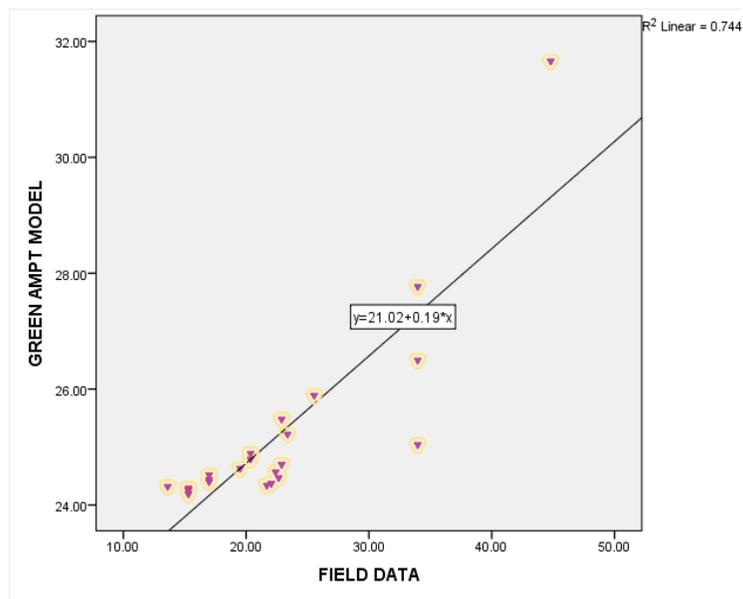


Figure 5: Green ampt’s Model vs Field Data

From the best fit line Field infiltration rate

$$x = \frac{y - 21.02}{0.19}$$

Where (y) is corresponding Green ampt's Model value.

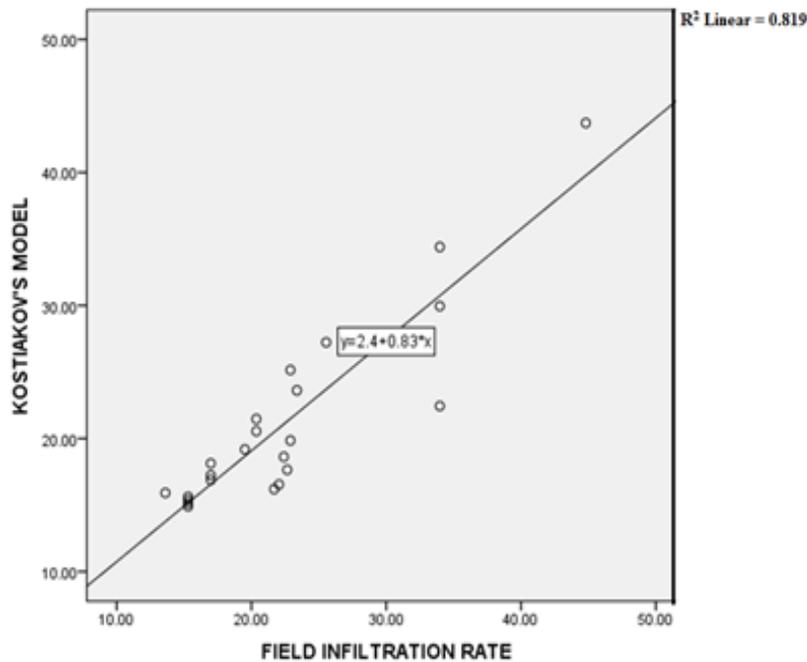


Figure 6: Kostiakov's Model vs Field Data

From the best fit line Field infiltration rate

$$x = \frac{y - 2.4}{0.83}$$

Where (y) is corresponding Kostiakov's Model value.

6. Conclusions

From the analysis of field infiltration rate with other infiltration models at Residential area, the following conclusions are arrived.

- Infiltration capacity curve for the site has been plotted.
- Constant infiltration rate for Residential area is obtained as 15.3 cm/hr
- Significance of field infiltration rate with other models has been analyzed using one way ANOVA test and found within reliable significance level.
- Correlation of field data with various infiltration models has been studied.
- Based on decision factor parameter, it was found that Kostiakov's model is the best fit model with observed infiltration rate for the Residential area.

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