Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 1, January : 2024

EXPERIMENTAL INVESTIGATION TO EVALUATE DIFFERENT PARAMETERS OF EMPIRICAL INFILTRATION MODEL FOR RAJKOT SOIL AND MATHEMATICAL VALIDATION OF THE SAME

Ms. B. Das, Senior Lecturer, Dept. of Civil Engineering, IIMT Group of College, Greater Noida.

Abstract
The constant infiltration rates of soil under different soil conditions are calculated in the Rajkot district. Experimentation work is carried out on various soil samples to determine their properties. The double ring infiltrometer is used for the measurement of infiltration rate. The study aims to determine constant infiltration rates of the soils under different soil conditions and compare it with the infiltration rates obtained by Kostiakov, Modified Kostiakov, and Horton's models. The values of various constants of the models are calculated by mathematical and graphical approaches. For getting the best fitting model for a particular soil and soil condition, the results obtained from various infiltration models are to be compared with the observed field data, and graphs are plotted. The parameters to be considered for the best fitting of the model were correlation coefficient and standard error. A new infiltration model will be developed using different methods and a comparison of its result will be done with field data.

Keywords: Infiltration, Infiltration rate, Infiltration models, double ring infiltrometer.

Introduction
Infiltration is the movement of water into the soil from the surface of earth. The water is driven into the porous soil by the force of gravity and capillary action. Firstly, the water wets soil grains and then the remaining water moves down due to resulting gravitational force. The rate at which a given soil can absorb water at a given time is called infiltration rate and it depends on soil characteristics such as soil texture, hydraulic conductivity, soil structure, vegetation covers etc [1]. Infiltration plays an important role in generation of runoff volume, if infiltration rate of a given soil is less than intensity of rainfall then it results in either accumulation of water on soil surface or in runoff. The different soil conditions affect the soil infiltration rate. Compacted soils due to movement of agricultural machines have a low infiltration rate which is prone to runoff generation. Infiltration will be maximum at the beginning and then it decays exponentially and gets a constant value. There will be a decrease in infiltration rate day by day due to the saturation of the soil whereas on the first day of precipitation, the infiltration rate will be more as the soil is in dry condition.
Infiltration of water into the soil has important impact on the overall functioning of the variable land-based activities. Two factors can greatly undermine availability of water for crops which is impervious layer and ground water table. The former might be due to excess infiltration which mostly a function of soil characteristic gets through the later may be largely due to the deposit of clay that can create crust below the surface. The study of infiltration comes in many hydrological problems like runoff estimation, soil moisture budgeting and for planning of irrigation. Infiltration has an important place in the hydrological cycle [2].

Infiltration Models
The following infiltration models were assessed for finding the best fitting model to observed field infiltration rate data.

1.1.1 Horton's Model:
Named after Robert E. Horton, Horton's equation is another viable option when measuring ground infiltration rates or volumes. It is an empirical formula that says that infiltration starts at a constant rate, f_o, and is decreasing exponentially with time, t. After some time when the soil saturation level reaches a certain value, the rate of infiltration will come to a constant rate f_c. Horton has expressed this decrease of infiltration capacity with time as an exponential decrease as

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

where,
f = infiltration capacity at any time t.
f_c = final steady state infiltration capacity.
f_o = initial infiltration capacity.
k = Horton's constant representing rate of decrease in infiltration capacity.
t = time in hours.

Kostiakov Model:

$f = at^b$

where,
f = cumulative infiltration at any time t.
t = time in min.
a and b are constants.

1.1.3. Modified Kostiakov Model:

$f = at^b + c$

where,
f = cumulative infiltration at any time, t.
t = time in min.
a, b, and c are constants whose values depends on soil type.

The objective of this paper is to determine the infiltration rate of soil in inner space and annular space using double ring infiltrometer and then compare the result with the infiltration rates obtained from Horton's, Kostiakov's and Modified Kostiakov's model. It also aims to develop a new infiltration model.

Marwadi Education Foundation college campus was selected for the study. It is in Rajkot district of Gujarat. The campus is approximately 15 km away from the main Rajkot city on Morbi highway. Data is collected from the open ground of campus.

Literature

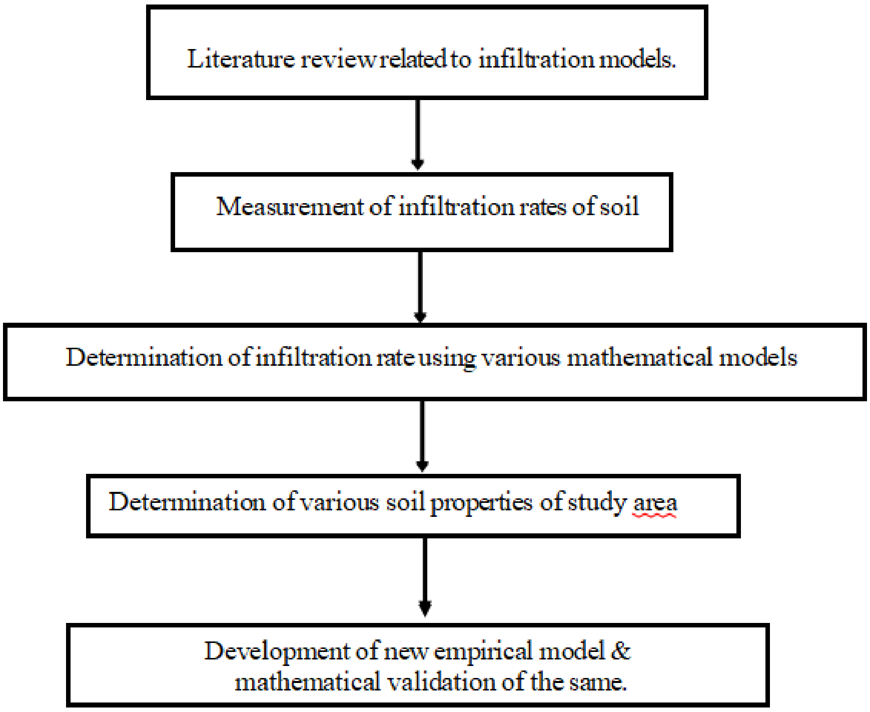
Robert Pit et al [3] examined a common but poorly understood problem associated with land development, namely the modifications made to soil structure and the associated reduced rainfall infiltration and increasing runoff. The project was divided into two separate major tasks: (a) Testing infiltration rates of impacted soils, and (b) Enhancing soils by amending with compost to increasing infiltration and prevent runoff.

Amreeta Champatiray [4] expressed infiltration rate in terms of volume of water poured per ground surface per unit of time. Soil erosion, surface runoff & ground water recharge affected by this process. Infiltration of water into the soil can be determined by a simple instrument called Double ring infiltrometer. Double ring infiltrometer is better than single ring infiltrometer as the water will penetrate only in one direction that is in the downward direction and prevents the spreading of water in the horizontal direction without much wastage of water.

Gayatri Das et al [5] has made an attempt to find the constant infiltration rates of different soils under different soil conditions. Field experiments were carried out at six different sites located within Guwahati. The highest infiltration rate obtained was 10.73cm/hr at Eastern Retreat and the lowest was 1.73cm/hr occurred at Bonda. Soil tests have also been done to know the soil type and how the infiltration curve varies for each soil type with respect to time.

Srijani et al [6] has evaluated infiltration characteristics of soils at Andhra University campus using a single and double ring infiltrometer. Experimentation work is carried out at five different points in the campus. The study is aimed at determining the constant infiltration rates of those soils using both the infiltrometers and comparing it with the infiltration rates obtained by Kostiakov, Philip's, and Horton's and Green-Ampt infiltration models. The values of various constants of the models are calculated by graphical approach. To get the best fitting model for a particular soil condition the results obtained from various infiltration models are compared with observed field data and graphs are drawn with correlation coefficient and standard error as tools.

Methodology



Data Collection
Data Collection (Monsoon Season)
Infiltration Data:

Double ring infiltrometer is used to collect the infiltration value of soil. Experiment was conducted on 30th July 2022 for approximately two hours. Data is collected until the constant infiltration value is obtained. Fig.3.1 represents the infiltration rate at time t.

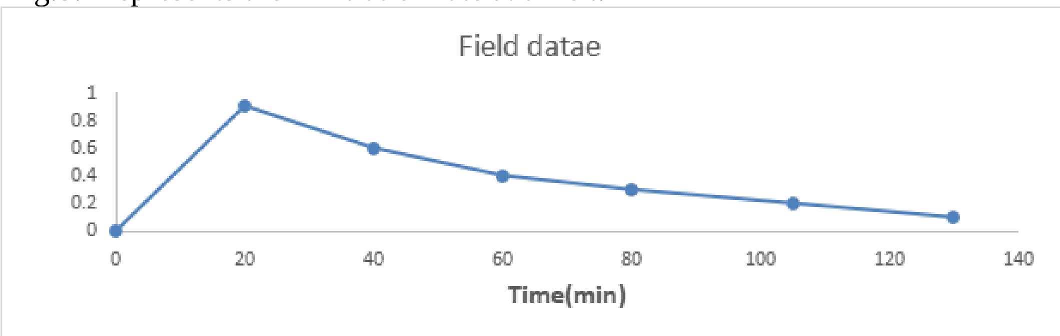


Fig.4.1 Graphical representation of field data (Monsoon Season)

Determination of soil type:

The Liquid Limit (LL) and Plastic Limit (PL) test was performed for the soil to determine its type which was obtained as 54 and 34 respectively.

Soil Classification according to Indian Standard Soil Classification System (ISSCS):

A-Line: PI = 0.73(LL – 20) = 0.73(54 – 20) = 24.82

Now, from the value of Liquid limit and Plasticity Index a point can be achieved in the plasticity chart as per ISSCS. After placing that point it is found that it lies above A-Line in the C-H zone. Thus, soil in which the experiment is performed is classified as clay soil with high plasticity (CH).

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 1, January : 2024

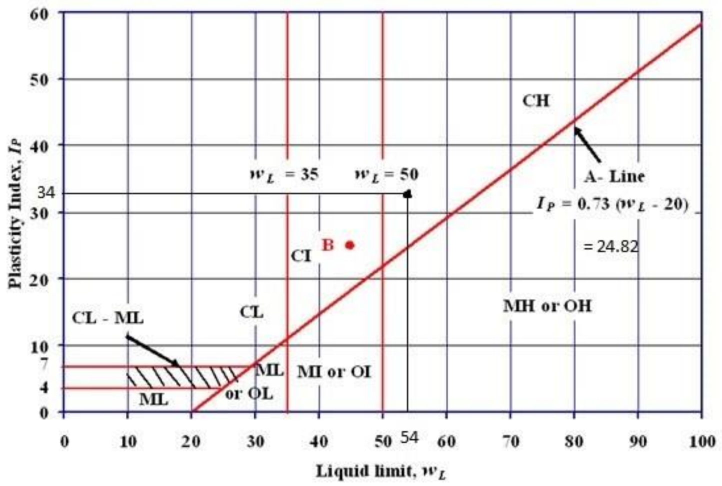


Fig. 4.2 Plasticity chart

Data Collection (Winter Season)
Infiltration Data:
Double ring infiltrometer is used to collect the infiltration of soil. Experiment was conducted on 16th February 2023 for approximately one hour. Data is collected until constant infiltration is observed. Figure 3.2 given below represents the infiltration rate at time t.

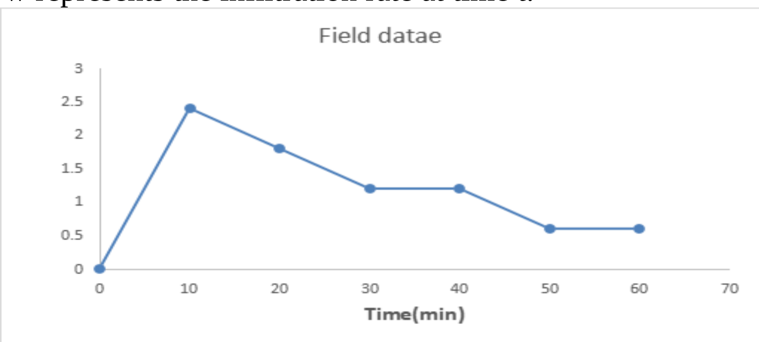


Fig. 4.3 Graphical representation of field data (Winter Season)

Analysis and Comparison of Various Models
5.1 Comparison based on Monsoon Data
Horton's Model:
$F = f_c + (f_o - f_c) e^{-kt}$

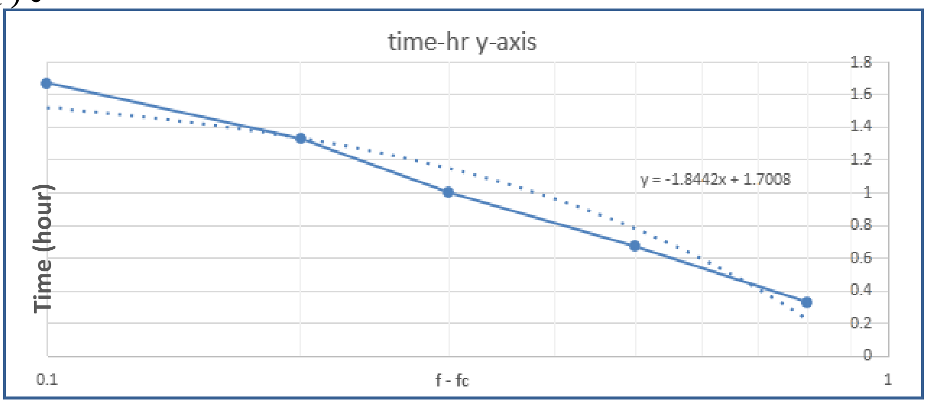


Fig.5.1 Graph for Horton's model (Monsoon)

Here, $f_c = 0.1$
$f_o = 0.9$
Slope = $\frac{-1}{k} log_e$ => -1.884 = $(\frac{-1}{k})\ log_e$ => k = 1.25

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 1, January : 2024

Now, from Horton's infiltration equation,

$f = f_c+(f_o-f_c)\, e^{-kt}$ => $f = 0.1+(0.9-0.1)\, e^{-1.25t}$ => $\mathbf{f = 0.1+(0.8)\, e^{-1.25t}}$

Kostiakov's Model:

$f = at^b$

From fig.5.2, equation of line is y = 0.6155x-0.8315,

in kostiakov's eq, b is slope, b = 0.6155

While a is anti-log of intercept, here intercept is -0.8315.

So, a=anti-log (-0.8315) = 0.147

Therefore, $\mathbf{f = 0.147t^{0.6155}}$

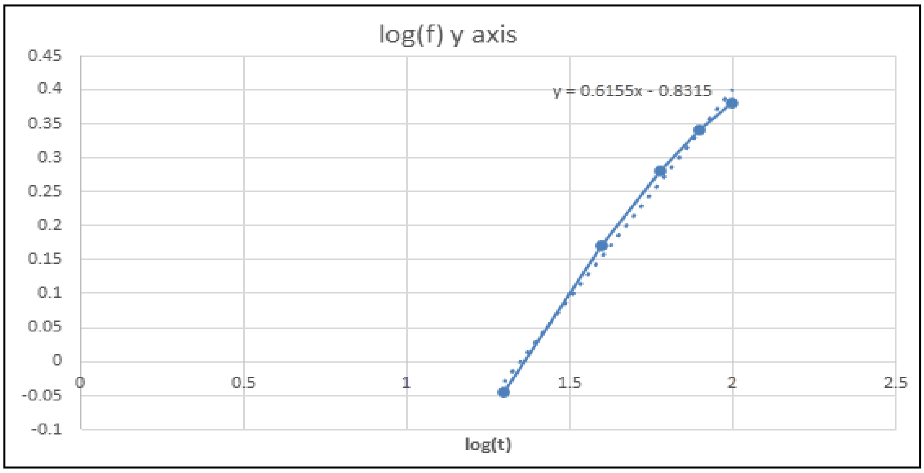


Fig.5.2 Graph for Kostiakov's model (Monsoon)

Modified Kostiakov's Model:

$f=at^b + C$

From calculation, c = 0.161

from graph, equation of line is y = 0.6939x - 1.0117

In kostiakov's eq, b is slope so here slope b = 0.6939

while a is antilog of intercept, here intercept is -0.8315.

So, a=anti log (-1.0117) = 0.097

Therefore, $\mathbf{f = 0.097t^{0.6939} + 0.161}$

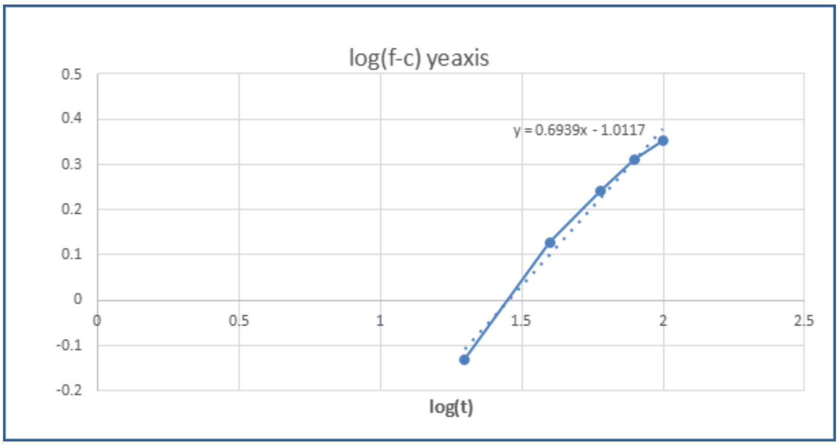


Fig. 5.3 Graph for Modified Kostiakov's model (Monsoon)

5.2 Comparison based on Winter Data

Horton's Model:

$F = f_c + (f_0 - f_c)\, e^{-kt}$

Here, $f_c = 0.6$; $f_0 = 2.4$

Slope = $\frac{-1}{k} log_e$ => $-0.354 = (\frac{-1}{k})\, log_e$ => k = 1.04

Now, from Horton's infiltration equation,

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 1, January : 2024

$f=f_c+(f_o-f_c)\ e^{-kt}$ => $f=0.6+(2.4-0.6)\ e^{-1.04t}$ => $\mathbf{f = 0.6+(1.8)\ e^{-1.04t}}$

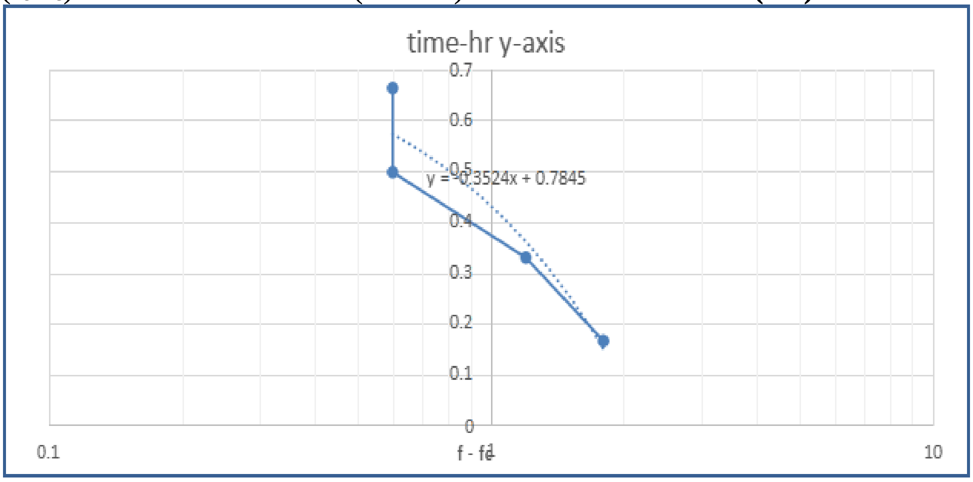


Fig. 5.4 Graph for Horton's model (Winter)

Kostiakov's Model:

$f = at^b$

From fig.5.5, equation of line is y = 0.6368x-0.2272

in kostiakov's eq, b is slope so here b = 0.6368,

while a is anti-log of intercept, here intercept is -0.8315.

So, a=anti-log(-0.2272) = 0.5926

Therefore, $\mathbf{f = 0.5926\ t^{0.6368}}$

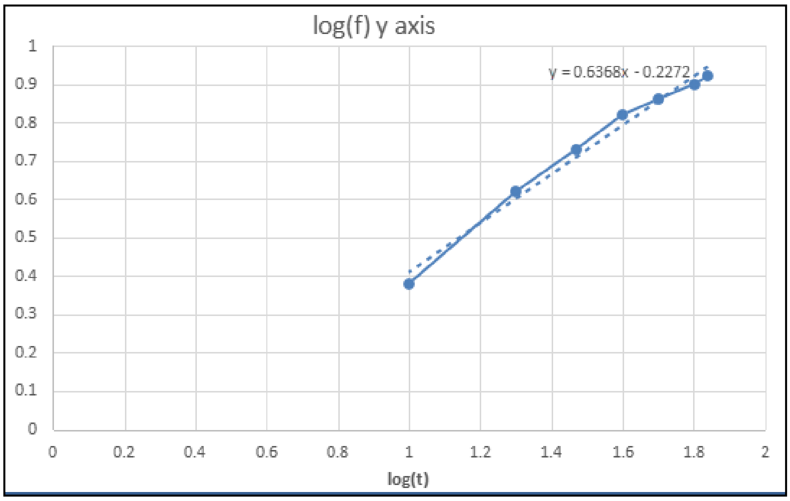


Fig.5.5 Graph for Kostiakov's model (Winter)

Modified Kostiakov's Model:

$f=at^b + C$

From calculation, c = 2.007

from graph, equation of line is y = 1.3479x - 1.5747

In kostiakov's eq, b is slope. so here slope b = 1.3479

while a is antilog of intercept, here intercept is -1.5747.

So, a=anti log (-1.57477) = 0.0266

Therefore, $\mathbf{f = 0.0266t^{1.3479} + 2.007}$

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 1, No. 1, January : 2024

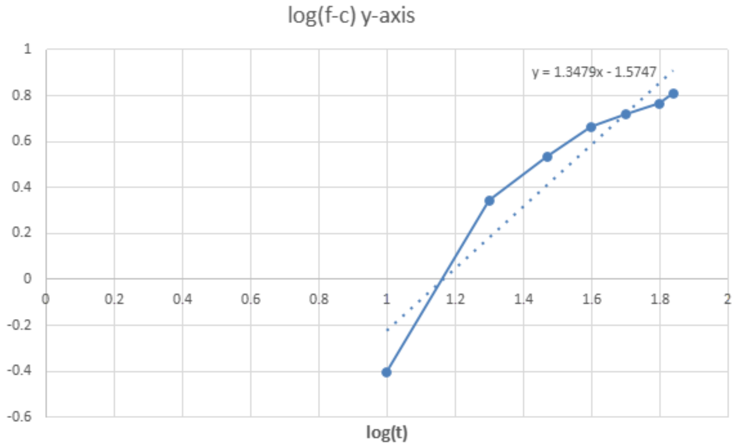


Fig. 5.6 Graph for Modified Kostiakov's model (Winter)

Result

To get the best fitting model for a particular soil condition the results obtained from various infiltration models are compared with observed field data and graphs are drawn with correlation coefficient and standard error as tools.

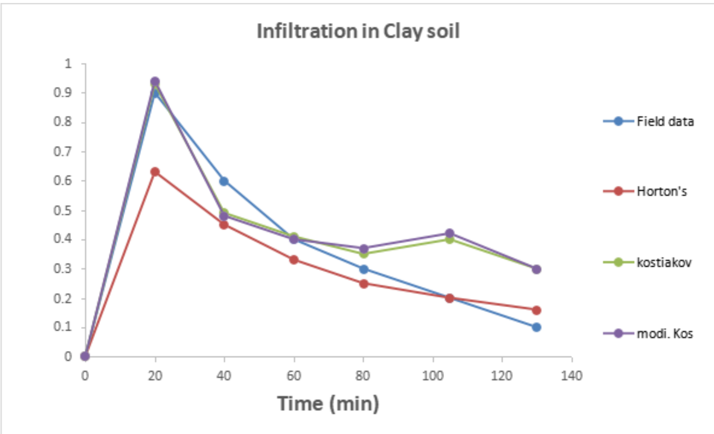


Fig. 6.1 Comparison between field data with different infiltration models (Monsoon Season).

The above figure graphically represents the comparison of the data obtained from the experiment done in monsoon season with the infiltration models as per Horton, Kostiakov and Modified Kostiakov. The value of standard error as per Horton, Kostiakov and Modified Kostiakov is 0.15, 0.23 and 0.21 respectively. The value of correlation coefficient as per Horton, Kostiakov and Modified Kostiakov is 0.97, 0.94, & 0.5 respectively.

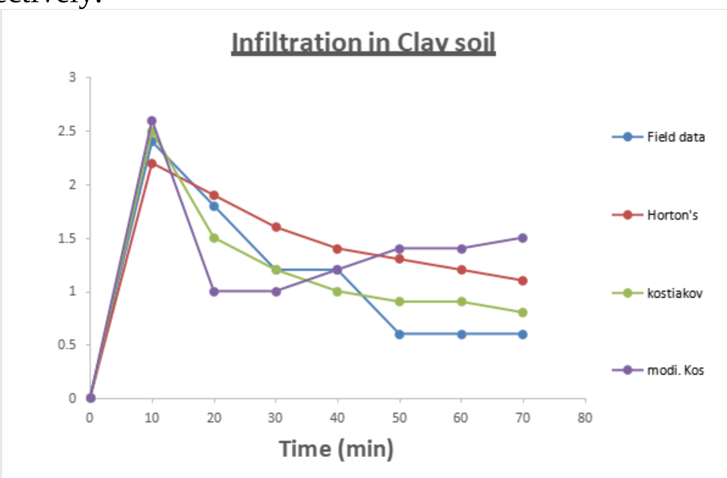


Fig. 6.2 Comparison between field data with different infiltration models (Winter Season).

The above figure graphically represents the comparison of the data obtained from the experiment done in winter season with the infiltration models as per Horton, Kostiakov and Modified Kostiakov. The value of standard error as per Horton, Kostiakov and Modified Kostiakov is 0.15, 0.23 and 0.21 respectively. The value of correlation coefficient as per Horton, Kostiakov and Modified Kostiakov is 0.97, 0.94, & 0.5 respectively.

Conclusion

During the experiments conducted in monsoon season, it was observed that the infiltration rate became constant after a short time interval. It was observed during the study that the soil condition has a significant effect on the infiltration rate. The infiltration curve shows a higher initial infiltration rate which then decreases with time before it reaches a steady state condition. The values of standard error and correlation coefficient is found to be different for different infiltration models. On comparing the values, it has been observed that the value of Horton's infiltration model is the best fitting model with a higher degree of correlation coefficient and minimum standard error.

References

[1] Gray, D.M; Norum, D.L. The Effect of soil moisture on infiltration as related to runoff and recharge. Hydrology Symposium No. 6, National Research Council of Canada 1967.
[2] Rawls, W.J. Green-ampt Infiltration parameters from soils data. J. Hydraul. Eng. 1983, 109, 62-70.
[3] Pit, R. et al. Infiltration Through Disturbed Urban Soils and Compost-Amended Soil Effects on Runoff Quality and Quantity. Volume: EPA/600/R-00/016, December 1999.
[4] Champatiray, A. Experimental Study for Determination of Infiltration Rate of Soils in Field Using Double Ring Infiltrometer. J. Hydraul. Eng. 2014, 212, 44-86.
[5] Das, G.; Saikia, M. Experimental Study on Infiltration in Guwahati Using Double Ring Infiltrometer. ISSN (Online): 2319-8753 2016, 5 (12).
[6] Sreejani, T.P. et al. A Study on Infiltration Characteristics of Soils at Andhra University Campus, Visakhapatnam. ISSN 2249-3131, Number 1 (2017), 7, 29-44.