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# A Comparative Study on the Infiltration Characteristics of Soils in Srikakulam District, Andhra Pradesh, India

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**Abstract:** The groundwater resources are decreasing day by day as less amount of rainfall is contributing to natural recharge on one hand and on the other, there is rapid infra-structure development. So there is an urgent need for artificial recharge of groundwater. For effective planning and management of artificial recharge systems in an area, one needs to understand the infiltration characteristics of that region. The present study is aimed to estimate the infiltration characteristics based on the experimental data obtained by using double ring infiltrometer. This study has a scope for understanding the variation of the infiltration capacity with respect to space as well as time and identification of the most suitable mathematical model to be adopted for infiltration. The infiltration tests were conducted in the study area at ten locations in three different seasons and the infiltration capacity was modelled using Horton, Philip and Kostiakov. The model parameters obtained are highly fluctuating with respect to time and space indicating that the infiltration equation is highly location and season specific. The $f_0$ and $f_c$ values (Horton's model) are very high in the pre-monsoon season when compared to the post-monsoon season since the soil is dry and the ability of the soil to allow rain to permeate through it is very high. Horton's model is considered as to be the best amongst the three models considered for this study based on the comparison with the field data.

**Key words:** Rainfall, artificial recharge, groundwater, infiltration, double ring infiltrometer, mathematical models.

## Introduction

Water is an important source in our planet and plays a vital role in the daily life of all living beings. Due to the usage of water in huge quantities for various purposes in unscientific manner, there is shortage of water in terms of both quantity and quality. Water is described as liquid gold and it has been said as "oil of the 21$^{st}$ century" by several people. Man is not realizing the importance of water in the present scenario and misusing it for his own purposes. Water which occurs as precipitation onto the surface exists in various forms and only a very small amount of that is available for utilization by the living beings. In order to effectively utilize the available water resources, man has to overcome the problems in the system of water conservation.

The infiltration process is one of the arcs of the hydrologic cycle which is the basic input for the subsurface aquifer system. So the groundwater potential of any region mainly depends upon the infiltration characteristics of the region which may vary with respect to time, space, soil and climatic parameters. The infiltration process is a highly complex hydrological process to determine as it has interactions with the stream/river network, land and oceans.

The infiltration capacity of a soil under given state is defined as the maximum rate at which it is capable of absorbing water. This maximum rate of infiltration is not constant under all soil conditions. Thus, in the estimation of surface runoff, groundwater recharge and also in the water balance studies, the information regarding the rate of infiltration are required with respect

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to time, space as well as soil and climatic conditions. In addition, quantification of infiltration is also necessary to determine the availability of water for crop growth and to estimate the amount of additional water needed for irrigation (Zolfaghari et al., 2012).

Researchers suggest that infiltration capacity rapidly declines during the early part of a storm and then tends towards an approximately constant value after a couple of hours for the remainder of the event. The infiltrated water fills the available storage spaces and reduces the capillary forces drawing water into the pores. Clay particles in the soil may swell as they become wet and thereby reduce the size of the pores. In areas where the ground is not protected by a layer of forest litter, raindrops can detach soil particles from the surface and wash fine particles into surface pores where they can impede the infiltration process.

A field experiment was conducted by Bodhinayake et al. (2004) in a silt loam soil in Saskatchewan, Canada to explore the usefulness of tension and double-ring infiltrometer for the determination of soil hydraulic properties in sloping landscapes. Chowdary et al. (2006) studied the effect of the parameters on wetting front and observed that the length of wetting zone at the central axis of the infiltrometer increases with increasing diameter and head of ponding. It was found that the lateral component of infiltration reduced by three to six times with double ring infiltrometer. To determine the size effect of double ring infiltrometer, Lai et al. (2007) measured the saturated hydraulic conductivity at seven sites using four different sizes of double-ring infiltrometer. Field and simulation results both demonstrated that the variability in measured hydraulic conductivity was higher for smaller inner rings and gradually decreased as the ring size increased.

Ogbe et al. (2011) conducted field experiments to assess the predictability of Kostiakov, modified Kostiakov, Philip and Horton models on sandy soil and compared the measured as well as predicted cumulative infiltration using these models under local conditions. The results of the study showed that the cumulative infiltration predicted by different infiltration models were very close to the field measurements for all the strips as indicated from the average values of the slope between the measured and predicted by the infiltration models respectively. Zolfaghari et al. (2012) investigated the ability of seven different infiltration models to design the infiltration process based on the data collected from various parts of Iran and ranked them. They found that the Soil Conservation Services model obtained the lowest rank in comparison with Horton, Philip, Kostiakov, Swartzendruber, Modified Kostiakov and Revised Modified Kostiakov models.

Jafarinia and Fuladipanah (2014) investigated the ability of Kostiakov, Philip and Soil Conservation Services (SCS) models to design the infiltration process in Shazand plane, Arak, Iran. They concluded that SCS model was most appropriate to simulate the infiltration process. Literature shows that it is important to conduct comparative analysis of different infiltration models for any given location to determine the most suitable model for the infiltration process. As far as the knowledge of the authors is concerned, earlier studies have not been conducted to determine the most suitable model for the infiltration process in Srikakulam district of Andhra Pradesh. Therefore, in the present study the infiltration capacity has been estimated at various locations of the Srikakulam district using a double ring infiltrometer and the experimental data has been compared with various infiltration models. The study has a scope of understanding the variation of the infiltration capacity with respect to time and space.

## Measurement of Infiltration

Double ring infiltrometer is the most commonly used flooding type infiltrometer and the same has been adopted for this study. It consists of two rings driven into soil uniformly without tilt and distributing the soil to the least to a depth of about 15 cm and 10 cm of the cylinder above the ground. The diameters of the rings may vary between 25 and 60 cm and the height of the rings may be of 25 cm. The surface of the soil inside the ring is protected by placing a perforated metallic dish over it. A pointer is set inside the inner ring till water level touches the tip of the pointer and infiltration is allowed to proceed. Water is then applied in both the inner and outer rings to maintain a constant depth of about 5 cm. Water is replenished after the level falls by about 1 cm in order to make the level constant. The water depth in the inner and outer rings should be kept same during the observation period. Readings of the volume of water added at successive time intervals to maintain constant depth of flooding in the inner ring are taken to facilitate the computation of infiltration capacity rate. As the purpose of 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 maintain the same depth as in the inner ring. The experiment has to be carried out till a constant infiltration rate is observed. The observations are continued till a constant infiltration rate is obtained which may take 3 to 6 hours depending on the type of soil. The equations that are commonly adopted for estimating the rate of infiltration are Horton, Philip and Kostiakov's equations. The same has been discussed below.

**Horton's Equation**

This equation is based on the principle of decay. The standard form of this equation is

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

where $f_o$ = initial rate of infiltration or maximum rate of infiltration; $f_c$ = minimum rate of infiltration or constant rate of infiltration; $t$ = time at which the rate of infiltration is $f$; and $k$ = rate of decrease in infiltration capacity.

$f_o$, $f_c$ and $k$ are known as parameters of the Horton's infiltration model and depend on several factors listed in the previous section.

**Philip's Equation**

The standard form of Philip's equation is

$$f = k + S\, t^{-1/2}/2$$

where $k$ and $S$ are model parameters. $f$ = rate of infiltration at the time $t$, $S$ = sorptivity and $k$ = constant.

**Kostiakov's Equation**

The standard form of Kostiakov's equation is

$$F = at^n$$

where $F$ = cumulative depth of infiltration, $a$ and $n$ are the model parameters and $F$ = cumulative rate of infiltration at the time $t$.

## Study Area and Experimental Program

The experiment was conducted at Rajam which is located at 18.28°N and 83.40°E, in Srikakulam district of Andhra Pradesh (India). It has an average elevation of 41 m (137 feet) above mean sea level. This region is classified as humid region based on the actual annual average rainfall of the region. The people of this region suffer for water for domestic purposes during non-monsoon season because of shallow aquifer in the region. So protection of natural groundwater resources is of paramount importance. Plenty of rain water is available during monsoon season so by understanding the infiltration characteristics of the regions, appropriate water management practices can be adopted.

Study area spreads across 117 acres. It is located at a distance of 1.5 km from Rajam bus station towards Palakonda. Basically, the region is tropical and having summer maximum temperature of 45°C and summer minimum temperature of 25°C and winter maximum and minimum temperatures are 28°C and 19°C respectively. The actual annual average rainfall of the region is 912 mm.

For conducting infiltration tests, 10 locations were identified at different elevations in the study area. The tests were conducted at those locations in three different seasons, namely, Season 1: During monsoon, Season 2: Pre monsoon and Season 3: Post monsoon.

**Specifications of Double Ring Infiltrometer**

The instrument consists of two concentric rings: inner and outer rings. The outer ring is 30 cm diameter; the inner ring 15 cm diameter and height of the rings is of 25 cm made from stainless steel with sharp edge at end. The two rings are driven into the ground and partially filled with water. The double ring design helps prevent divergent flow in layered soils. The outer ring acts as a barrier to encourage only vertical flow from the inner ring.

## Results and Discussion

The various results obtained are presented and discussed in this section.

The experimental data at the ten locations in all three seasons were obtained by conducting infiltration tests using double ring infiltrometer. By using the experimental data, the infiltration equations were obtained by using regression analysis technique. Three different equations namely Horton, Philips and Kostoakov have been used in this study.

The seasonal variation of the model parameters of Horton's, Philip's and Kostoakov's are presented in Figures 1-7.

Figure 1 shows the variation of $f_0$ with respect to different locations for three different seasons. It is observed that the $f_0$ values are highly fluctuating in season 1 in comparison to other two seasons. This is because the nature of the soil and topography are different in various locations in the study area and therefore the rate of infiltration is also varying. Moreover, season 1 corresponds to monsoon, so the antecedent moisture condition could influence the infiltration rate. The infiltration curve corresponding

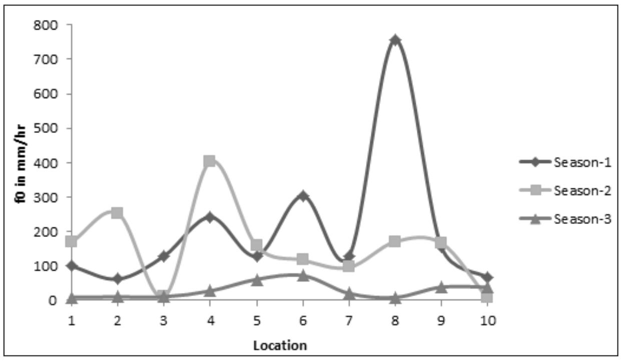


**Figure 1: Seasonal variation of $f_0$ at all locations (Horton's model).**

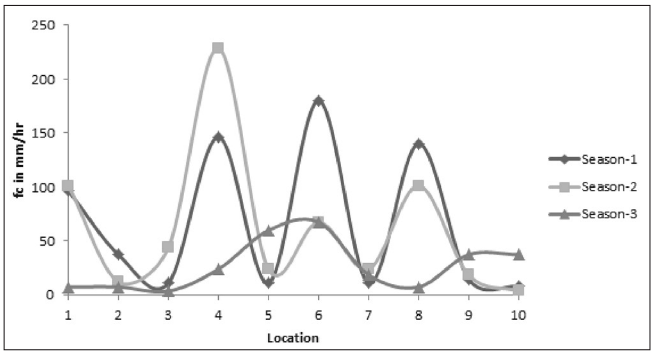


**Figure 2: Seasonal variation of $f_c$ at all locations (Horton's model).**

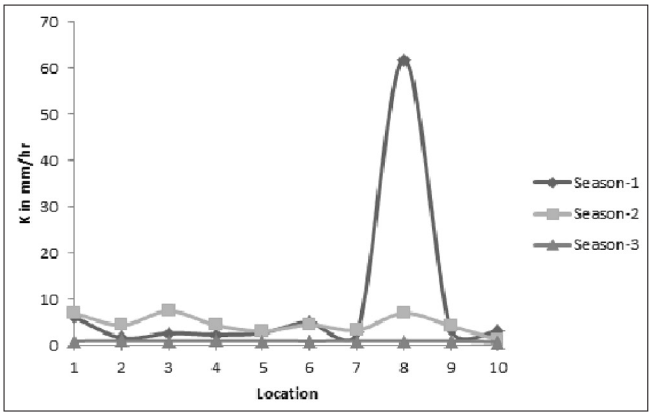


**Figure 3: Seasonal variation of $k$ at all locations (Horton's model).**

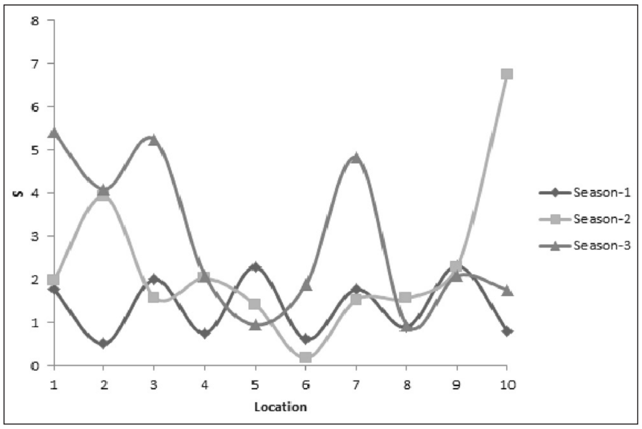


**Figure 4: Seasonal variation of $S$ at all locations (Philip's model).**

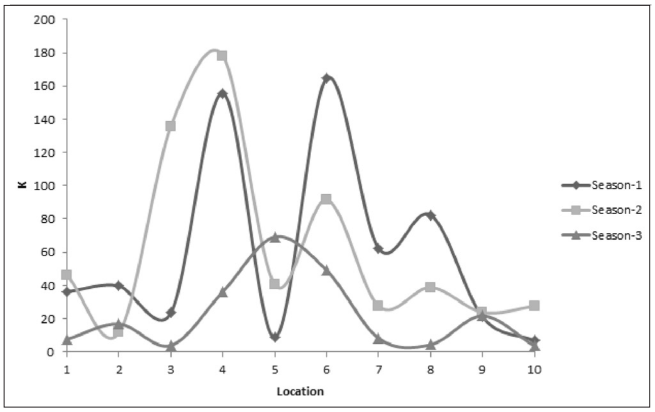


**Figure 5: Seasonal variation of $K$ at all locations (Philip's model).**

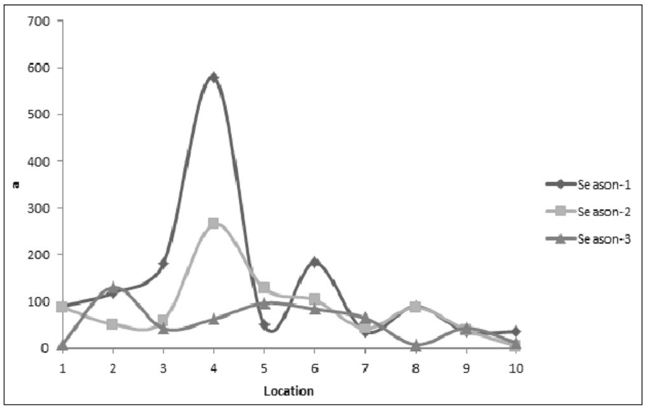


**Figure 6: Seasonal variation of $a$ at all locations (Kostiakov's model).**

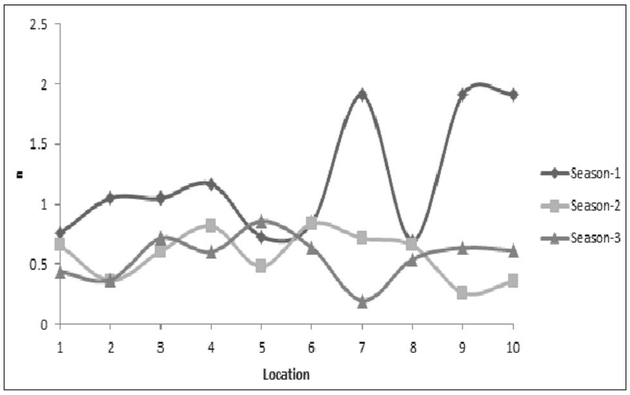


**Figure 7: Seasonal variation of $n$ at all locations (Kostiakov's model).**

to season 2 also is fluctuating since the scope for infiltration of rainfall is high in the pre monsoon season. In season 3, the infiltration curve is uniform since this is post monsoon season where the soil has already been saturated and thus has resulted in very low values.

Figure 2 shows the variation of $f_c$ values with respect to different locations in the three seasons. It is observed from the figure that $f_c$ values are varying in all the three seasons with different magnitudes for the same reasons mentioned above. The profile for season 3 is also fluctuating here since the soils in locations 4, 5, and 6 are more permeable compared to other locations.

Figure 3 shows the variation of *k* with respect to different locations for three different seasons. It is observed from the figure that the decay constant values are almost similar in all the locations for the three seasons except location 8. This may be because the average soil properties in this region may be similar. Even the decay constant is similar; the rate of infiltration ultimately depends on the initial rate of infiltration, which in turn depends on the soil, topography and climate of the region. In the post monsoon season (Season 3), since the soil is already saturated, the decay constant is very insignificant. Moreover, the infiltration rate has attained a constant value.

Figure 4 shows the variation of sorptivity with different locations for three seasons. It is observed from the figure that sorptivity in season 1 (monsoon) is lower compared to post monsoon (season 3) because of the soil properties and topography of the region.

Figures 5, 6 and 7 show the variation of *k*, *a* and *n* with respect to different locations in three different seasons. The variation of *k* in the first and second season is very much similar. The profile for '*a*' is varying in all the three seasons. The profile for '*n*' is following a similar trend for all the three seasons. All these constants are influenced by the soil properties, topography of the location and the climatic conditions existing in the different locations in this study.

The model parameters at all locations in all the three seasons are highly fluctuating representing that the infiltration equation is location and season specific. However, to represent a single equation for the entire area, the average values have been considered. The seasonal average values of Horton's parameters and their corresponding equations are presented in Table 1.

The average values of Horton's parameters obtained by considering all three seasons and all locations, are found to be of $f_0$ = 130.6563 mm/hr, $f_c$ = 51.7937 mm/hr and $K$ = 4.8423 hr$^{-1}$. The Horton's equation representing the entire area for all the three seasons is $f = 51.5937 + 78.8627e^{-4.8423t}$. The seasonal average values of Philip's parameters and their corresponding equations are presented in Table 2.

**Table 1: Seasonal average values of Horton's parameters and its equation**

| Season | $f_0$ (mm/hr) | $f_c$ (mm/hr) | $K$ (hr$^{-1}$) | Equation |
|---|---|---|---|---|
| 1 | 207.139 | 65.706 | 9.134 | $f = 65.706 + 141.433e^{-9/134t}$ |
| 2 | 155.095 | 62.525 | 4.607 | $f = 62.525 + 92.57e^{-4.607t}$ |
| 3 | 29.735 | 27.150 | 0.906 | $f = 27.150 + 2.585e^{-0.906}$ |

The average values of Philip's parameters obtained by considering all three seasons and all locations, are $S$ = 2.207 and $K$ = 48.108. The Philip's equation representing the entire area for all the three seasons is $f = 48.108 + 1.104t^{-1/2}$.

The seasonal average values of Kostiakov's parameters and their corresponding equations are presented in Table 3.

The average values of Kostaikov's parameters obtained by considering all three seasons and all locations, are $a$ = 94.038 and $n$ = 0.7802. The Kostiakov's equation representing the entire area for all the three seasons is $F = 94.038t^{0.7802}$. This equation represents the cumulative infiltration rate. In order to compare the models, it is converted in terms of actual infiltration rate by differentiating and the corresponding equation is $f = 73.765t^{-0.22}$.

The average values of infiltration rates obtained in the field and values obtained by various models are presented in Table 4.

The models are validated with the field data and shown in Figure 8.

**Table 2: Seasonal average values of Philip's parameters and its equation**

| Season | S | K | Equation |
|---|---|---|---|
| 1 | 1.372 | 60.1102 | $f = 60.1102 + 0.686t^{-1/2}$ |
| 2 | 2.322 | 62.1344 | $f = 62.1344 + 1.161t^{-1/2}$ |
| 3 | 2.927 | 22.0798 | $f = 22.0798 + 1.4635t^{-1/2}$ |

**Table 3: Seasonal average values of Kostiakov's parameters and their equations**

| Season | a | n | Equation |
|---|---|---|---|
| 1 | 140.06 | 1.2031 | $F = 140.06t^{1.2031}$ |
| 2 | 86.828 | 0.5764 | $F = 86.828t^{0.5764}$ |
| 3 | 55.226 | 0.561 | $F = 55.226t^{0.561}$ |

**Table 4: Validation of the models with the field data**

| | *Rate of infiltration (f) in mm/hr* | | | |
|---|---|---|---|---|
| *Time in Hrs* | *Horton's* | *Philips* | *Kostiakov's* | *Field data* |
| 0.017 | 124.342 | 56.660 | 181.570 | 91.932 |
| 0.033 | 118.701 | 54.155 | 155.890 | 88.698 |
| 0.067 | 108.699 | 52.384 | 133.841 | 83.145 |
| 0.133 | 92.944 | 51.131 | 114.912 | 74.938 |
| 0.267 | 73.275 | 50.246 | 98.659 | 65.878 |
| 0.533 | 57.554 | 49.620 | 84.705 | 60.132 |

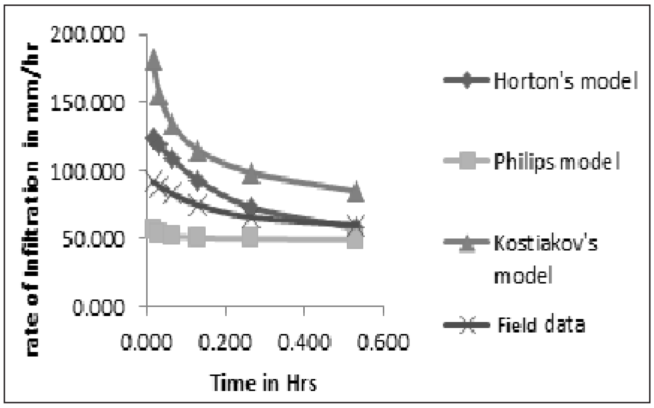


**Figure 8: Validation of the models with the field data.**

From Figure 8, it is observed that the Horton's model is closer to the field data whereas Kostoakov's model has overestimated while Philip's model has underestimated the values. The percentage deviation of infiltration values obtained from models (Horton, Philip and Kostiakov) with respect to the field data are 23.84%, –32.39% (negative sign indicates that values are lower compared to field values) and 65.59%. So Horton's model is considered to be the best amongst the three models considered for this study.

## Summary and Conclusion

The infiltration tests using double ring infiltrometer were conducted in the study area at ten locations in three different seasons. Three different infiltration models (Horton, Philip and Kostiakov) were adopted to identify the best model that can estimate the infiltration capacity in the study area. The infiltration equations were obtained based on the three models considered. The field data was compared with the data obtained by the models. Since it is difficult to update the model parameters every time and many equations are obtained for a given location, the average of the parameters have been considered by conducting tests at sufficient number of locations and in different times to represent a single infiltration equation.

The following conclusions are drawn based on the various results obtained.

- The parameters of all the three models at all locations in all the three seasons are highly fluctuating indicating that the infiltration equation is location and season specific. A single equation at any point in the study area and at any time may not yield accurate results.
- The Horton's equation, Philip's equation and Kostiakov's equations representing the entire area for all the three seasons based on the average model parameters obtained are $f = 51.5937 + 78.8627e^{-4.8423t}$; $f = 48.108 + 1.104t^{-1/2}$ and $f = 73.765t^{-0.22}$ respectively.
- The Horton's model is closer to the field data whereas Kostoakov's model has overestimated the infiltration capacity while Philip's model has underestimated the same. Thus, Horton's equation is recommended for this study area at any point of time.
- The $f_0$ and $f_c$ values (Horton's model) are very high in the pre-monsoon season when compared to the post-monsoon season since the soil is dry and the ability of the soil to allow rain to permeate through it is very high.
- The constants *k*, *a* and *n* are influenced by the soil properties, topography of the location and the climatic conditions existing in the different locations in this study.
- Horton's model is considered to be the best amongst the three models considered for this study based on the comparison with the field data.

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