

Evaluation of cumulative infiltration models under different land uses in a temperate sub-alpine zone of Arunachal Pradesh, India

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Abstract

In the present study, various infiltration models were assessed under various land uses, including forest land (FL), Grassland (GL), and paddy field (PF). The trials were conducted at several sites using the double-ring infiltrometer. The empirical to physical foundations of the selected infiltration models utilized in the study is the basis for their applicability. They estimate the experimental field's infiltration capacity or cumulative infiltration. The models' parameters rely on the features of the field. The parameters of the infiltration model are derived using nonlinear regression fitting. RMSE and coefficient of determination were used to assess infiltration models (R^2). Minimum RMSE and maximum values of R^2 were utilized to determine the best appropriate model.

The average R^2 values for Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, and Re-Modified Kostiakov's models are 0.999, 0.997, 0.999, 0.981, 0.995, and 0.999, respectively. The modified Kostikovs model has the lowest RMSE and most significant R^2 values, at 0.107 and 0.999, respectively. Regarding forest land usage, RMSE R^2 indicates that Modified Kostikovs's model performs better than Kostiakov's SCS model, Philip's, Horton's, and Re-Modified Kostikovs's model. Modified Kostiakov's model is therefore recommended. R^2 indicates that Re-Modified Kostikov's model performs better in Grassland RMSE than Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, and Re-Modified Kostikov's. Consequently, Re-Modified Kostikov's model performs the best among the chosen models. In the example of the Paddy field, a comparison of RMSE and R^2 reveals that Modified Kostiakov's model performs better than Kostiakov's, SCS, Mod. Kostiakov's, Philip's, Horton's, and Re-

Modified Kostiakov's models. Consequently, the modified Kostiakov model may be favoured in paddy fields.

Keywords: Cumulative Infiltration models, Double ring infiltrometer Forest land, Grassland, Paddy field

1.0 INTRODUCTION

Infiltration is a critical component of the hydrological cycle (Sihag et al. 2017). Water content, field density, suction head, temperature, humidity, rainfall intensity, and impurity type all impact infiltration rate. Gravity and capillary action are two essential elements that regulate the infiltration process. Gravity is a natural phenomenon, and capillary action is a liquid's capacity to flow in small areas. The infiltration process is governed by three mechanisms: initial water entry through the soil/plant surface, water flow through the unsaturated zone, and soil water storage capacity depletion. The soil is a reservoir that holds water for plant growth and is supplied by infiltration. As a result, computation of infiltration at the watershed size is required (Anjaneya Prasad et al. 2015).

The amount of water infiltrates into the soil is an essential metric for water resource management, capacity, surface water runoff forecast, and soil conservation. Infiltration is essential in the process of hydrological cycles such as (a) estimating peak flow rates and volumes of runoff for dams, culverts, and bridges, (b) estimating surface runoff and overland flow, (c) watershed planning and management, (d) estimating groundwater recharge, and (e) assessing soil moisture deficit and planning irrigation and drainage systems, etc. The flux a soil profile can absorb through its surface when water is hammered over it is referred to as its infiltration capacity. When the soil is dry, the infiltration rate is significant at first. It gradually drops until it approaches an asymptotically constant rate, frequently referred to as the final infiltration capacity or the soil infiltration capacity. Soil infiltration capacity determines the amount and time distribution of excess rainwater available for runoff during a storm. The soil infiltration rate should determine the maximum rate of irrigation. When irrigation water is applied at a higher pace, ponding and surface runoff occur. Infiltration rates are used to calculate abstractions in hydrograph analysis, which is then used to build hydraulic structures and urban drainage systems, design flood estimating, flood forecasting, and flood warning systems (Islam 2019).

Infiltration models created by several scholars are used to assess the infiltration rate. As a result, various attempts to mimic soil water infiltration have been made (e.g., Kostiakov, 1932; Lewis, 1937; and Philip, 1957). Several theoretical and empirical models have been produced throughout the last century. Ideal physical models were used to create theoretical models. These physical-based models consider the soil media capillary tubes that infiltrate water into the porous media. The theoretical models can calculate infiltration parameters based on soil physical attributes such as hydraulic conductivity, porosity, soil water pressure head, and soil water content. The land use pattern for a specific soil is essential in defining infiltration properties and is of interest to soil scientists, hydrologists, agronomists, and agricultural engineers.

Infiltration models can be divided into three types (Mishra et al. 2003; Sihag et al. 2017): Physical representations: Darcy's law and the law of mass conservation are used to get these (e.g., Richards 1931; Philips 1957), Semi-empirical models include: These include simple hypotheses about the relationship between cumulative infiltration and infiltration rate (e.g., Holtan 1961; Singh and Yu 1990) and empirical models: These are based on laboratory and field data (e.g., Kostikov 1932; Horton, 1941)

Water is a vital natural resource that influences crop output and is required for plant growth. Infiltration capacity is an important metric when designing irrigation systems, particularly surface irrigation systems and runoff generated in fields and forests. Water infiltration through surface soil is a complicated combination of rainfall and irrigation intensities, soil type, and surface condition (Mishra 2003). These factors influence the ability of water to move through the soil. Because of differences in soil properties within a field, the infiltration rate can range from very low to very high. This could be managed somehow, and irrigation efficiency might be significantly improved. Soil moisture tension and soil infiltration rate are essential elements that must be addressed when selecting when to irrigate and how much water to apply in quickly changing soil systems (Shukla 2003). As a result, the experiment is carried out in various land uses such as paddy field, grasslands, and dense forests. Different infiltration models examine the infiltration data and help locate the best suitable models using these models. Infiltration features are quantified when field infiltration data is mathematically matched to infiltration models. A study is being planned in the Papumpare district of Arunachal Pradesh to establish infiltration rates and fit several infiltration models in diverse land uses (Paddy Field, Grass Land, and Forest).

2.0 DATASET AND METHODOLOGY

2.1 Study Area

The experiments were conducted in selected land uses of the Papumpare district of Arunachal Pradesh. Arunachal Pradesh is one of the Northeastern hilly states of India and is situated in the foothills of the Himalayas. It receives heavy rainfall of about 2,000 to 3,000 mm between May and September yearly. The natural vegetation in this area is humid semi-evergreen and sub-tropical evergreen forests. Crops in this area are mainly paddy, Tea: Millet, oil seeds, and maize. The land used for experiments was a paddy field, Grassland and dense forest. The experiments were conducted with the help of a double-ring infiltrometer.

2.2 Equipment and procedure used for the experiment

The experiment used hand hoes, local knives for cleaning and digging, buckets, and scales. Infiltration trials continued until each land use's infiltration rate stabilized (Johnson, 1963). The recommended procedure of Mishra et al. (2003), Machiwal et al. 2006; Sihag et al. (2017) applied to carry out field experiments. Infiltrometers have two concentric metal cylinder rings, a rammer, and a measurement gauge. The inner and outer rings have 25 cm and 35 cm diameters and 25 cm heights. Both rings were

concentric on the soil surface and pounded into the soil consistently at 12 cm each using the rammer.

A thin plastic sheet was placed inside the ring to prevent soil damage from water splashing. The plastic sheet was flooded to 15-20 cm. Ground cover was removed without disturbing the soil before the trial. The rings were placed and inserted into the earth until they were secure, around 10mm. Water filled the outer and inner rings. Water infiltration into the soil was observed regularly. To ensure saturation, the outer ring contained enough water during each experiment. The experiment proceeded until a constant volume was added to time, and all observations, including time and water volume, were recorded. Six land use sites measured infiltration rates, and this observed data were used to assess different infiltration models selected for the study.

2.3 Selected Infiltration Models

The following infiltration models were assessed to find a best-fitting model to observe infiltration data in the land used.

2.3.1 Kostiakov model:

Kostiakov (1932) proposed an empirical equation to calculate cumulative infiltration (Shukla 2003; Uloma et al.2014)

$$C_t = at^b \quad \text{Eq. (1)}$$

2.3.2 Modified Kostiakov model:

It is an empirical model to overcome the limitation of Kostiakov, also called the Kostiakov-Lewis or Menzencev model (Sihag et al. 2017).

$$C_t = at^b + c \quad \text{Eq. (2)}$$

2.3.3 Revised modified Kostiakov model:

Four parameters revised modified Kostiakov infiltration model developed by Parhi *et al.* (2007):

$$C_t = \frac{a}{b} t^{(b+1)} + \frac{c}{1-d} t^{(1-d)} \quad \text{Eq. (3)}$$

2.3.4 Horton model:

Horton's (1940) three-parameter semi-empirical infiltration model) or the simpler version of Horton's model published by Davidoff and Selim (1986), represented a decline in infiltration capacity with time as an exponential decrease as

$$C_t = ct + m(1 - e^{-at}) \quad \text{Eq. (4)}$$

Unlike the Kostiakov model, infiltration in the Horton model is non-zero when t approaches infinity (Mishra et al. 2003).

2.3.5 Philips Model:

Philips (1957) proposed a model based on a semi-analytical solution to the Richards flow equation. Philips employed a time series to solve the Richards equation in the solution. By ignoring the higher-order variables, we obtained a two-term infiltration equation with physical meaning for both parameters:

$$C_i = St^{\frac{1}{2}} + At \quad \text{Eq. (5)}$$

Philip's numerical approach for obtaining the parameters S and A is too cumbersome for practical usage (Al-Azawi 1985). The regression model fitting approach was used to determine S and A parameter values. Soil surface characteristics heavily influence soil water penetration. The soil surface conditions were not considered when developing the Philip model, which may diminish its reliability in practice. The fundamental disadvantage of this equation is that for large t values, its infiltration rate forecasts are not accurate (Mishra et al. 2003; Sihag et al. 2017).

2.3.6 SCS model:

As experimental findings of the US Department of Agricultural, Natural Resources and Conservation Service summarized in the case of long-term experiment data, the application of the Kostikov model is complex. Therefore, they recommended a coefficient of 0.6985 to be added to the Kostikov model to improve the performance and better practical applicability as:

$$C_i = at^b + 0.6985 \quad \text{Eq. (6)}$$

In Eq. 1 to Eq. 6, C_i is cumulative infiltration at any time t , S = Sorptivity ($LT^{1/2}$), A = saturated hydraulic conductivity (LT^{-1}), t is a time of infiltration in min, a , b , c , d , k , m are parameters of different infiltration models to be determined with observed data using the curve-fittings method.

3.0 ANALYSIS RESULTS

The land use used for the infiltration test was forest land (FL), grassland (GL) and paddy field (PF) in Papumpare District to deal with the spatial heterogeneity in the infiltration process. Six tests were done at various land uses. The predicted models are Kostikov, SCS, modified Kostikov, Philip's, Horton's, and Re-Modified Kostikov (RMK) equations were chosen for evaluation in the study. These models were tested using field infiltration data. These infiltration equations were evaluated using experimental data from the study area to calculate model parameters. The parameters of all six infiltration models (infiltration models for all three locations) were derived using nonlinear regression analysis, and values are reported in Table 1, Table 2 and Table 3. Analyze infiltration data and derive model parameters using least squares. RMSE (mm/h) and R^2 indices assessed infiltration models. The most suited model was selected based on the lowest values of RMSE (mm/h) and the highest value of R^2 .

3.1 Cumulative Infiltration rate in different land use

3.1.1 Forest land use:

The infiltration experiment is employed in a variety of land uses, including forest land (FL), grassland (GL), and rice fields (PF). The experiment was conducted six times in different locations on forest land using the double ring infiltrometer depicted in Fig.1. The trials were carried out from November to February since the duration and severity of rainfall are expected during these months, and the soil is under water stress (i.e., low moisture content of the soil). Carroll et al. (2004) discovered that vegetation and parent material frequently increase the rate of infiltration. Infiltration rates are 60 times higher under trees than under woodland shelter belts and grazed pasture, and runoff volumes are reduced by 78% under trees (Marshall et al., 2014). Environmental variables that improve infiltration rates in forest land include earthworms and tree roots that generate cracks and voids.

The infiltration models employed in the study range from empirical to physical. They calculate the experimental field's infiltration capability or cumulative infiltration. The field characteristics determine the model parameters. Nonlinear regression analysis was used to determine the parameters of the infiltration model. According to the preceding explanation, the specifications for soil qualities for various land use categories differ. The values of infiltration parameters obtained from each model for six distinct experimental sites from the same land use are shown in table 1. The average values of the infiltration parameters from the field experiment for Kostiakov's model, SCS model, Modified Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's model were (0.512, 0.695), (0.358, 0.760), (0.505, 0.654, -0.539), (-0.623, 0.428), (0.100), and (0.671, 0.373, 0.113). The decay constant 'k' (0.1) in the Hortons model was the same in all experiment locations.

Table 1: Infiltration parameters of models in forestland.

T. N.	Equation fitting Parameters:(Forest Land Use)													
	Kostiakov's Model		SCS's model		Mod- Kostiakov's model			Phillip's model		Hortons model	RMK's model			
	a	b	a	b	a	b	c	s	a	k	a1	b1	a2	b2
1	0.488	0.673	0.324	0.745	0.523	0.66	-0.129	-1.8	1	0.1	4.037	1	0.206	0.367
2	0.346	0.755	0.224	0.832	0.447	0.709	-0.458	-0.429	0.321	0.1	-0.0002	0.836	0.04	0.155
3	0.555	0.721	0.414	0.773	0.744	0.669	-0.77	-0.347	0.319	0.1	-0.005	0.1	0.075	0.153
4	0.512	0.681	0.348	0.75	0.582	0.658	-0.257	-0.386	0.305	0.1	-0.0005	0.1	0.143	0.292
5	0.514	0.713	0.369	0.771	0.549	0.701	-0.15	-0.378	0.317	0.1	-0.0008	0.1	0.124	0.254
6	0.656	0.628	0.466	0.687	0.183	0.527	-1.469	-0.396	0.308	0.1	-0.006	0.1	0.09	0.179
Avg	0.512	0.695	0.358	0.760	0.505	0.654	-0.539	-0.623	0.428	0.100	0.671	0.373	0.113	0.233

3.1.2 Grassed land

It was observed that infiltration is greater on Grassland than on bare land. As a result, the maximum amount of rainwater is incorporated into the soil with minimal runoff. As a result, it appears critical to maintaining a good grass cover on pasture and range areas throughout the year to protect the soil from excessive erosion. This may aid in

boosting infiltration and decreasing runoff. When growing vegetation cannot be maintained, any dead grass and tree residues significantly impact boosting infiltration and minimizing runoff, as well as water and wind erosion. Due to the rainfall that occurred during the experiment, which caused complete saturation of the soil, the number of experiments conducted in Grassland was restricted to four. As a result, the results of these four trials were incorporated into the study. Nonlinear regression analysis is used to determine the parameters of the infiltration models. An infiltration capacity experiment was carried out in six distinct locations for Grassland to determine the parameters of each model. Table 2 shows the values of model parameters acquired from grassed land. Infiltration parameters from the field experiment were obtained as (0.473, 0.694), (0.317, 0.77), (0.48, 0.661, -0.427), (-0.404, 0.311), (0.100), and (0.668, 0.519, 0.119, 0.262). The decay constant 'k' (0.1) in the Hortons model was the same in all experiment locations.

Table 2: Infiltration parameters of models in Grassland.

Site No.	Equation fitting Parameters:(Grassland)													
	Kostiakov's model		SCS's model		Mod. Kostiakov's Model			Phillip's model		Horton's model	RMK's model			
	a	b	a	b	a	b	c	S	A	k	a1	b1	a2	b2
1	0.432	0.672	0.261	0.763	0.49	0.65	-0.19	-0.399	0.292	0.1	2.083	1	0.159	0.346
2	0.294	0.75	0.163	0.858	0.239	0.788	0.256	-0.408	0.295	0.1	0.0001	0.813	0.109	0.308
3	0.556	0.637	0.364	0.713	0.887	0.555	-0.922	-0.486	0.344	0.1	-0.002	0.1	0.13	0.27
4	0.544	0.669	0.374	0.735	0.089	0.582	-1.087	-0.386	0.306	0.1	-0.006	0.1	0.065	0.145
5	0.487	0.742	0.363	0.793	0.485	0.743	0.009	-0.364	0.317	0.1	1.932	1	0.141	0.273
6	0.526	0.695	0.374	0.755	0.692	0.647	-0.625	-0.378	0.31	0.1	-0.002	0.1	0.11	0.232
Avg.	0.473	0.694	0.317	0.770	0.480	0.661	-0.427	-0.404	0.311	0.1	0.668	0.519	0.119	0.262

3.1.3 Paddy Field

Infiltration is one of the most critical factors determining water use efficiency and water and chemical transfer in paddy fields. Infiltration rate is influenced by soil texture and structure, bulk density, water ponding depth, groundwater table, puddling intensity, and hardpan hydraulic conductivity. The parameters obtained from the paddy field infiltration model are detailed in Table 3. The parameters of the infiltration models are determined using nonlinear regression analysis. Six different site infiltration parameters were developed for each model under the same land use but at separate testing locations. The field characteristics influence the parameters of the models; the average values of (Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's model infiltration parameters from the field experiment were (0.239, 0.550), (0.065, 0.851), (-2.091, 1.694, 0.319), (-0.716, 0.385), (0.1). In the Hortons model, the decay constant 'k' (0.1) was the same in all experiment locations.

Table 3: Infiltration parameter in paddy field

T. N.	Equation fitting Parameters:((Paddy Field)													
	Kostiakov's model		SCS's model		Mod-Kostiakov's model			Phillip's model		Horton's Model	RMK's model			
	a	b	a	b	a	B	c	s	a	k	a1	b2	a2	b2
1	0.233	0.460	0.017	0.919	-0.527	0.565	0.319	-0.471	0.255	0.100	0.000	0.100	0.096	0.474
2	0.118	0.573	0.009	1.000	-5.415	4.474	0.100	-0.492	0.263	0.100	0.000	0.885	0.004	0.100
3	0.128	0.662	0.019	1.000	-0.454	0.275	0.532	-0.484	0.268	0.100	-0.002	0.194	0.008	0.100
4	0.459	0.482	0.213	0.607	-3.739	2.956	0.218	-0.451	0.263	0.100	-0.004	0.100	0.042	0.167
5	0.228	0.614	0.075	0.806	-0.659	0.474	0.492	-1.928	1.000	0.100	-0.001	0.100	0.033	0.199
6	0.265	0.509	0.057	0.773	-1.750	1.418	0.253	-0.472	0.263	0.100	-0.003	0.100	0.028	0.169
Avg.	0.239	0.550	0.065	0.851	-2.091	1.694	0.319	-0.716	0.385	0.100	-0.002	0.247	0.035	0.202

3.2 Performance Evaluation of Selected Cumulative Infiltration Models

Infiltration models were evaluated using RMSE (mm/h) and coefficient of determination (R^2). The most suitable model was selected based on minimum RMSE (mm/h) and maximum values of R^2 criteria.

3.2.1 Forest land

Table 4 summarizes the forest land findings. For Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's model, the computed average RMSE values were 0.115, 0.300, 0.107, 1.479, 0.369, and 0.274 mm/h, and the R^2 values were 0.999, 0.997, 0.999, 0.981, 0.995, and 0.999, respectively.

Table 4: Value of RMSE (mm/h) and R^2 for forest land

Parameters	Test	Kostiakov model	SCS model	Mod Kostiakov model	Philip model	Horton model	RMK model
RMSE (mm/h)	1	0.155	0.285	0.209	1.357	0.204	0.209
	2	0.043	0.386	0.082	1.842	0.493	0.393
	3	0.189	0.337	0.156	1.085	0.413	0.163
	4	0.196	0.356	0.081	1.616	0.466	0.629
	5	0.051	0.225	0.057	1.401	0.265	0.138
	6	0.054	0.214	0.059	1.574	0.374	0.113
	Avg.	0.115	0.300	0.107	1.479	0.369	0.274
R^2	1	0.998	0.997	0.998	0.982	0.999	0.998
	2	0.998	0.995	1.000	0.964	0.991	0.999
	3	0.999	0.997	0.999	0.986	0.994	1.000
	4	0.999	0.998	1.000	0.983	0.995	1.000
	5	1.000	0.998	1.000	0.983	0.997	1.000
	6	1.000	0.999	1.000	0.987	0.997	1.000
	Avg.	0.999	0.997	0.999	0.981	0.995	0.999

Fig. 1 to Fig. 6 shows the observed and predicted infiltration rates for the abovementioned models. They show that all the Modified Kostikov's model values are within the 10% error band from the line of perfect agreement than the other infiltration models (Kostiakov's model, SCS model, Modified Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's model). The modified Kostikov's model exhibits the lowest RMSE (mm/h) and the most significant R² values, 0.107 and 0.999, respectively. Similarly, a comparison of the RMSE and R² indicates that Modified Kostikov's model outperforms Kostiakov's, SCS, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's models. Thus, Modified Kostiakov's model outperforms all other models for the study region.

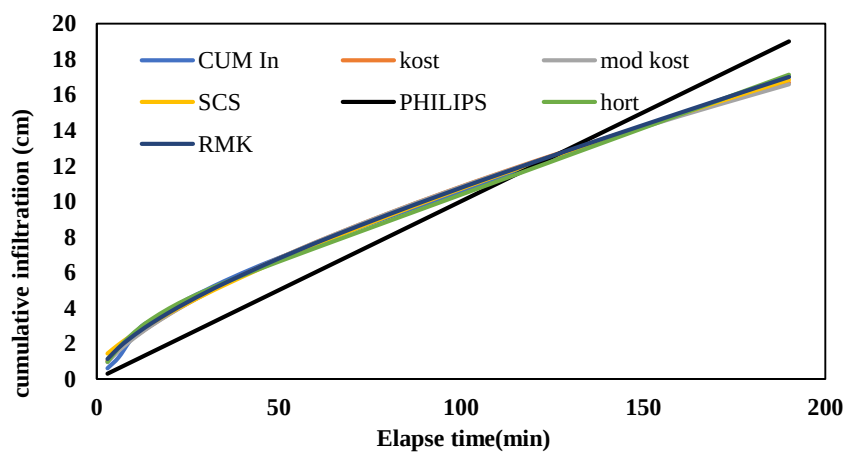


Figure 1: Cumulative infiltration Measured Vs Predicted by different models in forest land use at site 1

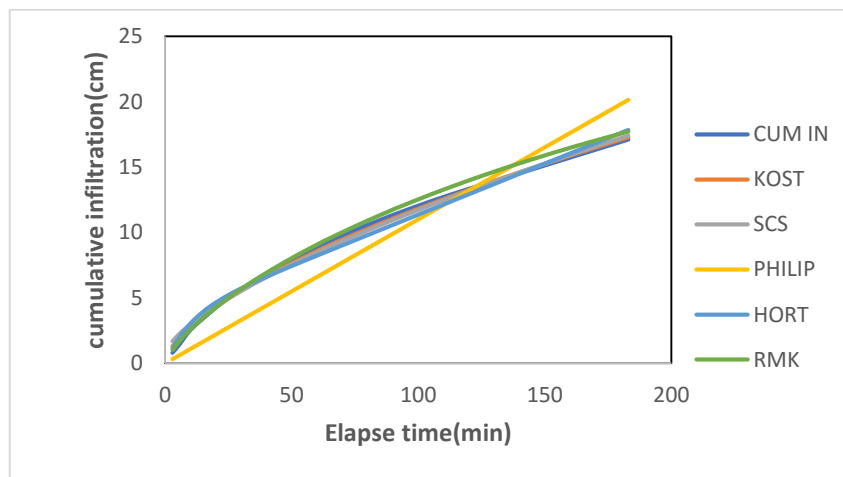


Figure 2: Cumulative infiltration Measured Vs Predicted by different models in the forest at site 2

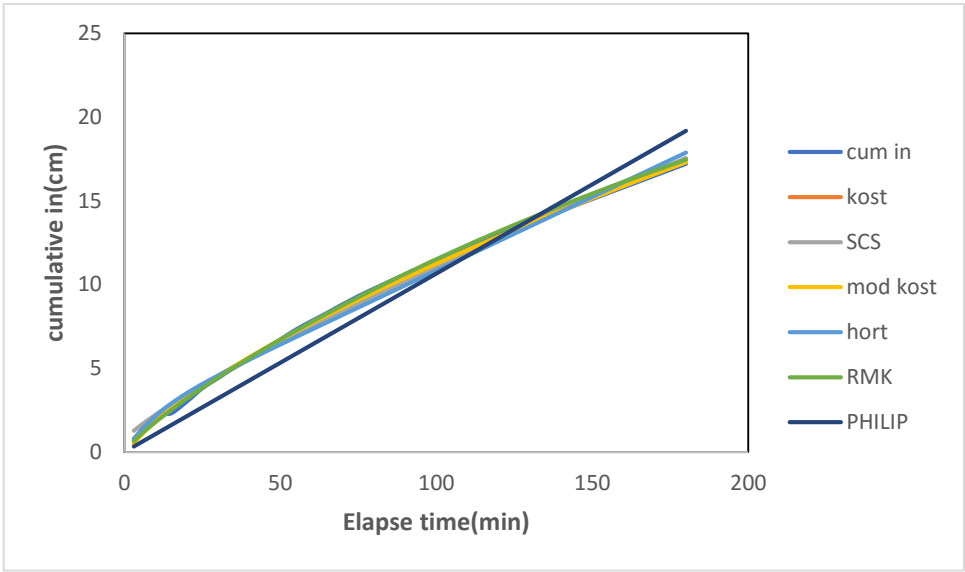


Figure 3: Cumulative infiltration Measured Vs Predicted by different models in the forest at site 3

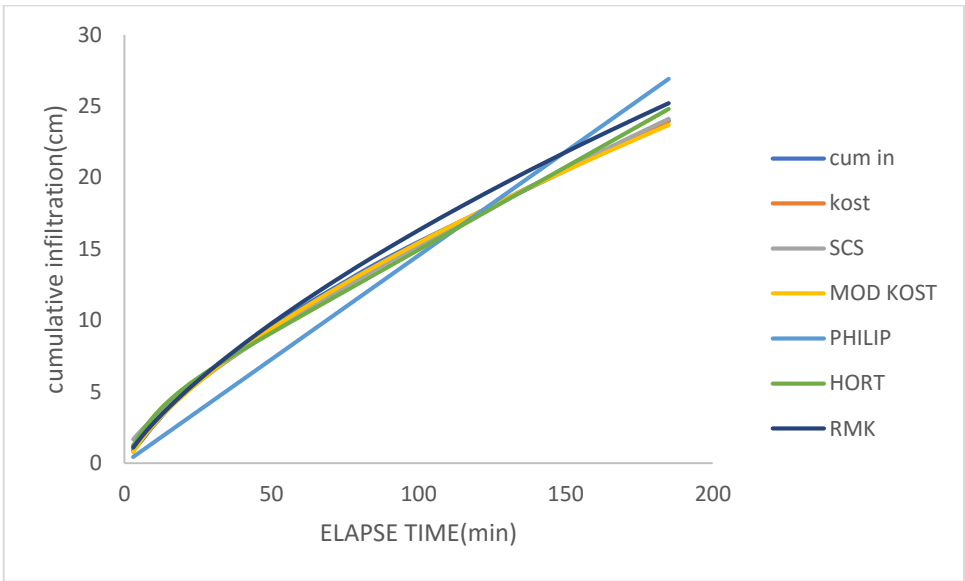


Figure 4: Cumulative infiltration Measured Vs Predicted by different models in the forest at site 4

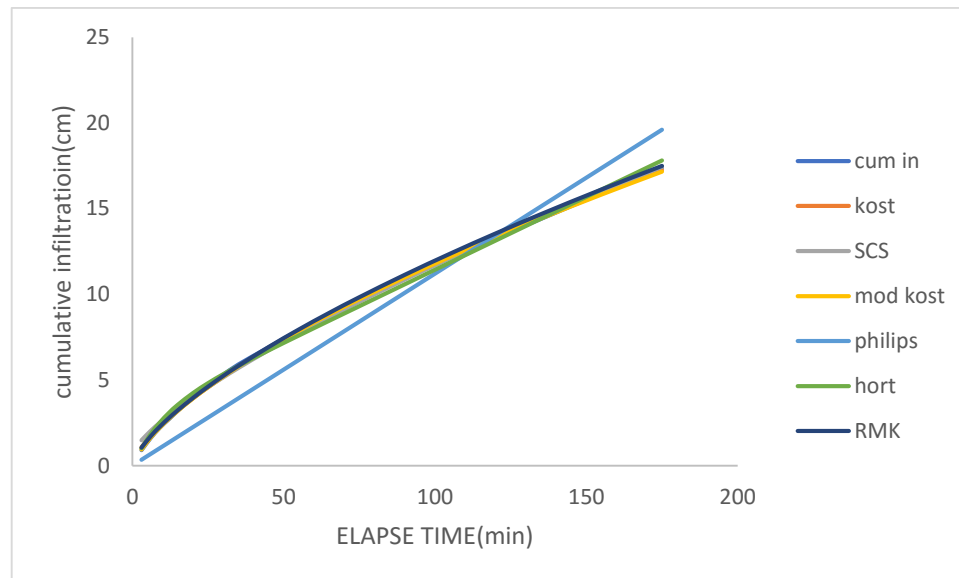


Figure 5: Cumulative infiltration Measured Vs Predicted by different models in the forest at site 5

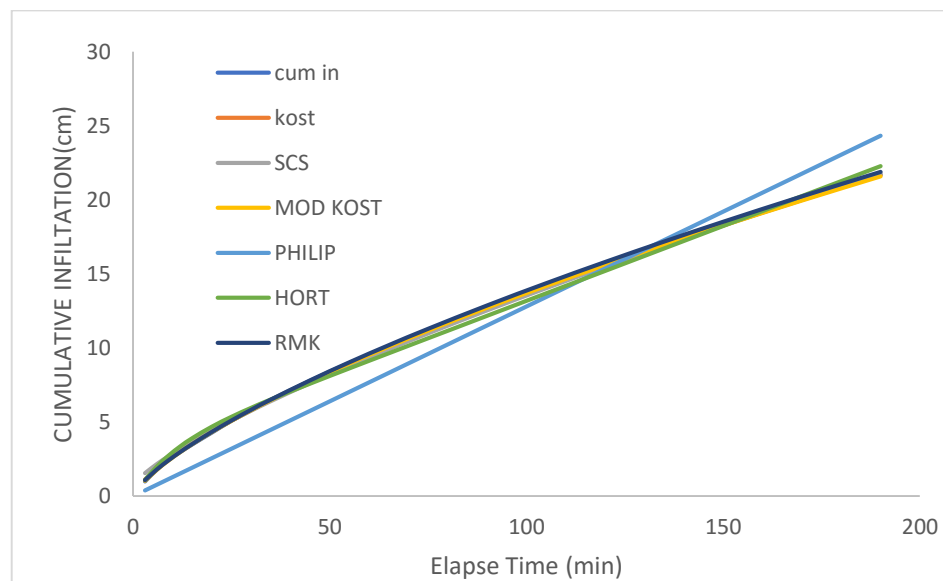


Figure 6: Cumulative infiltration Measured Vs Predicted by different models in forest land use at site 6

3.2.2 Grassland

The RMSE and R^2 approaches were used to evaluate infiltration models. The best model was chosen based on the highest RMSE and R^2 criterion values. For Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's model, Horton Re-

Modified Kostiakov's model, and Philip's model, in that order. Table 5 summarises the findings of the experiment on forest land use.

Table 5: Value of RMSE (mm/h) and R^2 (R square) for Grassland

Parameters	Test no.	Kostiakov model	SCS model	Mod Kostiakov model	Philip model	Horton model	RMK model
RMSE (mm/h)	1	0.077	0.138	0.051	0.782	0.085	0.022
	2	0.221	0.344	0.139	1.403	0.267	0.194
	3	0.221	0.366	1.004	1.551	0.426	0.143
	4	0.160	0.304	0.097	1.601	0.363	0.142
	Avg.	0.170	0.288	0.323	1.334	0.285	0.125
R^2	1	1.000	0.999	1.000	0.994	1.000	1.000
	2	0.998	0.994	0.999	0.969	0.996	0.998
	3	0.998	0.995	1.000	0.972	0.993	0.999
	4	0.999	0.998	1.000	0.981	0.996	0.999
	Avg.	0.999	0.997	1.000	0.979	0.996	0.999

Fig.7 to Fig. 10 provide information about the observed infiltration rate and predicted infiltration rate values of the models mentioned above and suggest that all the values of Re-Modified Kostikov's model is within the 10% error band from the line of perfect agreement than the other infiltration models (Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's and Philip's model). Similarly, a comparison of the RMSE, R^2 , indicates that the Re-Modified Kostikov's model outperforms Kostiakov's SCS model, Mod. Kostiakov's model, Horton's model, Re-Modified Kostiakov's model, and Philip's model. Thus, among all models described above for the study region, Re-Modified Kostikov's model performs best; thus, this model was selected to determine the infiltration rate of this study area.

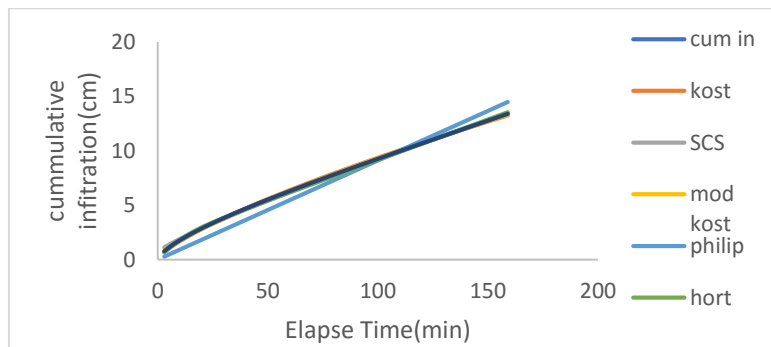


Figure 7: Cumulative infiltration Measured Vs Predicted by different models in grassland use at site 1

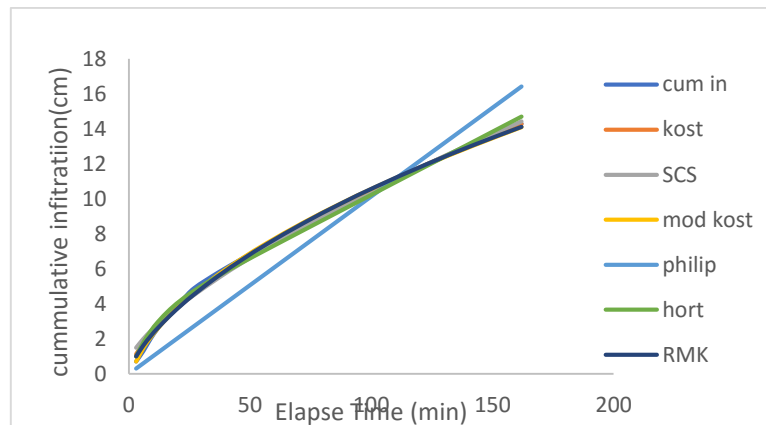


Figure 8: Cumulative infiltration Measured Vs Predicted by different models in grassland use at site 2

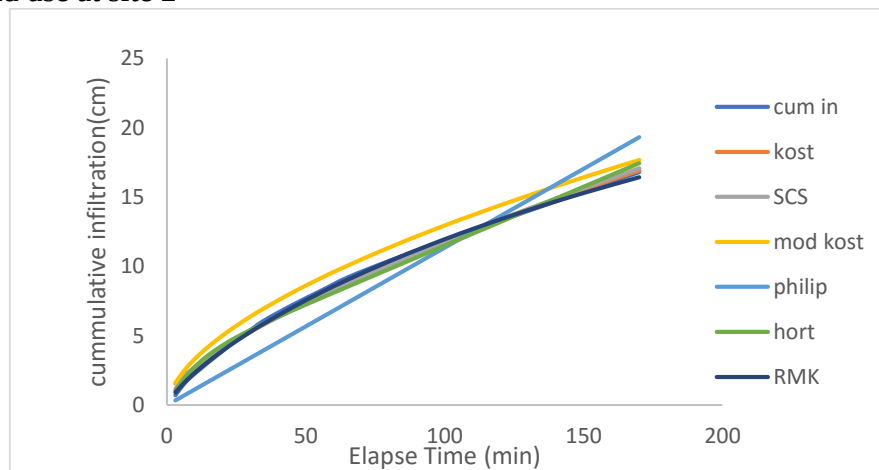


Figure 9: Cumulative infiltration Measured Vs Predicted by different models in Grassland at site 3

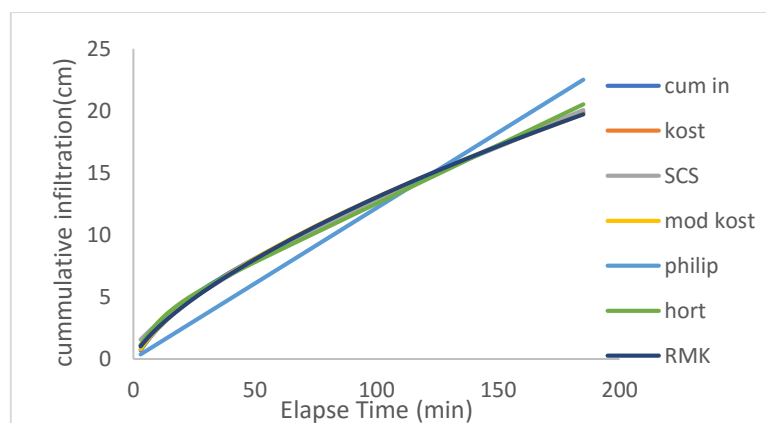


Figure 10: Cumulative infiltration Measured Vs Predicted by different models in the grass at site 4

3.2.3 Paddy field

The RMSE and R^2 approaches were used to evaluate infiltration models. The best model was chosen based on the maximum RMSE and R^2 criterion values. For Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, and Re-Modified Kostiakov's and Philip's model, the computed average RMSE values were 0.117, 0.231, 0.051, 0.538, 0.165, and 0.397 mm/h, while the R^2 values were 0.983, 0.947, 0.995, 0.921, 0.976, and 0.9 respectively. Table 6 summarises the forest land findings.

Table 6: Value of RMSE (mm/h) and R^2 for paddy field

<i>Parameters</i>	<i>Test no.</i>	<i>Kostiakov model</i>	<i>SCS model</i>	<i>Mod Kostiakov model</i>	<i>Philip model</i>	<i>Horton model</i>	<i>RMK model</i>
RMSE (mm/h)	1	0.089	0.186	0.081	0.412	0.083	0.088
	2	0.111	0.229	0.042	0.287	0.147	0.141
	3	0.053	0.173	0.022	0.338	0.114	0.191
	4	0.219	0.304	0.092	1.008	0.310	0.830
	5	0.090	0.220	0.029	0.619	0.185	1.061
	6	0.140	0.274	0.039	0.565	0.154	0.070
		0.117	0.231	0.051	0.538	0.165	0.397
R^2	1	0.979	0.928	0.983	0.915	0.988	0.980
	2	0.959	0.890	0.994	0.890	0.939	0.974
	3	0.997	0.976	1.000	0.976	0.989	1.000
	4	0.981	0.965	0.997	0.893	0.966	0.990
	5	0.997	0.984	1.000	0.962	0.990	0.993
	6	0.982	0.940	0.999	0.894	0.986	0.995
	Avg.	0.983	0.947	0.995	0.921	0.976	0.988

Fig.11 to Fig. 16 show the abovementioned models observed and predicted infiltration rates. They show that all the Modified Kostiakov's model values are within the 10% error band from the line of perfect agreement than the other infiltration models (Kostiakov's model, SCS model, Modified Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's model). Similarly, when compared to the RMSE, R^2 indicates that Modified Kostiakov's model outperforms Kostiakov's model, SCS model, Modified Kostiakov's model, Philip's, Horton's, Re-Modified Kostiakov's, and Philip's model. Thus, Modified Kostiakov's model outperforms all other models for the study region; thus, this model was chosen to assess the infiltration rate of this study area.

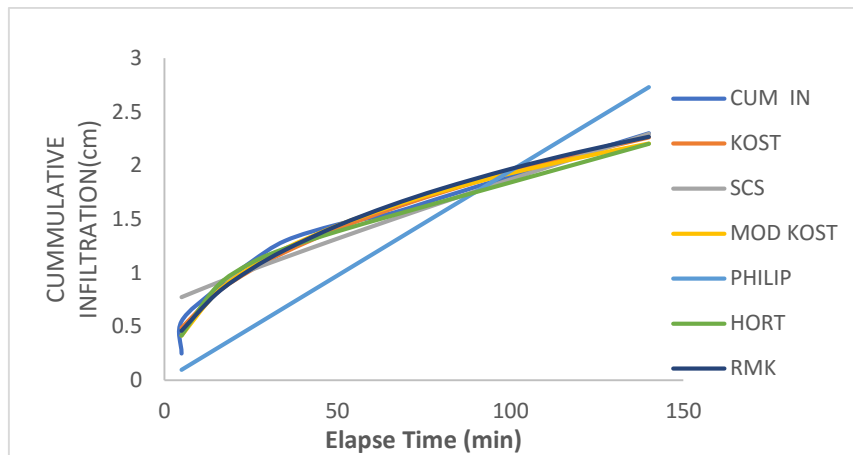


Figure 11: Cumulative infiltration Measured Vs Predicted by different models in paddy field use at site 1

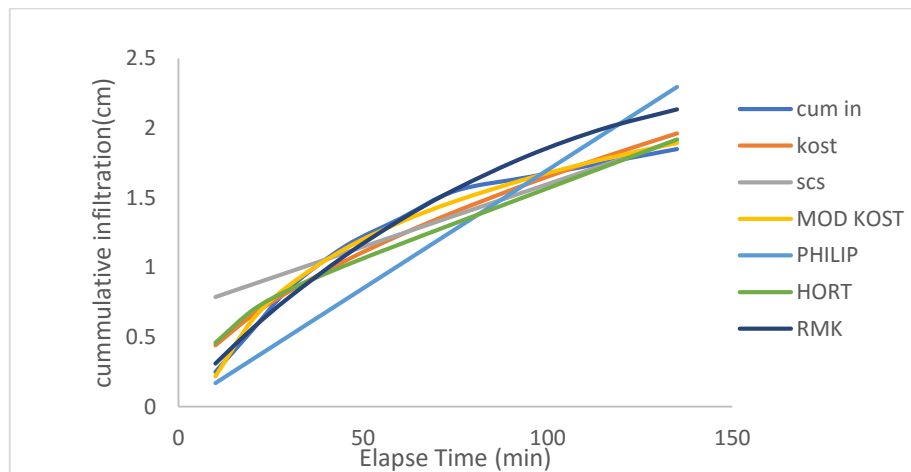


Figure 12: Cumulative infiltration Measured Vs Predicted by different models in a paddy field at site 2

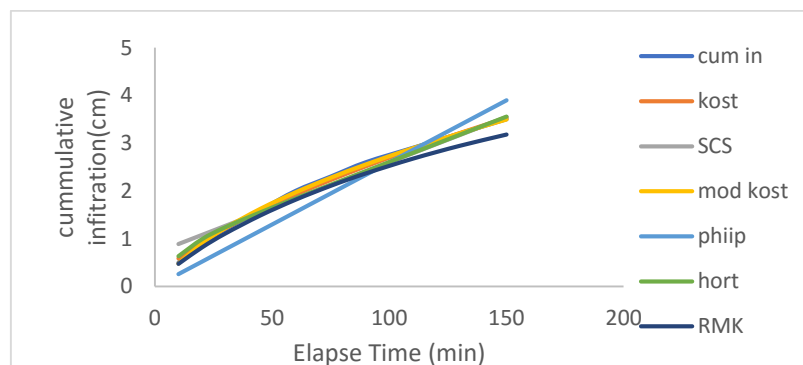


Figure 13: Cumulative infiltration Measured Vs Predicted by different models in a paddy field at site 3

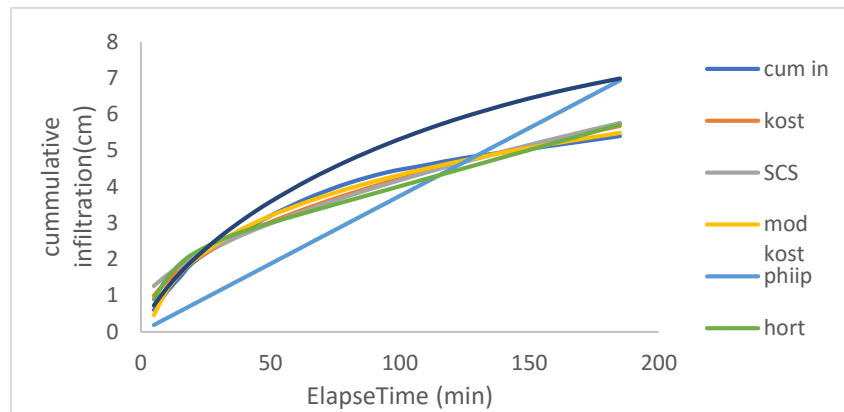


Figure 14: Cumulative infiltration Measured Vs Predicted by different models in a paddy field at site 4

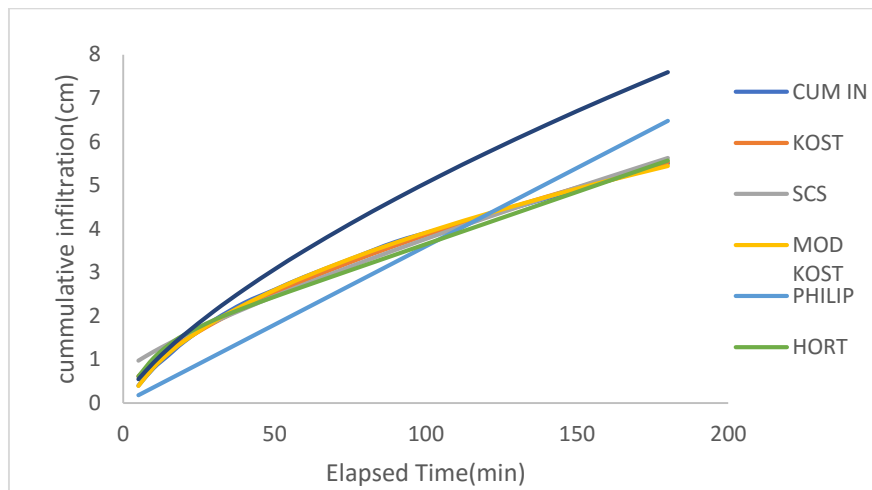


Figure 15: Cumulative infiltration Measured Vs Predicted by different models in a paddy field at site 5

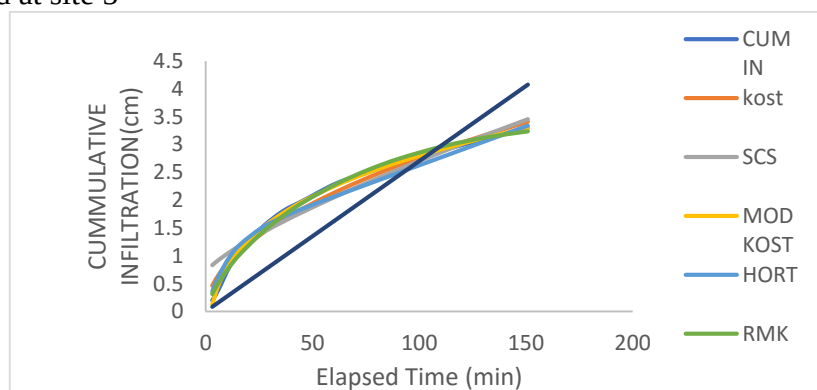


Figure 16: Cumulative infiltration Measured Vs Predicted by different models in a paddy field at site 6

4.0 DISCUSSION

The infiltration experiment is employed in a variety of land uses, including forest land (FL), grassland (GL), and rice fields (PF). The experimental land consists of a paddy field, Grassland, and a deep forest. The studies were conducted using double-ring data from three different land uses. The experiment was carried out six times in different locations on forest land using a double-ring infiltrometer. The trials were carried out between November and February since rainfall duration and intensity are typical during these months, and the soil is under water stress (i.e., low moisture content). Vegetation and parent material frequently increase the rate of infiltration. Infiltration rates are 60 times higher under trees than under woodland shelter belts and grazed pasture, and runoff volumes are reduced by 78% under trees (Marshall et al., 2014). Environmental variables that improve infiltration rates in forest land include earthworms and tree roots that generate cracks and voids.

The infiltration models utilized in this research are entirely empirical or physical. They estimate the experimental field's infiltration capacity or cumulative infiltration. The models' parameters rely on the features of the field. The parameters of the infiltration model are derived via nonlinear regression analysis. RMSE and coefficient of determination were used to assess infiltration models (R^2). Minimum RMSE and maximum values of R^2 were utilized to determine the best appropriate model.

In the case of forest land, Kostiakov's (0.512, 0.695), SCS (0.358, 0.760), and Mod. Kostiakov's (0.505, 0.654, -0.539), Philip's (-0.623, 0.428), Horton's (0.1), and Re-Modified Kostiakov's (0.671, 0.373, 0.113, 0.23) were shown to have the best parameters. By Horton's model, the constant of decay 'k' (0.1) was the same at all experiment locations. Kostiakov's (0.115), SCS's (0.300), and Mod. Kostiakov's (0.107), Philip's (1,479), Horton's (0.369), and Re-Modified Kostiakov's (0.274) mm/h were the calculated average RMSE values for forest land. The average R^2 values for Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, and Re-Modified Kostiakov's models are 0.999, 0.997, 0.999, 0.981, 0.995, and 0.999, respectively. The model modified by Kostiakov's had the lowest RMSE and highest R^2 values, 0.107 and 0.999, respectively. Roy & Chatterjee (2022) also reported similar findings in the case of forest land use.

In the case of Grassland, Kostiakov's (0.473, 0.694), SCS (0.317, 0.77), and Mod. Kostiakov's (0.48, 0.661, -0.427), Philip's (-0.404, 0.311), Horton's (0.100), and Re-Modified Kostiakov's (0.668, 0.519, 0.119, 0.262) were the models with the most accurate parameters. Kostiakov's (0.170), SCS's (0.288), Mod. Kostiakov's (0.323), Philip's (1,334), Horton's (0.285), and Re-Modified Kostiakov's (0.125) mm/h and R^2 values were Kostiakov's (0.997), SCS model (0.997), Mod. Kostiakov's (1.00), Philip's (0.979), and Horton's (0.996). Following Horton's model, the decay constant 'k' (0.1) was identical across all testing sites. Similar findings by Wu et al. (2016) and Dagadu & Nimbalkar (2012) reported a constant decay constant in evaluating different infiltration models in China.

The parameters of various selected models were obtained in the case of the paddy field (Kostiakov's (0.239, 0.550), SCS (0.065, 0.851), Mod. Kostiakov's (-2.091, 1.694, 0.319), Philip's (-0.716, 0.385), Horton's (0.1), and Re-Modified Kostiakov's (-0.002, 0.247, 0.035, 0.202). The computed average RMSE values were Kostiakov's

(0.117), SCS's (0.231), Mod. Kostiakov's (0.051), Philip's (0.538), Horton's (0.165), and Re-Modified Kostiakov's (0.397) mm/h, respectively, and the R^2 values were Kostiakov's (0.983), SCS's (0.947), Mod. Kostiakov's (0.995), Philip's decay constant 'k' (0.1) in Horton's model was the same in all experiment locations. Patle (2021) also identified that the Kostikov model better fits with experimental data in the hilly micro watershed of Sikkim, India. Our findings align with Michewal (2006), Shihag et al. (2017), and Karahan & Pachepsky (2022) reported infiltration characteristics changes as land use.

5.0 CONCLUSIONS

The following conclusions were drawn from the present study

1. In the forest land use, the RMSE, R^2 suggests a better performance by Modified Kostikov's model compared to Kostiakov's, SCS model, Philip's, Horton's, and Re-Modified Kostiakov's. Thus, Modified Kostiakov's model is recommended
2. In the grassland RMSE, R^2 suggests a better performance by Re-Modified Kostikov's model than Kostiakov's model, SCS model, Mod. Kostiakov's model, Philip's, Horton's, and Re-Modified Kostiakov's. Thus, Re-Modified Kostikov's model performs best among all the selected models
3. In the Paddy field case, statistical indicators suggest a better performance by Modified Kostiakov's model than Kostiakov's, SCS model, Philip's, Horton's, and Re-Modified Kostiakov's. Thus, Modified Kostiakov's model may be preferred in the case of the Paddy field.
4. The performance of different selected models is site-specific and varied per land use.

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