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Evaluation of Horton and Modified Kostiakov infiltration model for suitability on hilly slopes

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ABSTRACT

A study was carried out to determine the suitability of infiltration models that can be used successfully in hill slopes. The study was conducted on cultivated land at College of Post Graduate Studies in Agricultural Sciences (CPGSAS Campus) at Umiam (Latitude 25˚40' N, Longitude 91˚ 54' E), College of Agriculture (COA Campus) at Kyrdemkulai (Latitude 25˚ 44' N, Longitude 91˚ 49' E) and NBPGR Campus at Umiam (Latitude 25˚ 41' N, Longitude 91˚ 55' E). In this study infiltration in channel section was measured with the help of cut-throat flumes, since use of double ring infiltrometer on slope was difficult. Wherever the observation points were on surface of mild slopes, double ring infiltrometer was also used. Ten points were considered for infiltration measurement. The previous studies indicated the suitability of two models *viz.* Horton and Modified Kostiakov on different situations, hence the same models were taken under this study for evaluation on sloppy surface. Two statistical comparison criteria *viz.* root mean square error (RMSE) and coefficient of determination (R^2) were used to determine the best performing infiltration models. Test statistics (RMSE (2.63) and R^2 (0.93) values revealed that Horton infiltration model was the best to predict infiltration rate in hill slope. Horton model also gave the best prediction of infiltration rate and basic infiltration rate in hill slope. It was also recorded that Horton model gave the best prediction of infiltration rate and basic infiltration on plain surface.

Introduction

Infiltration is the process of water movement from the ground surface into the soil and has an important role in surface and subsurface hydrology, groundwater replenishment, irrigation and soil erosion. Infiltration not only controls the division of water into soils, water redistribution within soils, and even water deep percolation down to groundwater but also influence the occurrence time and amount of runoff (Moore *et al.,* 1981). Neglecting the infiltration process in irrigated soils will lead to low application efficiency (Machiwal *et al.,* 2006). Recent attention has been paid to mountain resources because at least half of the world's population depends on water flowing in or from mountains (Price, 1999). The importance of mountains as sources of fresh water further underscores the need for better understanding the water cycle, including infiltration processes on mountain slopes. Knowledge of hill-slope hydrology has been hampered by the lack of measurement of soil hydraulic properties. Normally infiltration is measured by double ring infiltrometer. However, double ring infiltrometer is not suitable for hilly slopes because inserting rings into sloppy surface soil and the uneven water column within the infiltrometer are associated constraints. Further, hill slope infiltration barely has any storage water over the surface, unlike the condition we maintain in double ring infiltrometer measurement. Many researchers have compared the accuracy of the models by comparing the computed and observed infiltration rates (Hopmans, 1995; Mishra *et al.,* 2003; Chahinian *et al.,* 2005; Highlight *et al.,* 2010).

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However, available literatures are silent about the efficacy of these models on a hill slopes. Gifford *et al.* (1976) observed that among the Horton, Kostiakov and Philip's models, the Horton model gave the best fit of infiltration data in mostly semi-arid rangelands in Australia. Similarly, Machiwal *et al.* (2006) observed, infiltration was well described by Philip's model in a wasteland in Kharagpur, India. Hajabbasi and Mohammed (2006) evaluated the Kostiakov, Horton, and Philip's infiltration models under different tillage and rotations in a clay-loam in North-west Iran and reported that the Horton's model gave the best prediction of infiltration rate in that region. Roohian *et al.* (2005) suggested that Horton's model gives an acceptable estimate of the final infiltration rate under given soil texture conditions. The present infiltration measurement scheme is proposed to use cutthroat flume on a channelized surface flow over hill slope. The observed data was used to evaluate the Modified Kostiakov and Horton equations.

2. Materials and Methods

Objective of the study was to determine the suitability of the infiltration models on hilly areas at different slopes. In order to achieve the objectives, random locations with different slopes were chosen in the experimental farms of College of Post-Graduate Studies in Agricultural Sciences, College of Agriculture, Kyrdemkulai and National Bureau of Plant Genetic Resources, Umiam centres. Two different measurement schemes were undertaken for achieving accuracy of field observed data for both infiltration rate and basic infiltration rate. In slope land observations were expected to be erroneous due to uneven water surface within the rings of the double ring infiltrometer. For conducting enormous filed testing of infiltration, three specific places were identified in District RI-bhoi of Meghalaya namely, (1) CPGSAS Campus at Umiam (Latitude 25˚ 40' N, Longitude 91˚ 54' E) (2) COA Campus at Kyrdemkulai (Latitude 25˚ 44' N, Longitude 91˚ 49' E) (3) NBPGR Campus at Umiam (Latitude 25˚ 41' N, Longitude 91˚ 55' E). The geography of the district experiences different types of climate ranging from tropical climate in the areas bordering Assam to the temperate climate adjoining the East *Khasi* Hills district. Minimum and maximum average temperature during the crop period in the study site ranged from 20.07^0C to 26.7^0C, respectively. Out of total annual rainfall (2000 mm), about 419 mm was received during October-March. The average relative humidity ranged from 44.30% to 87.20% during the crop period. The average wind speed ranged between 0.8 and 2.8 kmph during October to March. Soils of the observation sites were shady-clay-loam with bulk density ranging from 1.18 to 1.52 g cc^{-1}. The soil physical properties of the observation points are given in Table 1.

Table 1. Physico-chemical properties of soil collected from the experimental field

Points	Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Total porosity (%)	OM (%)
1	0-15	61.90	12.65	25.45	1.36	2.17	47.20	2.33
	15-30	57.13	12.33	30.54	1.34	1.82	38.81	1.86
2	0-15	62.11	11.96	25.93	1.34	2.13	39.92	1.60
	15-30	60.00	11.83	28.17	1.27	2.19	46.84	1.45
3	0-15	58.54	12.82	28.64	1.42	2.21	42.01	1.09
	15-30	57.35	12.50	30.15	1.37	1.81	39.98	0.91
4	0-15	68.62	10.77	20.61	1.43	2.26	42.01	2.64
	15-30	65.33	11.50	23.17	1.46	1.92	40.76	2.48
5	0-15	72.23	9.56	18.21	1.52	2.34	41.02	2.22
	15-30	69.92	10.67	19.41	1.41	1.74	42.88	1.78
6	0-15	66.61	11.21	22.18	1.34	2.26	43.07	2.28
	15-30	65.00	11.81	23.19	1.31	2.01	45.82	1.60
7	0-15	62.83	11.37	25.8	1.34	2.22	42.01	2.53
	15-30	58.30	12.56	28.14	1.36	1.70	40.76	2.43
8	0-15	55.55	13.52	30.93	1.35	2.24	41.02	2.42
	15-30	58.33	12.55	29.12	1.35	1.74	42.88	1.71
9	0-15	56.55	13.37	30.08	1.32	2.24	43.07	2.38
	15-30	55.00	12.83	32.17	1.18	2.01	45.82	1.55
10	0-15	54.00	13.95	32.05	1.35	2.23	47.26	1.91
	15-30	56.76	12.11	31.13	1.28	1.87	50.57	1.60

All the points but point 5 of observation have soil texture Sandy Clay Loam with high infiltration potential. Points 1 to 6 have slopes ranging from 0.72% to 2.82% and hence found suitable for double ring infiltrometer to measure infiltration. The points of observation from 7 to 10 have slopes ranging from 8.13% to 20.8%, hence cutthroat flumes were used for measurement.

Double ring infiltrometer:

The standard double ring infiltrometer set comprises of a couple of concentric rings (Figure 1). The diameter of the inner ring is 30 cm and the outer ring is 60 cm and the two rings have a depth of 30 cm. The double ring infiltrometer made of rust proof galvanized steel sheet. A hammer and plate is used for hammering and inserting the rings to the desired level in the ground surface. Double ring infiltrometer has two rings: an inner and outer ring. The purpose is to create a one dimensional flow of water from the inner ring, as the analysis of data is simplified. If water is flowing in one-dimension at steady state condition, and a unit gradient is present in the underlying soil, the infiltration rate is approximately equal to the saturated hydraulic conductivity.

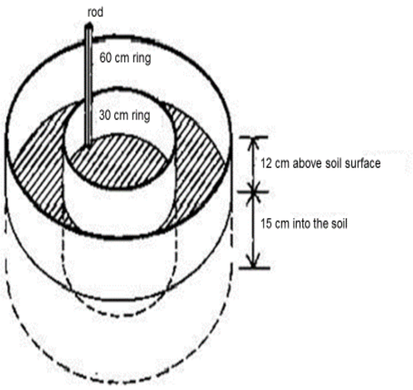
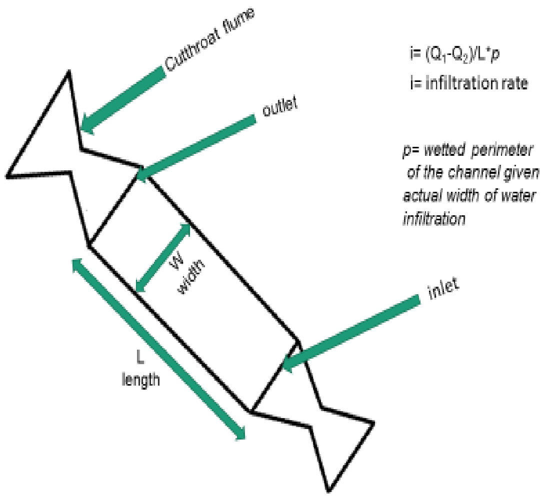


Figure 1. Schematic Diagram of Double Ring Infiltrometer

The inner ring is driven into soil vertically to a depth of 10 cm so that remaining 20 cm of the cylinder is above the ground. The outer ring is also inserted concentric to the inner cylinder. Both the cylinders are filled with water to equal height so as to provide equilibrium hydraulic head both inside and outside of the smaller cylinder. The drop of water level in the inner cylinder is recorded in given duration with the help of hook gauge placed over the rim of the cylinders. As the water levels drop, refilling of the water is necessary to maintain a nearly equal hydraulic heads throughout the observation period. Care should be taken not to disturb the soil surface while refilling with water. The procedure is continued till a constant rate of water infiltration is achieved, which is considered to be the basic rate of infiltration.

Cutthroat flume:

Cutthroat flumes originally made for measurement irrigation water flow. The advantage of the flume is that unlike Pershall flume, it can be used on level surface and no drop of hydraulic head is required for measurement of discharge. It gives accurate readings of water flow even for a small discharge. Since it can be installed on any channel section, two cutthroat flumes can used to measure the inflow and outflow of water for a uniform channel section of known length. The difference of discharges between the inflow and outflow gives the actual amount of water infiltrated in the channel section. A schematic diagram of measurement of infiltration with the help of cutthroat flume is given in Figure 2.



The infiltration is given by the difference of discharges between the inflow and outflow flume divided by the actual area of infiltration which is the product of length of uniform channel section and the wetted perimeter of the channel. The measurement of wetted perimeter is taken very carefully by taking average value of multiple measurements within the channel section.

Infiltration models:

The literature survey on the infiltration models indicated that in most of the studies conducted worldwide, Horton and Modified Kostiakov models were found to give accurate prediction of infiltration on level surfaces. Looking into it, the present study was also taken up to examine the effectiveness of these two models on slopes where no hydraulic head is created for measuring infiltrations.

Table 2. Characteristics of Test Locations with Information on Instrumentation

Point No.	Land use	Slope (%)	Soil type	Instrument used	Duration of the test
1	Lemon grass	1.12	Sandy clay loam	Double ring infiltrometer	3 hrs
2	Fallow land	2.64	Sandy clay loam	Double ring infiltrometer	3 hrs
3	Fallow land	0.72	Sandy clay loam	Double ring infiltrometer	3 hrs
4	Paddy	2.53	Sandy clay loam	Double ring infiltrometer	3 hrs
5	Mustard	2.82	Sandy loam	Double ring infiltrometer	3 hrs
6	Cabbage	1.57	Sandy clay loam	Double ring infiltrometer	3 hrs
7	Paddy	11.43	Sandy clay loam	Cutthroat flume	6 hrs
8	Mustard	14.8	Sandy clay loam	Cutthroat flume	6 hrs
9	Cabbage	8.13	Sandy clay loam	Cutthroat flume	6 hrs
10	Fallow land	20.8	Sandy clay loam	Cutthroat flume	6 hrs

Table 3. Observed infiltration rates of various experimental sites

Time (min)	Infiltration rates (cm/h)									
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
5	13.2	15.6	6.0	57.6	103.2	28.8	11.6	12.3	8.9	6.6
10	9.6	9.6	4.8	45.6	94.8	20.4	11.6	10.1	6.1	6.6
15	8.4	7.2	4.8	34.8	61.2	13.2	8.9	5.3	6.1	3.4
20	8.4	6.0	3.6	31.2	46.8	10.8	6.1	4.0	3.1	3.4
25	7.2	6.0	3.6	30.0	40.8	9.6	6.1	2.7	3.1	1.7
30	4.8	6.0	3.6	30.0	40.8	9.6	6.1	2.7	3.1	1.7
35	4.8	-	-	30.0	40.8	9.6	-	-	-	-
40	4.8	-	-	-	-	-	-	-	-	-
Constant Infiltration Rates (cm)	4.8	6.0	3.6	30.0	40.8	9.6	6.1	2.7	3.1	1.7

Modified Kostiakov model (Mezencev, 1948):

$$i = i_c + B' t^{-(n+1)}$$

Where, i is the infiltration rate, i_c is the constant infiltration rate, B' and n are constants and t is the time of infiltration.

Horton model (1940):

$$i = i_c + (i_0 - i_c)e^{-kt}$$

Where, i is the infiltration rate, $i_0$is the initial infiltration rate, i_c is the final constant infiltration rate and k is the constant.

Estimation and inter-comparison of model parameters:
Root mean square error (RMSE):

Mean-squared error is the most commonly used measure of success of numeric estimation, and root mean-squared error is the square root of mean-squared error after we give it the same dimensions as the estimated values themselves. This method exaggerates the estimated error-the difference between estimated value and observed value (actual value). The root mean squared error (RMSE) is computed as:

$$\text{RMSE}=\sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(x-y)^2\right)}$$

Where, x is the calculated value, y is the observed value and n is the number of observation.

Coefficient of determination:

The Coefficient of determination is the square of the coefficient of correlation r^2 which is calculated to interpret the value of the correlation. It is useful because it explains the level of variance in the dependent variable caused or explained by its relationship with the independent variable.

Results and Discussion

The observations of infiltration were taken at ten different locations within the three farms as mentioned earlier. Initial infiltration was very high (103.2 cm/h) at point 5. The constant infiltration rate was also very high at point 5 (40.8 cm/h). It can be seen from the table1 and 2 that the point 5 has soil texture sandy loam with very high percentage of sand content (72%) with bulk density of 1.52 g/cm^3, hence high infiltration rate was found acceptable. Similar trend was also found at point 4 and 6 (Table 3). At other points of observation the initial infiltration were ranging from 6.0 cm /h to 15.6 cm/h and the basic infiltration rates were ranging from 1.7 cm/h to 6.1 cm/h. Considering the soil texture and sand percentage at these points, the infiltration rates were considered within the acceptable range.

These results were in conformity to the previous researches (Dagadu and Nimbalkar, 2012; Archana, 2015).

Table 4. Model parameter values of the Horton and Modified Kostiakov infiltration models

Points	Horton's model	Modified Kostiakov model	
	$i = i_c + (i_0 - i_c)e^{-kt}$	$i = i_c + B't^{-(n+1)}$	
	K	B′	n
Point 1	6.72	0.37	0.29
Point 2	7.71	0.35	0.36
Point 3	6.99	0.30	0.35
Point 4	8.12	0.70	0.45
Point 5	6.80	2.71	0.37
Point 6	6.42	0.69	0.38
Point 7	2.04	1.20	-0.11
Point 8	1.92	3.50	-0.06
Point 9	1.90	2.30	0.03
Point10	2.10	1.05	0.20

Based on the infiltration values *i.e.* instantaneous and constant rates, the model parameters were determined. The model parameters as obtained from the observed data for Horton and Modified Kostiakov Models were presented in Table 4.

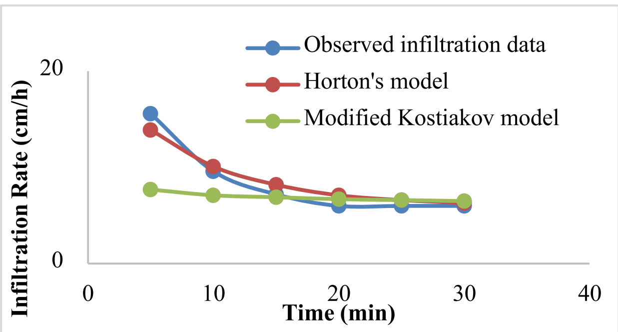
Model parameters were however variable at points of observation. It was obviously due to soil physical properties and antecedent moisture content at the time of observation. One set of infiltration data at every point of observation was kept separately for model validation after derivation of model parameters from the observed data. The model validation was done point wise and the observed and predicted values of the models were then compared with test statistics RMSE and R^2. The model wise RMSE and R^2 values at all ten points of observation is given in Table 5. Execution assessment parameters of infiltration models.

The observed and predicted values for both the models at ten points of observation were also presented graphically at Figure 3 (a) through A (j). From the Table 5, it can be observed that the RMSE values are very low for all the points in case of Horton model (average values of 2.08) as compared to the same in case of Modified Kostiakov model (9.18). It indicates that Horton model is better suited for all the slopes, from flat lands to hill slopes. Looking at R^2 values (average value of 0.93), Horton model was found to predict consistently similar values to that of observed values for all the points as compared to Modified Kostiakov model. Modified Kostiakov model predictions were not close at points 4, 8 and 10 to the observed values.

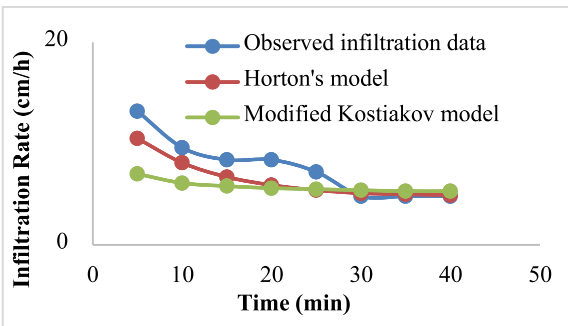
Table 5. Root mean square error (RMSE) values and R^2 test values

Points	RMSE values		R^2 test values	
	Horton's model	Modified Kostiakov model	Horton's model	Modified Kostiakov model
point 1	3.4046	5.3766	0.9006	0.8978
point 2	0.7722	3.6129	0.9784	0.9732
point 3	0.2069	0.0218	0.9149	0.9044
point 4	2.7548	14.6254	0.9866	0.5592
point 5	6.3568	36.5011	0.9215	0.8822
point 6	1.6092	8.7702	0.9826	0.9720
point 7	2.3478	2.8998	0.9060	0.8852
point 8	1.2488	15.4506	0.8713	0.7251
point 9	2.0705	4.0447	0.9240	0.8962
point 10	0.0669	0.5214	0.9034	0.7736

a) Point 1



b) Point 2



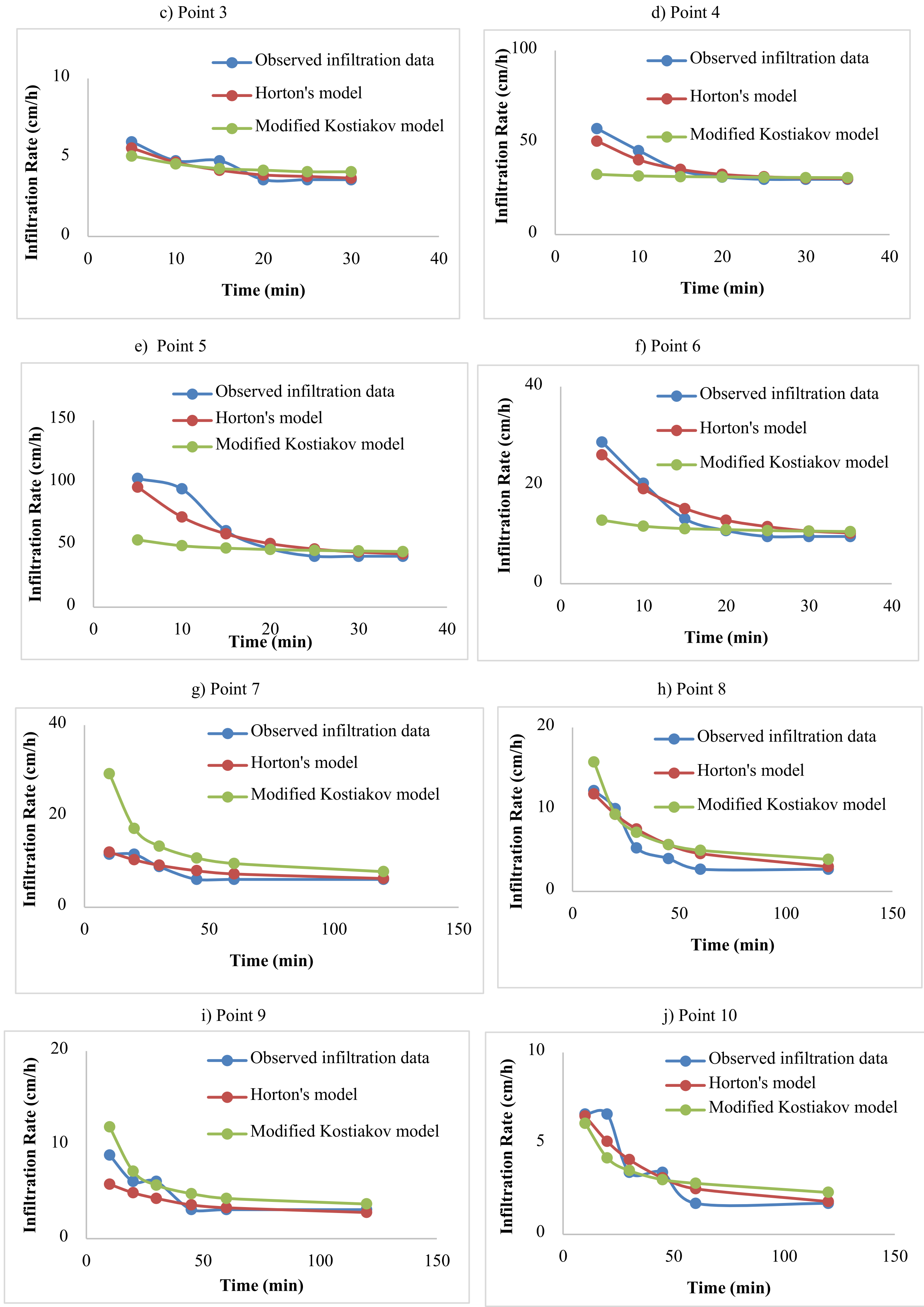


Figure 3. Variation of observed and expected infiltration rate for study area

Conclusions

The infiltration test in the study was successfully carried out with the help of Cutthroat flumes up to the slope of 20%. However, at higher slopes, use of cutthroat flumes may also be difficult due to high velocity flow of water which will tend to be turbulent and erosive. The comparative studies of the predicted values of infiltration by two models *i.e.* Horton and Modified Kostiakov Model with the observed values at different points with varying slopes and soil properties particularly, soil texture, revealed that Horton model can be successfully used for infiltration prediction with greater accuracy on hill slopes.

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