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Infiltration Modelling for Forested Micro Watersheds in Mussoorie Region of Lower Himalayas

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Abstract : Various investigators have performed field investigations in India and abroad to ascertain the effects of various landuses on infiltration. However, such result for Mussoorie region is almost non-existent. The present investigation deals with infiltration characteristics of forested watershed which plays a significant role in hydrological studies and simulation of flow process. This paper presents the first hand information related to infiltration characteristic for two micro watersheds of mussoorie region. An attempt has been made to model the infiltration behaviour of these watersheds using Kostiakov model.

INTRODUCTION

The sustainable development of any watershed requires precise quantitative assessment of different hydrological parameters based on reasonably valid scientific principles. The watershed characteristics are greatly determined by its vegetational cover, geomorphology, area, slope, geology and drainage basin dynamics. The changes in vegetational cover in a watershed affects the hydrological cycle of that watershed; which means that the forest has very important role in controlling or modifying the hydrological processes in a watershed. The proper management of watershed is essential for the conservation of water and land resources and their management for optimum productivity.

The influence of forests on their environment forms part of a complex relationship between environment and forest vegetation. Number of investigations in the past decades has ascertained the influences of forest on hydrological parameters and water availability. Hence the area of impact of forests on various hydrological parameters, viz., rainfall, interception, infiltration, soil moisture, evapotranspiration, groundwater, water yield, soil loss and floods etc. forms an important research thrust in hydrology (NIH, 1990). Among these, infiltration has the significant position. Determination of infiltration characteristics of a watershed is the basic necessity for its water management practices.

Infiltration rates widely vary with different landuses under diverse hydroclimatic environments. Infiltration is an important parameter in the hydrologic cycle and is the only process by which precipita-tion enters the earth's surface and becomes potentially available to plant and animal life. Infiltration is an integral part of the rainfall-runoff process and this information is required for planning and design of water resources systems.

The maximum rate at which the soil can absorb water through the soil surface is termed as infiltration capacity. This is a func-tion of soil moisture condition. At saturation, infiltration capacity is minimum and is the characteristics of the soil i.e. texture, structure, organic matter content, type of clay mineral, antecedent soil moisture etc. It also depends on landuse (Table 1).

STUDYAREA

Two micro-watersheds namely, Arnigadh and Bansigadh located 30 km north of Dehradun near Mussoorie were selected (Fig.1). Slope is precipitous. Arnigadh micro-watershed having an area of 3 $km^2$is covered with dense Quercus forests while Bansigadh micro watershed having an area of 2 km^2 is covered with degraded forests of Quercus (Fig 2). Both the micro watersheds are south facing located on the same mountain range. Highest and lowest elevations of both the project area are approximately same. Maximum relief of Arnigadh and Bansigadh are 540 m and 580 m respectively. Streams in both the catchments are second order streams (Table-2).

Over 50% area of the Arnigad is covered with dense Oak forests (0.4< crown density <0.7) and 20% area is covered with very dense Oak forests (crown density > 0.7). Habitation is mostly on the ridges. 75% area of the Bansigad is under degraded or open forests. Dense forests also constitute approximately 20% area and habitation covers 5% of the area. Under wooded area in both

Table 1. Landuse and Infiltration capacity (cm/hr)

Textural Class	Bare	Vegetation
Loamy Sand	2.5	5.0
Loam	1.3	2.5
Silt Loam	0.8	1.5
Clay Loam	0.3	0.5

(Source : Lee, 1980)

Table 2. Morphometric features of Arnigadh and Bansigadh micro watersheds

Features	Arnigadh	Bansigadh
Aspect	Southern	Southern
Area	3 km^2	2 km^2
Perimeter	6992 m	5947 m
Elevation	1620 – 2160 m.	1640 – 2220 m
Max. Relief	540 m	580 m
Relief Ratio	0.216	0.374
Stream Order	2	2
Form Factor	0.457	0.33
Circulatory Ratio	0.74	0.68
Elongation Ratio	0.763	0.649
Drainage Density	2050 m/km^2	1880 m/km^2

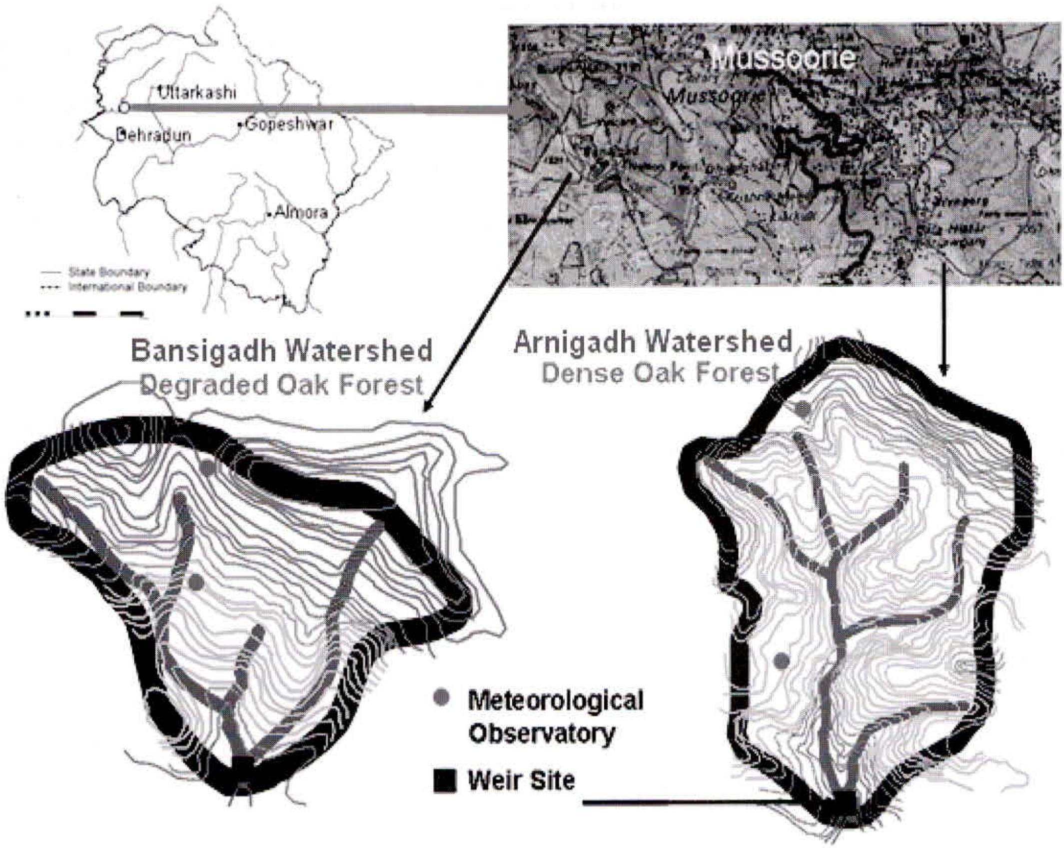

Fig. 1: Location map of microwatersheds

Fig 2. View of forest cover in Bansigadh and Arnigadh micro watersheds

the catchments, average tree density in dense forests is higher by 30%. Average diameter (dbh) in dense forests is 30.6 ± 8.2 (SD) cm in comparison to 15.5 ± 6.6 (SD) cm in the degraded forests. Average organic carbon content over the depth of 15 cm in the dense forests is 3.31% while it is 2.37% in the degraded forests over the same depth. Average porosity of soil over the depth of 15 cm is 54.23% and 48.57% in dense forests and degraded forests respectively.

The average air temperature varies between 15.5°C (minimum) and 25°C (maximum) in degraded watershed and 18°C to 22°C in forested watershed. The relative humidity is observed minimum in summer months and maximum in rainy months. The evaporation rate varied from minimum 2.5 mm/day in rainy months to maximum 6 mm/day in summer months. Rainfall during April 2008 to March 2009 was measured 2905 mm at Arnigadh watershed and 2958 mm at Bansigadh watershed.

Geology

The Dehradun- Mussoorie area lies in the Lower Himalayas is an environmentally sensitive, demographically active, minerologically rich, economically growing and sociologically sensitive region. The region lies in a crucial environmental belt. The minerals are located in the Krol nape series of rock which lies on the geologically sensitive. Mussoorie area had been an active mining belt for over four decades, from 1950's to 1990. The mining has left an imprint on the terrain and on the people. Its impacts are both environmental and socio-economic. Mussoorie is endowed with one of the purest limestone deposits in the country having more than 99% purity which is claimed to be fit for producing high grade steel in the country.

Garhwal Himalayas of Mussoorie comprises rocks of the Jaunsar (Chandpur phyllites and Nagthat quartzites) and Mussoorie Group (Shales, sandstone, greywacks, calcareous slates, dolomite and limestone of Blaini- Krol- Tal sequence) of Proterozoic-Cambrian age.

FIELD INVESTIGATION AND INFILTRATION MODELLING

Hydrological field investigations were carried out at various places in the two micro-watersheds namely, Arnigad and Bansigad Watershed of Mussoorie to study the infiltration characteristics of forestlands. Measurement of infiltration rates were carried out using double ring cylindrical infiltrometers (size: 30 cm inner, 45 cm outer diameter and height 45 cm) made of mild steel sheet. Infiltrometers were penetrated into the ground upto 15cm depth using a wooden hammer striking on mild steel plate appropriately placed on top of the cylinders. Both cylinders were filled with water ensuring equal water levels in inner and outer cylinders. The infiltration rates were measured using constant head method (inner cylinder) till steady infiltration rate was achieved.

Infiltration modelling is basically a tool for prediction of hydrological behaviour of a basin. The complex mechanism of water movement underneath the land surface and insufficient understanding on the actual processes involved therein have given to the development of several infiltration loss models from time to time. A multitude of infiltration models used in applied hydrology and soil science exists. The most widely used empirical equation is the Kostiakov equation.

The observed data of infiltration rates were fitted with popular Kostiakov infiltration model. Kostiakov (1932) provided an empirical equation and is known as Kostiakov equation. The equation is given as:

$$f = \alpha.\beta.t^{(\beta-1)} \qquad (t \text{ ‘‘‘0})$$

where, 'f' is rate of water infiltrated (cm/hr.); 't' is time elapsed from start of the ponding of the water, and, 'α' and 'β' are empirical constants. The constant 'α' depends on soil characteristics and initial moisture content, and the constant 'β' depends on soil characteristics. This model can also be further represented as:

$$f = C \cdot t^m$$

where $C = \alpha.\beta$ and $m = (\beta-1)$

After taking the $\log_{10}$ both side, model can be further reduced to linear form as follows:

$$\log_{10}(f) = m \cdot \log_{10}(t) + \log_{10}(C)$$

further, this equation can be written as:

$$Y = m. X + C$$

where $Y = \log_{10}(f)$; $X = \log_{10}(t)$ and $C = \log_{10}(C)$ This is a standard equation of straight line and parameters of the Kostiakov model can be calculated by least square technique. In this method $\log_{10}$ values of the observed infiltration rate *(f)* is plotted on Y scale against X axis values of $\log_{10}$ of the observed elapsed time *(t)*.

PERFORMANCE EVALUATION OF MODEL

The criterion for goodness-of-fit of model was evaluated by determining the efficiency as (Nash & Sutcliffe 1970):

$$Efficiency = (1-D_1/D_0) * 100$$

where D_1 is the sum of squares of deviations between computed and observed data, expressed as:

$$D_1 = \Sigma(Y_0 - Y_1)^2$$

and D_0 is the initial variance, which is the sum of the squares of deviations of the observed data about the observed mean, expressed as:

$$D_0 = \Sigma(Y_0 - Y_m)^2$$

where Y_0 = observed data; Y_1 = computed data and Y_m = mean of observed data.

The efficiency varies on a scale of 0 to 100. It can also assume a negative value if $D_1>D_0$, implying that the variance in the observed and computed infiltration values is greater than the model variance. In such a case, the mean of the observed data fits better than the applied model. An efficiency of 100 implies that the computed values are the same as the observed ones, which is the perfect fit.

RESULTS AND ANALYSIS

Detailed study of infiltration characteristics helps planners, engineers, hydrologists, farmers, agriculture specialists and decision makers in number of ways like: to estimate peak rate and volume of runoff in planning and construction of bridge, dam, culverts etc., to estimate surface runoff and overland flow, to estimate ground water recharge, to plan for watershed management, for planning irrigation and drainage system and so on.

The study aims to determine average cumulative infiltration function from point infiltration measurements and to know the mean steady infiltration rate under different landuse conditions. In pursuit of these objectives, infiltration tests have been carried out in several places in Mussoorie region of lower Himalayas.

Based on the field tests, results were analyzed and typical infiltration rate and cumulative infiltra-tion curves were developed for each site. The results show large variations of infiltration rates depending upon various landuse types.

The present investigations show initial infiltration rates in the order of 19.92 to 101.04 cm/hr (mean: 83.10+48.2 cm/hr) and 31.68 to 63.6 cm/hr (mean: 49.38+13.2 cm/hr) for Bansigadh and Arnigagadh watershed respectively.

The steady infiltration rates were observed in the order of 8.10 to 30.33 (mean: 21.48+10.3 cm/hr) for Bansigadh watershed and for Arnigagadh watershed it ranges from 2.16 to 32.28 cm/hr (mean: 17.93+13.2 cm/hr). Various researchers have reported higher infiltration rates in forested lands (Mistry & Chatterjee, 1965; Patwary et al., 1997). The studies conducted elsewhere also indicated higher infiltration rates under forest landuse (Molchanov, 1960; Kittredge, 1948; Annon, 1962; Wood, 1977; Lee, 1980). Representative mean values of initial and steady state infiltration rate of these two micro watersheds are summarized in Table 3.

A horizontal bar diagram of initial and steady state infiltration rates with landuses have been presented in Fig. 5 and 6. Trend of cumulative infiltration and time to reach steady infiltration rate under different landuse conditions in Bansigadh and Arnigadh Watersheds are shown in Fig. 7 and 8. From these diagrams one can easily understand the decreasing/increasing behavior of the infiltration criteria under study area.

In Bansigadh watershed, it is found that the steady infiltration rates decrease in order of dense forest, agricultural land, open forest and degraded forest. While in Arnigadh watershed, it decreases in order of dense forest, open forest, degraded forest and agricultural land. Results of field tests are summarized in Table 3 and Figs. 3 to 8.

Table 3. Infiltration results under Bansigadh and Arnigadh watersheds of Mussoorie region

Watershed	Site No. for Infilt. Tests	Representative Landuse	Initial Infilt. Rate - After 5 minute (cm/hr)	Mean Initial Infilt. Rate of Watershed (cm/hr)	Steady State Infilt. Rate (cm/hr)	Mean Steady Infilt. Rate of Watershed (cm/hr)	Total Cumulative Depth to Reach Steady Infil. Rate (cm)	Mean Cumulative Depth to Reach Steady Infil. Rate for watershed (cm)	Time to Reach Steady Infil. Rate (minute)	Mean Time to Reach Steady Infil. Rate for watershed (minute)
Bansigadh	Site-1	Agricultural	101.04	83.10 ± 48.2(SD)	28.89	21.48 ± 10.3(SD)	162.50	108.16 ± 76.6(SD)	265	197.5 ± 59.5(SD)
	Site-2	Dense Oak Forest	134.4		30.33		181.93		220	
	Site-3	Degraded Oak Forest	19.92		8.10		21.88		125	
	Site-4	Open Oak Forest	77.04		18.60		66.34		180	
Arnigadh	Site-5	Degraded Land	51.96	49.38 ± 13.2(SD)	12.69	17.93 ± 13.2(SD)	35.10	71.77 ± 56.3(SD)	110	170.0 ± 51.6(SD)
	Site-6	Open Oak Forest	50.28		24.57		122.77		230	
	Site-7	Agricultural	31.68		2.16		12.38		150	
	Site-8	Dense Oak Forest	63.6		32.28		116.83		190	

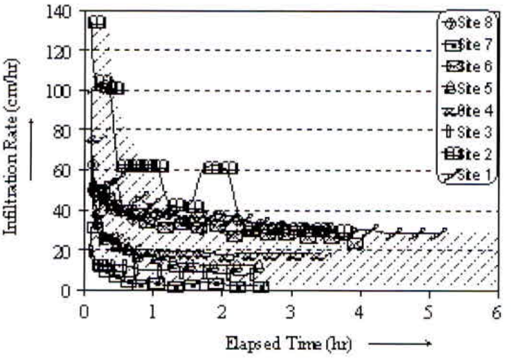

Fig. 3. Overall variation in observed infiltration rate curves

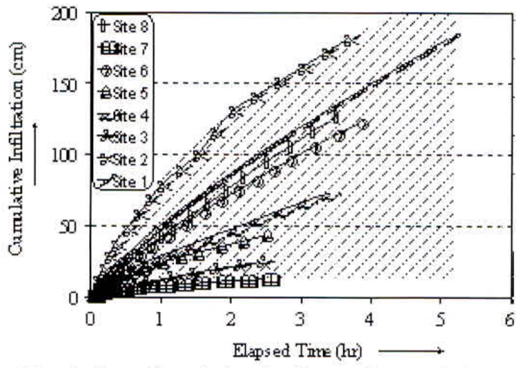

Fig. 4. Overall variation in observed cumulative infiltration curves

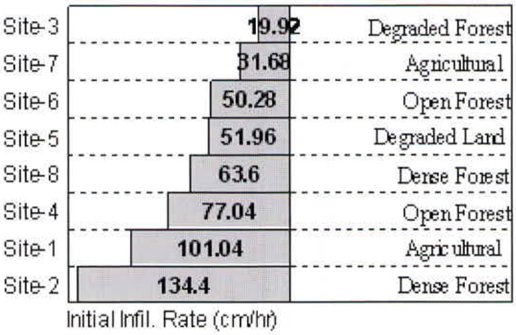

Fig. 5. Trend of initial infiltration rate (after 5 minute) under different landuse

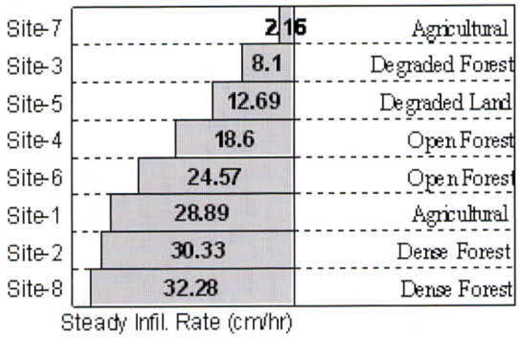

Fig. 6. Trend of steady infiltration rate under different landuse

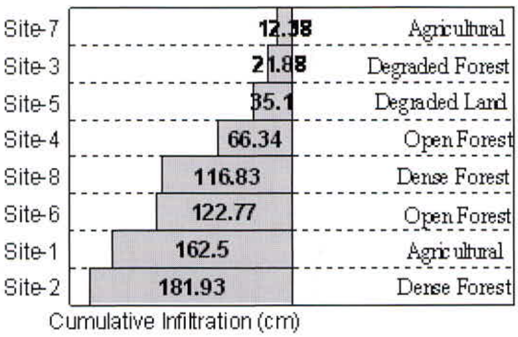

Fig. 7. Trend of cumulative infiltration under different landuse

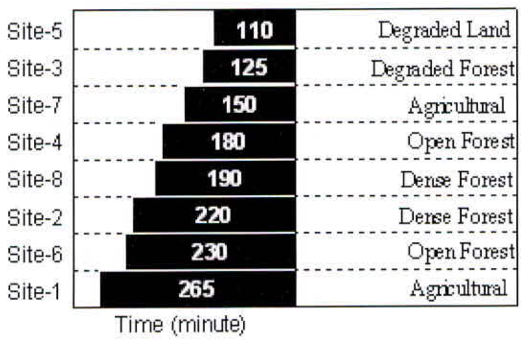

Fig. 8. Time to reach steady infiltration rate

An attempt has been made to understand the hydrologic response of two micro-watersheds based on observed infiltration data. Modeling infiltration from micro-watersheds assumes importance for evaluation of watershed development and management programme. Results show that the efficiency of the cumulative values of the Kostiakov model with observed cumulative infiltration is very strong (99-100%). Cumulative infiltration is a required for efficient use of irrigation water requirements and management practices.

The least square parameters of Kostiakov infiltration model is given in Table 4. It was observed that Kostiakov model has resulted in higher correlation coefficient (R^2) values at majority of sites, and their values of R^2 vary from 0.7775 to 0.9726 (Table 5).

Kostiakov infiltration model was evaluated using regression coefficient (R^2), Sum of Square of Relative Errors (SSRE) and efficiency methods. Findings are summarized in Table 5. Observed and modelled infiltration curves are presented in Fig. 9. Relative error distribution of Kostiakov model is also presented through Figs. 10 and 11.

Table 4. Least square parameters of Kostiakov model

Test Sites ►	Site-1	Site-2	Site-3	Site-4	Site-5	Site-6	Site-7	Site-8
Constant : C ►	*41.13*	*54.323*	*9.999*	*22.412*	*16.588*	*34.414*	*3.92*	*37.833*
Slope : m ►	*-0.244*	*-0.409*	*-0.224*	*-0.31*	*-0.41*	*-0.191*	*-0.716*	*-0.141*

Table 5. Evaluation of Kostiakov infiltration model

Infiltration Test Sites	Efficiency %	R^2	SSRE	Efficiency %	R^2	SSRE
	for infiltration rate			for cumulative infiltration		
Site-1	82.10	0.8342	0.1955	99.99	0.9925	0.0762
Site-2	89.10	0.8991	0.4463	99.94	0.9979	0.0349
Site-3	85.90	0.8614	0.0800	99.98	0.9746	0.0182
Site-4	71.30	0.7775	0.3840	99.88	0.9847	0.2549
Site-5	96.60	0.9726	0.0522	99.99	0.9973	0.0188
Site-6	94.90	0.9503	0.0407	100.00	0.9896	0.0123
Site-7	89.90	0.9497	0.6184	99.69	0.9871	0.1347
Site-8	80.50	0.8107	0.0838	99.99	0.9648	0.0306

CONCLUSIONS

The land use/cover, soil texture and morphological characteristics of a watershed have direct bearing on hydrological processes. Various hydrological processes such as infiltration is influenced significantly by these characteristics. Accurate estimation of infiltration is essential for better understanding of the rainfall runoff relationship of a watershed. The estimation in infiltration rates in such areas is required for the calculation of runoff for hydrological structures design purposes and also for assessing the effect of land use changes and management of water resources.

The influence of forest cover on infiltration rates have been studied in two microwatershed of Mussoorrie area. It is found that, watershed area covered with dense oak forest showing highest infiltration rates, which is about 2.5 times higher than the degraded forest cover. The present study show that forest cover controls the infiltration rates significantly in hilly areas. It was observed that Kostiakov model has resulted in higher correlation coefficient at majority of sites, and their R^2 values vary from 0.7775 to 0.9726. The study reveals that Kostiakov model can be used for similar watersheds. The findings of the study could be used for proper planning and watershed management in the Lesser Himalayan region.

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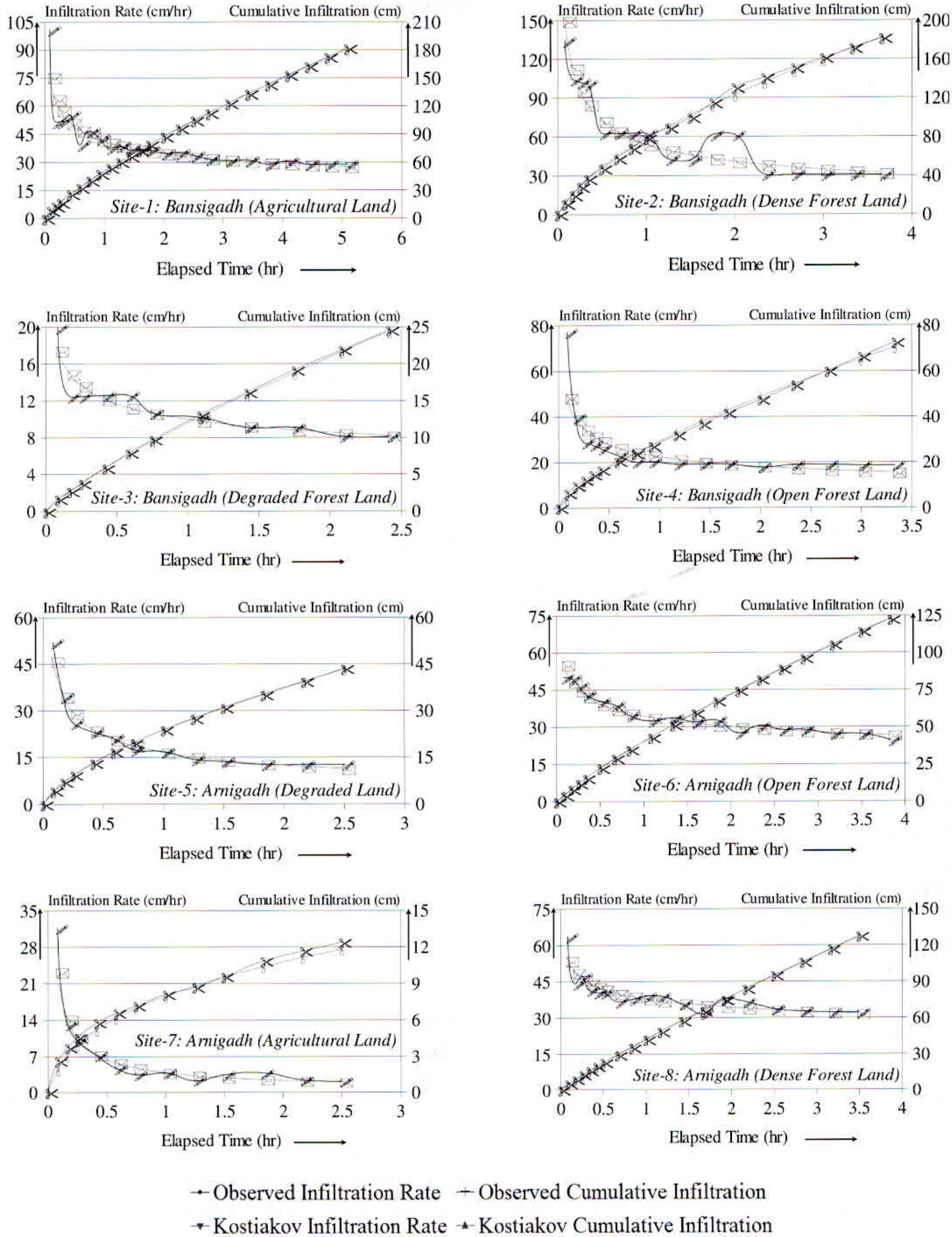

Fig. 9. Behaviour of Kostiakov infiltration model with observed infiltration curves

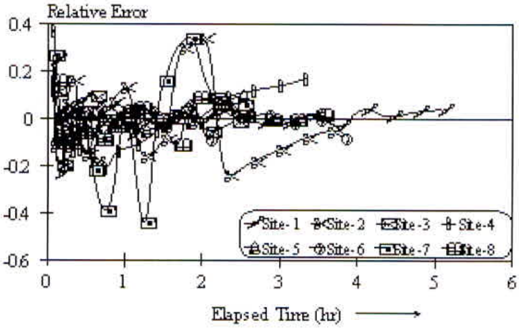

Fig.10. Relative error distribution of Kostiakov infiltration rate model

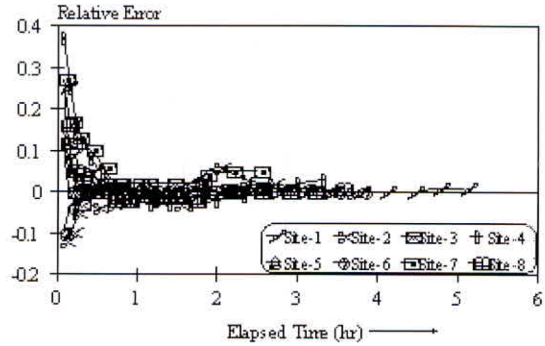

Fig.11. Relative error distribution of Kostiakov cumulative infiltration model

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