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Comparison of measured historical, computed and simulated runoff depths using two different ratios of initial abstraction to soil moisture retention parameters in semiarid tropical environments

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ABSTRACT

The runoff measurement, computation and simulation have been generally employed for flood impact analysis, hydraulic structure design, and water resource management under different geographical regions, climates and environments. The investigation was conducted to compare the measured historical, computed and simulated daily runoff depth for two gauged micro-watersheds I and II in the catchment(s) of Patiala-Ki-Rao watershed (s) in submontane tract of Punjab. However, afforestation and fencing were applied to micro-watershed I and only fencing was applied to micro-watershed II. The SCS-CN method using Ia/S = 0.2 and Ia/S = 0.05 was used to simulate e runoff depth for total 42 rainstorms for the historical 6- years as 1983, 1984, 1986, 1987, 1991 and 1994. The computed daily runoff depth (min to max) with Ia/S = 0.2 showed higher coefficient of variation (%CV= 128.6 to 21.2) than with Ia/S = 0.05 (%CV = 59.1 to 17.1). The computed daily runoff depth (min to max) with Ia/S=0.05 performed better than that with Ia/S=0.2. Whereas, simulated daily runoff depth with Ia/S=0.05 performed better than that with Ia/S=0.2 for both the micro-watersheds I and II due to their higher coefficient of determination (R^2) and low root mean square error (RMSE) obtained between simulated daily runoff depth and historical daily runoff depth (R^2=0.90 with Ia/S=0.05 as compared to R^2=0.78 with Ia/S=0.2 and RMSE=6.5 with Ia/S=0.05 as compared to RMSE=19.5 with Ia/S=0.2 for micro-watershed I and II respectively). However, there was potential increment in runoff with increase in rainfall depth. However, the results of the present investigation were well correlated at low to moderate daily rainfall depths. The results of the investigation further suggested three is need to test other approaches to analyze surface runoff depths at higher rainfall depths I the watersheds of submontane Punjab .

Keywords: Rainfall depth, runoff depth, rainfall-runoff relationships, Curve Number method

INTRODUCTION

The selection of rainfall-runoff model is often a compromise between model complexity (simple versus complex) and the availability of input data (King *et al.*, 1999). The merits of simple versus complex and physical based models have been heavily debated (Loague and Freeze, 1985, Michaud and Sorooshian, 1994, Doherty and Christensen, 2011). Several studies have addressed the differences between rainfall-runoff models, especially the popular Curve Number (Bales and Betson, 1981) and Green-Ampt models (Wilcox *et al.*, 1990; King *et al.*, 1999). However, both models proved successful in modeling runoff for a watershed (Wilcox *et al.*, 1990, King *et al.*, 1999). Both have limitations with model assumptions and data input needs. Wilcox *et al.* (1990) compared the Curve Number and Green-Ampt models on six watersheds in Arizona, Idaho, Nebraska, Oklahoma, and Texas. On the Goodwin Creek watershed in Mississippi (King *et al.*, 1999) found that Curve Number model simulated stream flow better than that the Green-Ampt model. However, both models performed satisfactorily. Even though the Green-Ampt model is physically based, Wilcox *et al.* (1990) showed that the many regression equations, needed to parameterize it, may dilute much of the physically based aspect of the model.

Most of the models employed at different places requiring large data set and complex in nature. In addition, complete understanding of the simulation studies is important for planning and management of soil erosion and maintaining maximum level of sustained agricultural production. However, there is little information available on the accurate runoff records in the watersheds of submontane Punjab which cover sufficient duration of rainfall distribution in two seasons i.e. summer as well as winter. Whereas, on the other hand, daily rainfall records representative of most of the watersheds in the area is generally available for both the seasons. Therefore, the models that can utilize these rainfall records to simulate runoff will be of great utility. The runoff can be estimated by developing suitable empirical rainfall-runoff relationships in the area. However, in addition to this, the most commonly employed Soil Conservation Service Curve Number (SCS-CN) method exists. The same can be widely used for the estimation of direct runoff for a given rainstorm from small agricultural watersheds. Due to its low input data requirements and its simplicity, many watershed models such as CREAMS (Knisel 1980), AGNPS (Young *et al*., 1989), EPIC (Sharpley and Williams, 1990) and SWAT (Arnold *et al*., 1996) take into account the CN model.

However, the SCS-CN (SCS 1972) method is based on a water balance and two fundamental hypotheses which can be expressed respectively as: $P = Ia+F+Q$; $\frac{Q}{(P-Ia)} = \frac{F}{S}$ and $Ia = S\lambda$, Where, P is the precipitation in mm, Ia is the initial abstraction in mm, F is the cumulative infiltration excluding Ia in mm, Q is the direct runoff in mm, S is the maximum potential moisture retention after beginning of the runoff in mm and λ is the initial abstraction ratio. Here $Q = \frac{(P-Ia)2}{(P+S-Ia)}$ if P>Ia, otherwise Q=0. The parameter S is defined as: $S = \frac{25400}{CN} - 254$; where CN is the Curve Number that varies with three antecedent soil moisture conditions such as CN I-dry, CN II-average, and CN III-wet.

Traditionally, Ia is equal to 0.2S. Since the history and documentation of this relationship are obscure, the assumption of Ia=0.2S has been frequently questioned for its validity and applicability. Therefore, invoking a critical examination of the Ia-S relationship for its pragmatic applications. Mishra *et al.* (2006) employing a large data set of 84 watersheds (area 0.17 to 71.99 ha) of USA, investigating several initial abstractions (Ia) - maximum potential moisture retention (S) relations incorporating antecedent soil moisture instead of antecedent precipitation. Jain *et al.* (2006) reviewed the Ia-S relationship and proposed a new non-linear relationship incorporating storm rainfall (P) and soil moisture retention parameter (S). Ponce and Hawkins (1996) suggest that the fixing of the initial abstraction ratio at 0.2 may not be the most appropriate number. However, it should be interpreted as a regional parameter.

In addition, in submontane Punjab, most of the agricultural watersheds are ungauaged having no record whatsoever of rainfall-runoff processes. Thereby, this, suggests employing an appropriate method to predict runoff from the watersheds. In addition, its estimation is essential in the design of soil and water conservation works. Therefore, selection of the proper Ia/S value is crucial in accurate estimation of runoff through the CN method (Jain *et al.* 2006). Keeping these points in view, therefore, the present study was planned with the objectives as listed below.

i) To determine the initial abstraction ratio (Ia/S) in an experimental Patiala-Ki-Rao watershed(s) by analysing the measured rainfall-runoff storms.
ii) To compare the performance of the traditional and modified Ia/S values with observed rainfall-runoff data.
iii) To assess potential changes in runoff with respect to long term changes in rainfall depths in submontane region.

MATERIALS AND METHODS

Description of Selected Watersheds

Four adjoining watersheds known as Patiala-Ki-Rao watersheds situated in foothills of the Shiwaliks (‘Kandi’ area) in district Roop Nagar (Punjab) have been regularly monitored for hydrological measurements. Of these, two watersheds, micro-watershed I and II were selected for this study as these varied in size, shape, slope, vegetation characteristics and applied treatments. However, these were contiguous to each other and situated at an elevation of 415 m above the mean sea level in the Shiwaliks. The instruments installed for recording of the watershed data were the Parshall Flume in watershed I and V-notch (120°) in watershed II, and automatic stage level recorders. In between these watersheds, there was a meteorological observatory fitted with self-recording and non- recording rain gauges, standard U.S. Open pan evaporimeter, wind anemometer, wet and dry bulb thermometers, maximum and minimum thermometers, and soil thermometer. However, afforestation, fencing and engineering treatments were applied in the watershed I; whereas, no such treatments were applied in the watershed II. The catchment area of the watershed I is 9.10 ha, and that of the watershed II is 13.5 ha, respectively. The mean slope of these watersheds is 39.6 and 32.1 per cent respectively as indicated in Table 1.

Data on daily rainfall, and runoff depth and other meteorological parameters of the selected watersheds have been gathered from the office of the Director, Zonal Research Station for Kandi Area, Ballowal Saunkhri, district Shaheed Sukhdev Singh Nagar, Punjab. In addition to this, wherever possible, the information on parameters of rainfall and runoff depths has been obtained from the relevant primary as well as secondary sources.

Climate

The area has a semi-arid climate according to the classification of Thornthwaite (1948). The mean monthly rainfall is the largest in July and the smallest in November. About 80 per cent of annual rainfall is received during the summer season and 20 per cent during the winter season. However, the rainfall received during the summer months is of major concern from the standpoints of its harvesting and is subsequent use for raising winter season crops. The monsoon rainstorms (summer season) received in the area is 20 to 30, of which 8 to 12 produce runoff and overland flow (Hadda and Sur, 1986). The 2 to 3 rainstorms occur with average intensity greater than 120 mm h^{-1} in the submontane Punjab (Hadda *et al.*, 2000). In the pre-monsoon months of May and June, high temperatures and arid desiccating winds create scarcity of fodder due to the grazing and browsing of available trees, bushes, and grasses by cattle. Because of the high temperature and low relative humidity during these months, vegetation cover on the ground is very sparse (Kukal *et al.*, 1991). This caused the large-scale runoff and soil erosion due to high intensity and short duration rainstorms received in the area (Hadda *et al.*, 2000).

Geology and Geomorphological Features

The area exhibits Shiwalik deposits which are alluvial detritus derived from the sub-aerial wastes of the mountains, swept down by seasonal ephemeral streams ('choes') and rivers (Wadia, 1976). These are composed of grey and hard sandstones, siltstones and red and purple Shale along with pseudo conglomerates of Middle Miocene to Helvetian age. The exact information on the age of these deposits is lacking. Geologists argue that these are deposited during the Pleistocene and the recent periods (Wadia, 1976)

The three main geomorphologica1 processes responsible for the development of the area are the seasonal ephemeral streams ('choes'), soil erosion and deposition. These processes are strongly influenced by the nature and extent of drainage area, main channel slope, relief ratio, watershed slope and climate. The information on geomorphologic characteristics of Patiala-Ki-Rao watersheds I and II are presented in Table 1.

Rainfall characteristics

Rainfall amount, duration and intensities and the kinetic energy of the rainstorms were calculated as listed below.

Rainfall amount and duration

The rainfall of a storm is divided into successive increments of uniform intensity. Using the recorded

Table 1. Geomorphologic characteristic at Patiala-Ki-Rao watersheds

Characteristics	Watershed I	Watershed II
Drainage area (ha)	9.10	13.5
Length of main channel (m)	530.0	186.0
Length of main valley (m)	550.0	30.6
Main channel slope (%)	14.3	11.3
Shape factor	1.3	2.1
Drainage density (km km^2)	6.6	12.0
Relief ratio	0.2	0.2
Watershed slope (%)	39.6	32.1

Source: Anonymous (2013)

rainfall charts, rainfall amounts (ordinate values) are plotted against the time (abscissa values). The summation of ordinate values gives the total rainfall amount, whereas the summation of abscissae values gives the total rainfall duration.

Average intensity

It was calculated as follows:

$$\text{Average intensity (mm/h)} = \frac{\text{Cumulative rainfall (mm)}}{\text{Total duration (h)}} \quad \ldots(1)$$

Maximum 60 minutes' intensity

The maximum 60 minutes' intensity is calculated using the fixed time base procedure. Each rainstorm was divided into successive segments of 60-minute durations and maximum amount of rainfall was chosen in a time interval of 60 minutes. Then the intensity was calculated as follows:

Maximum 60 minutes' intensity = Maximum rainfall amount received in 60 minutes in mm

Runoff depth

The Soil Conservation Service-Curve Number method was employed to compute the runoff which is discussed below.

The initial quantity of the interception, depression storage and infiltration that must be satisfied by any rainfall before runoff can occur is taken as Ia. It is assumed that the ratio of the direct runoff (Q) and the rainfall (P), minus the initial loss (P-Ia) and the storage capacity (S) are related by

$$\frac{Q}{(P - Ia)} = \frac{(P - Q - Ia)}{S} \quad \ldots(2)$$

Ia, is assumed to be a fraction of S. Traditionally, initial abstraction is taken as 20 per cent of the maximum potential retention, i.e.

$Ia = 0.2S$

$$\text{Then, } Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \ldots(3)$$

Where, P is Storm rainfall in mm and it should be > 0.2 S; Q is runoff in mm

The Curve Number (CN) as defined by the U.S. Soil Conservation Services (1964) is given by the relation as listed below.

$$CN = 1000 / (10+S) \quad \ldots(4)$$

$$S = [(1000 / CN) - 10)] \quad \ldots(5)$$

The Curve Numbers for different land use conditions and hydrologic soil groups are listed (Schwab1992).

The S is obtained as shown below using equation(s) 6 and 7 and expressed in mm.

$$CN = \frac{25400}{(254 + S)} \quad \ldots(6)$$

$$S = \frac{25400}{CN} - 254 \quad \ldots(7)$$

However, in evaluating antecedent moisture conditions, the values apply to antecedent rainfall condition II which is considered as an average value and relates to the CN-II.

Using the Curve Number, the soil moisture retention parameter and runoff depth can be computed. The description on hydrological soil groups A, B, C and D as described by Schwab *et al.*, (1992) has been employed.

Selection of Ia/S = 0.2 and Ia/S = 0.05

The relationship between initial abstraction (Ia) and soil moisture retention parameter (S) were used as per the existing SCS-CN method. To optimize on calibration and iterative process, the values of Ia/S = 0.2 (Traditional) and Ia/S = 0.05(Modified) has been selected from literature (Lim *et al.,* 2006; Wang *et al.,* 2008) and used in the existing SCS-CN runoff predicting equation to compute the runoff depth. This was calculated from daily rainfall depth using the relationship as listed in equation below.

$$Q = (P - 0.2S)^2 / (P + 0.8S)\ ;\ P > 0.2S \quad \ldots(8)$$

Again assuming initial abstraction, Ia = 0.05S and the surface runoff depth from daily rainfall amount, P was calculated using the relationship9, as listed further.

$$Q = (P - 0.05S)^2 / (P + 0.95S)\ ;\ P > 0.05S \quad \ldots(9)$$

Where, P is daily rainfall amount in mm; Q is daily surface runoff depth in mm and S is maximum moisture retention capacity of a given soil in mm.

However, in the traditional Ia, was considered as 20 per cent of the maximum soil moisture retention parameter (S) and Modified Ia, was considered as 5 per cent of the maximum soil moisture retention parameter (S)

The parameter(s) describing water retention, S in mm in the soil was calculated as discussed below.

Moisture equivalent = ½ * Maximum water holding capacity …(10)

The moisture equivalent is calculated from the maximum water holding capacity for different spots of the watershed. Then the value of moisture equivalent was converted into moisture storage for a particular depth profile by multiplying it with bulk density and depth of soil layer. After that, the soil moisture storage for depth(s) of 0-5, 5-10, 10-15 and 15-30 cm was obtained and computed as shown below.

$$\text{Maximum water holding capacity} = \frac{(\text{Fresh wt. of saturated soil-dry wt. of soil})}{\text{Dry wt. of soil}} \times 100 \quad \ldots(11)$$

Soil moisture storage

The procedure in detail has been described by Singh (2014) for depth wise computation of soil moisture storage for the micro-watershed (s) I and II.

Statistical analysis

The simulated and historical values of runoff depth(s) were compared by using descriptive statistics such as mean, standard deviation, coefficient of variation, coefficient of determination, root mean square error etc. for calibration and validation purposes as per the procedure described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Computation of daily runoff depth with Ia/S=0.2 and Ia/S=0.05 using soil moisture retention parameter as 9.0 cm

During the years 1983 to 1994, the information on Julian days, rainfall depth (min to max) and runoff depth (min to max) with Ia/S = 0.2 and Ia/S = 0.05 is presented in Table 2. In the years, the rainfall distributed from 48^{th} to 272^{th} Julian day. On these days, the rainfall depth (min to max) varied from 21 mm to 92.1 mm. However, runoff depth (min to max) correspondingly on these days varied from 0.1 mm to as large as 33.4 mm with Ia/S = 0.2. Similarly, on these days, during the years 1983 to 1994, the computed runoff depth with Ia/S = 0.05 varied from 2.5 mm to as large as 43.2 mm. The mean rainfall depth (min to max) varied from 28.6 mm to 83.0 mm, runoff depth (min to max) with Ia/S = 0.2 varied from 1.4 mm to 27.4 mm and with Ia/S = 0.05 varied from 5.3 mm to 36.6 mm, respectively. The coefficient of variation for rainfall depth (min to max) varied from 26.9 per cent to 10.6 per cent, for computed runoff depth (min to max) with Ia/S = 0.2 varied from 128.6 per cent to 21.2 per cent and with Ia/S = 0.05 varied from 59.1 per cent to 17.1 per cent. This further indicated that computed runoff depth with Ia/S = 0.05 performed better than that runoff depth with Ia/S = 0.2.

The information on computed storm wise runoff depth with Ia/S = 0.2 and Ia/S = 0.05 for total 42 rainstorm events for the given micro-watersheds during the years 1983, 1984, 1986, 1987, 1991 and 1994 is presented by Singh (2014). The runoff depth with Ia/S=0.2 showed higher coefficient of variation (CV% =108.2) than that with Ia/S=0.05 (CV% =76.5). De (2009) also showed the higher coefficient of variation (CV% = 215.8, 151.0 and 194.5) in runoff depth computed with Ia/S = 0.2 than that with Ia/S = 0.05 (CV% = 160.0, 125.7 and 144.5) for three years 2001, 2002 and 2003 respectively from an agricultural Kokowal-Majari-Jhunewal watershed.

Table 2. Computation of runoff depth using soil moisture retention (S) parameter as 9.0 cm with Ia/S=0.2 and Ia/S=0.05

Year	Julian day(s)	Rainfall depth (mm) (Min to Max)	Runoff depth (mm) with Ia/S=0.2 (Min to Max)	Runoff depth (mm) with Ia/S=0.05 (Min to Max)
1983	28 to 253	24.3 to 92.1	0.4 to 33.4	3.5 to 43.2
1984	40 to 261	23.2 to 91.8	0.2 to 33.2	3.2 to 42.9
1986	174 to 272	30.7 to 71.8	1.5 to 20.1	5.9 to 28.7
1987	207 to 248	42.2 to 85.8	5.1 to 29.1	11.1 to 38.5
1991	213 to 259	21.0 to 84.0	0.1 to 27.9	2.5 to 37.2
1994	184 to 245	30.6 to 73.0	1.5 to 20.8	5.8 to 29.6
Mean (mm)	141 to 256	28.6 to 83.0	1.4 to 27.4	5.3 to 36.6
±SD (mm)		7.7 to 8.8	1.8 to 5.8	3.1 to 6.3
CV (%)		26.9 to 10.6	128.6 to 21.2	59.1 to 17.1

Potential changes in daily runoff depth with rainfall depth

The information on potential changes in runoff depth with rainfall depth (Ia/S = 0.2) using soil moisture retention parameter as 9.0 cm (Fig. 1a). Runoff depth as a function of rainfall depth was evaluated by employing linear, power, and exponential functions. Of the evaluated functions, linear function (R^2 = 0.96) for runoff depth and rainfall depth showed significantly larger variation over power function (R^2 = 0.92) and exponential function (R^2 = 0.79). Similarly, the information on potential changes in runoff depth with rainfall depth (Ia/S = 0.05) using soil moisture retention parameter as 9.0 cm (Fig. 1b). Of the evaluated functions, power function (R^2 = 0.99) for runoff depth and rainfall depth showed significantly larger variation over the linear function (R^2 = 0.98) and exponential function (R^2 = 0.93). The similar kinds of results were reported by Mriganke (2009) as coefficient of

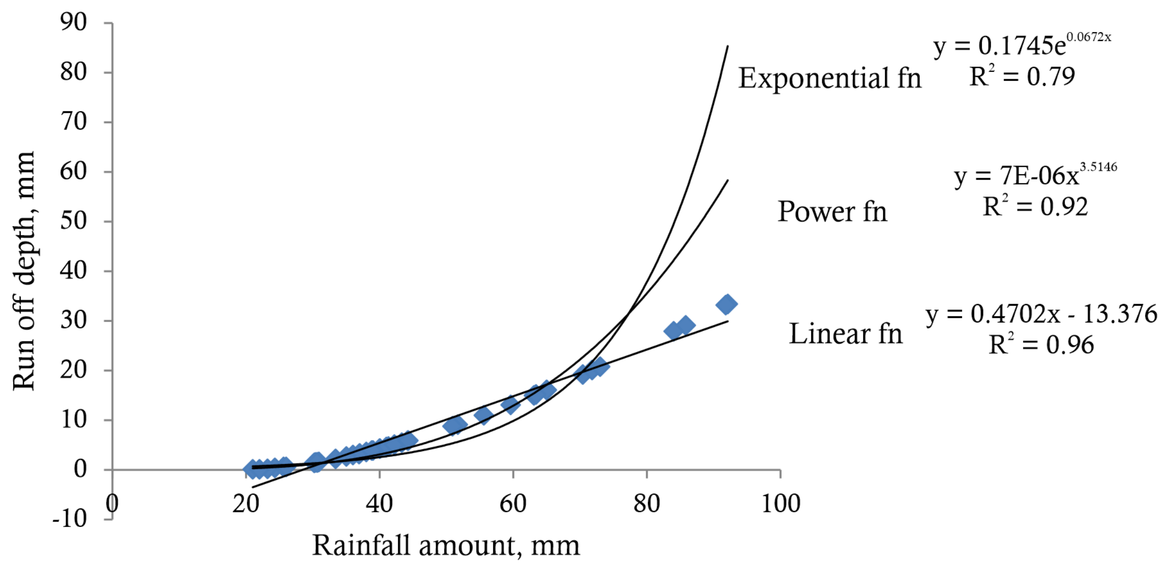

Fig. 1a. Potential changes in daily runoff depth with rainfall amount (Ia/S=0.2) using soil moisture retention (S) parameter as 9.0 cm

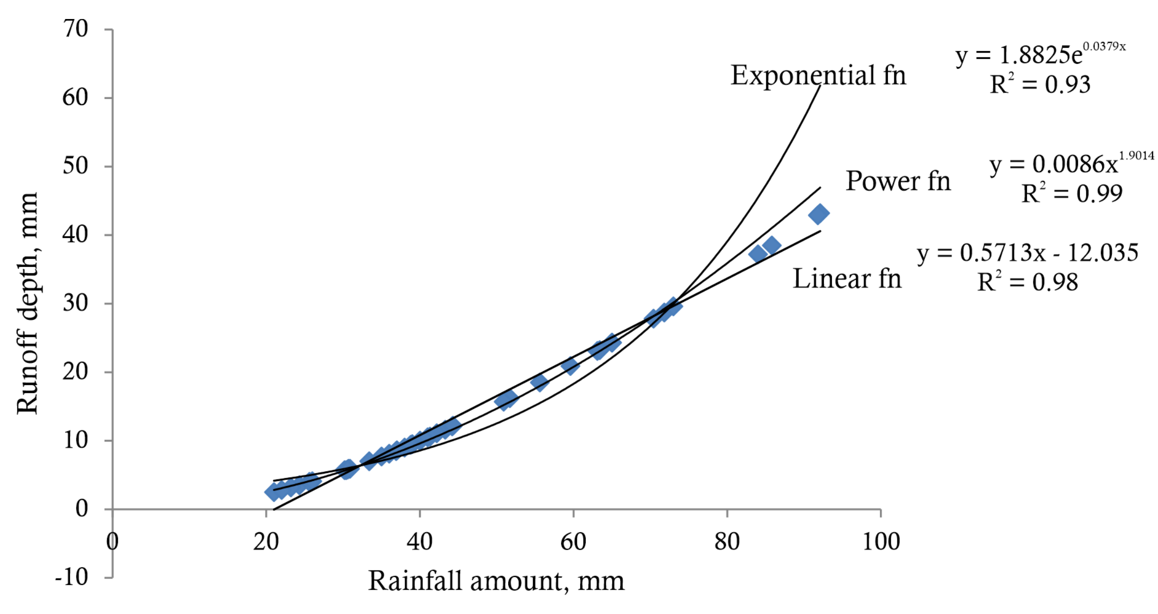

Fig. 1b. Potential changes in daily runoff depth with rainfall amount (Ia/S=0.05) using soil moisture retention (S) parameter as 9.0 cm

determination (R^2) between runoff depth and rainfall depth was higher ($R^2 = 0.999$) with Ia/S = 0.05 than that with Ia/S = 0.2 ($R^2 = 0.995$) from an agricultural watershed. This showed that daily runoff depth increased with increase in rainfall depth (Fig. 1a and 1b). Whereas Osborn and Lane (1969) also showed that runoff depth was most strongly correlated with maximum 15-minute's intensity of rainfall. Laflen and Saveson (1970) hypothesized that runoff depth can be expressed as the function of rainfall depth, but Hawkins (1975) reported that up to few cm of rainfall, runoff depth is more sensitive to Curve Number than that to the rainfall depth. This was further supported by Bondelid *et al.* (1982) who showed the effect of Curve Number variation that increased up to few cm of rainfall after that it decreased as the rainfall depth increased, as happened for the larger storms.

Simulated runoff

Comparison of historical and simulated daily runoff depth with Ia/S=0.2 and Ia/S=0.05 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed I

During the years 1983 to 1994, the information on Julian days, rainfall depth (min to max), historical runoff depth (min to max) and simulated runoff depth (min to max) with Ia/S = 0.2 and Ia/S = 0.05 is presented in Table 3. However, in the years, when the rainfall distribution from 48th to 272th Julian day, the rainfall depth (min to max) varied from 21 mm to 92.1 mm. However, the simulated runoff depth (min to max) correspondingly on these days varied from 0.1 mm to as large as 33.4 mm with Ia/S = 0.2. Similarly, on these days, during the years 1983 to 1994, the simulated runoff depth with Ia/S = 0.05 varied from 2.5 mm to as large as 43.2 mm. The historical runoff depth (min to max) varied from 0.8 mm to 52.8 mm. The mean rainfall depth (min to max) varied from 28.6 mm to 83.0 mm, historical runoff depth (min to max) varied from 4.7 mm to 32.3 mm, simulated runoff depth (min to max) varied from 1.4 mm to 27.4 mm with Ia/S = 0.2 However, with Ia/S = 0.05 the rainfall varied from 5.3 mm to 36.6 mm, respectively. The coefficient of variation in rainfall depth (min to max) varied from 26.9 per cent to 10.6 per cent, for historical runoff depth (min to max) varied from 57.1 per cent to 40.5 per cent. However, for simulated runoff depth (min to max) varied from 128.6 per cent to 21.2 per cent with Ia/S = 0.2 and with Ia/S = 0.05, it varied from 59.1 per cent to 17.1 per cent. The simulated runoff depth (min to max) with Ia/S = 0.05 was better related with historical runoff depth (min to max) than that with Ia/S = 0.2. This was further indicated with larger R^2 of simulated runoff depth (Ia/S = 0.05) with historical runoff depth than that with Ia/S = 0.2 for micro-watershed I.

Singh (2014) presented information on historical runoff depth and simulated storm wise runoff depth with Ia/S = 0.2 and Ia/S = 0.05 for total 42 rainstorms for the micro-watershed I during the years 1983, 1984, 1986, 1987, 1991 and 1994. The coefficient of variation for simulated runoff depth with Ia/S = 0.05 (CV% = 76.5) was better related with historical runoff depth (CV% = 78.5) over simulated runoff depth with Ia/S = 0.2 (CV% = 108.2). This indicated that simulated runoff depth with Ia/S = 0.05 performed better than that with Ia/S = 0.2 for micro-watershed I. However, the agreement between historical runoff depth and simulated runoff depth with Ia/S=0.2 and Ia/S=0.05

Table 3. Historical and simulated daily runoff depth with Ia/S=0.2 and Ia/S=0.05 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed I

Year	Julian day(s)	Rainfall depth (mm) (Min to Max)	Historical runoff (mm) (Min to Max)	Simulated runoff (mm) with Ia/S=0.2 (Min to Max)	Simulated runoff (mm) with Ia/S=0.05 (Min to Max)
1983	28 to 253	24.3 to 92.1	5.0 to 52.8	0.4 to 33.4	3.5 to 43.2
1984	40 to 261	23.2 to 91.8	4.0 to 42.0	0.2 to 33.2	3.2 to 42.9
1986	174 to 272	30.7 to 71.8	5.3 to 26.9	1.5 to 20.1	5.9 to 28.7
1987	207 to 248	42.2 to 85.8	9.3 to 21.8	5.1 to 29.1	11.1 to 38.5
1991	213 to 259	21.0 to 84.0	0.8 to 32.9	0.1 to 27.9	2.5 to 37.2
1994	184 to 245	30.6 to 73.0	4.3 to 17.9	1.5 to 20.8	5.8 to 29.6
Mean (mm)	141 to 256	28.6 to 83.0	4.7 to 32.3	1.4 to 27.4	5.3 to 36.6
±SD (mm)		7.7 to 8.8	2.7 to 13.1	1.8 to 5.8	3.1 to 6.3
CV (%)		26.9 to 10.6	57.1 to 40.5	128.6 to 21.2	59.1 to 17.1

appeared closely related as indicated by R^2 and low value of root mean square error (RMSE) in Table 3. The higher coefficient of determination (R^2=0.90) with Ia/S=0.05 as compared to R^2=0.78 with Ia/S=0.2 and low RMSE=6.5 with Ia/S=0.05 over RMSE=19.5 with Ia/S=0.2 for micro-watershed I were obtained through historical and simulated daily runoff depth with Ia/S = 0.05 (Table 3). This was further explained (Fig. 2a and Fig. 2b) that simulated runoff depth with Ia/S=0.05; performed better than that simulated runoff depth with Ia/S=0.2.

Comparison of historical and simulated daily runoff depth with Ia/S=0.2 and Ia/S=0.05 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed II

During the years 1983 to 1994, the information on Julian days, rainfall depth (min to max), historical runoff depth (min to max) and simulated runoff depth (min to max) with Ia/S = 0.2 and Ia/S = 0.05 is presented in Table 4. However, the rainfall distributed from 48th to 272th Julian day in the years 1983 to 1994. On these Julian days, the rainfall depth (min to max) varied from 21 mm to 92.1 mm.

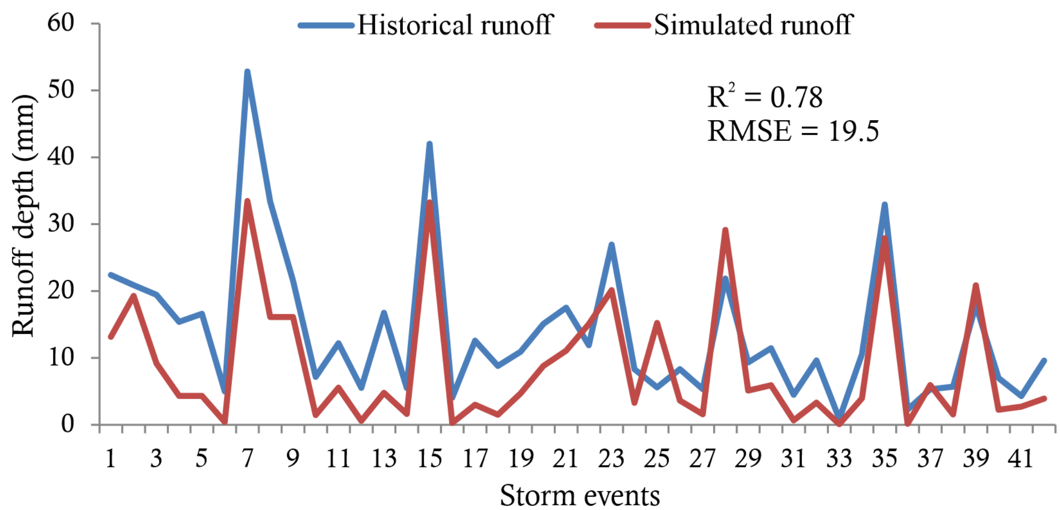

Fig. 2a. Comparison of historical and simulated daily runoff depth with Ia/S=0.2 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed I

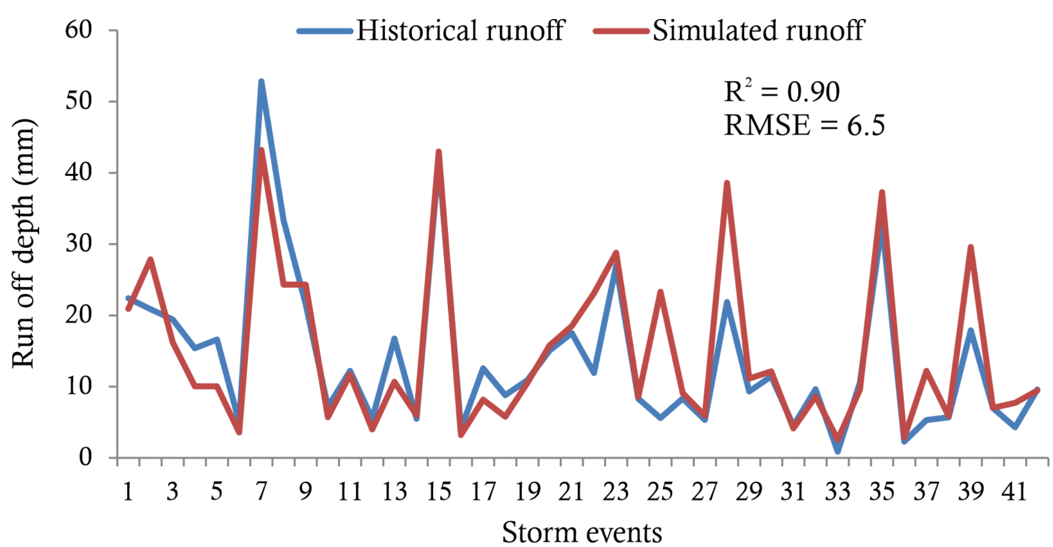

Fig. 2b. Comparison of historical and simulated daily runoff depth with Ia/S=0.05 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed I

Table 4. Historical and simulated daily runoff depth with Ia/S=0.2 and Ia/S=0.05 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed II

Year	Julian day(s)	Rainfall depth (mm) (Min to Max)	Historical runoff (mm) (Min to Max)	Simulated runoff (mm) with Ia/S=0.2 (Min to Max)	Simulated runoff (mm) with Ia/S=0.05 (Min to Max)
1983	28 to 253	24.3 to 92.1	4.3 to 43.2	0.4 to 33.4	3.5 to 43.2
1984	40 to 261	23.2 to 91.8	3.8 to 41.5	0.2 to 33.2	3.2 to 42.9
1986	174 to 272	30.7 to 71.8	4.9 to 26.5	1.5 to 20.1	5.9 to 28.7
1987	207 to 248	42.2 to 85.8	10.7 to 22.0	5.1 to 29.1	11.1 to 38.5
1991	213 to 259	21.0 to 84.0	2.1 to 35.8	0.1 to 27.9	2.5 to 37.2
1994	184 to 245	30.6 to 73.0	6.0 to 27.7	1.5 to 20.8	5.8 to 29.6
Mean (mm)	141 to 256	28.6 to 83.0	5.3 to 32.7	1.4 to 27.4	5.3 to 36.6
±SD (mm)		7.7 to 8.8	2.9 to 8.6	1.8 to 5.8	3.1 to 6.3
CV (%)		26.9 to 10.6	55.5 to 26.4	128.6 to 21.2	59.1 to 17.1

However, the simulated runoff depth (min to max) correspondingly on these Julian days varied from 0.1 mm to as large as 33.4 mm with Ia/S = 0.2. Similarly, on these days, in the years 1983 to 1994, the simulated runoff depth with Ia/S = 0.05 varied from 2.5 mm to as large as 43.2 mm. The historical runoff depth (min to max) varied from 2.1 mm to 43.2 mm. The mean rainfall depth (min to max) varied from 28.6 mm to 83.0 mm, historical runoff depth (min to max) varied from 5.3 mm to 32.7 mm, simulated runoff depth (min to max) with Ia/S = 0.2 varied from 1.4 mm to 27.4 mm and with Ia/S = 0.05 varied from 5.3 mm to 36.6 mm respectively. The coefficient of variation for rainfall depth (min to max) varied from 26.9 per cent to 10.6 per cent, for historical runoff depth (min to max) varied from 55.5 per cent to 26.4 per cent. However, for simulated runoff depth (min to max) with Ia/S = 0.2, it varied from 128.6 per cent to 21.2 per cent and with Ia/S = 0.05 it varied from 59.1 per cent to 17.1 per cent. The simulated runoff depth (min to max) with Ia/S = 0.05 was better related with historical runoff depth (min to max) over the simulated runoff depth (min to max) with Ia/S = 0.2. This was further indicated that computed runoff depth with Ia/S = 0.05 performed better than that with Ia/S = 0.2 for the micro-watershed II.

The information on historical runoff depth and simulated storm wise runoff depth with Ia/S = 0.2 and Ia/S = 0.05 for total 42 rainstorms for the micro-watershed II during the years 1983, 1984, 1986, 1987, 1991 and 1994 has been elaborated by Singh (2014) . The simulated runoff depth with Ia/S = 0.05 (CV% = 76.5) was better related with historical runoff depth (CV% = 73.7) over the simulated runoff depth with Ia/S = 0.2 (CV% = 108.2). This indicated that computed runoff depth with Ia/S = 0.05 performed better than that with Ia/S = 0.2 for the micro-watershed II. However, the agreement between historical runoff depth and simulated runoff depth with Ia/S=0.2 and Ia/S=0.05 appeared closely related as indicated by large value of calculated coefficient of determination (R^2) and low value of root mean square error (RMSE) in Table 5. The higher coefficient of determination (R^2=0.95 with Ia/S=0.05 as compared to R^2=0.85 with Ia/S=0.2) and low root mean square error (RMSE=6.4 with Ia/S=0.05 as compared to RMSE=12.9 with Ia/S=0.2) for micro-watershed II were obtained between historical and simulated daily runoff depth with Ia/S = 0.05 (Table 5). This suggested better simulated daily runoff depth with Ia/S=0.05 than that with Ia/S=0.2 (Fig. 3a and 3b).

However, for both the micro-watersheds, the descriptive statistics was better described with Ia/S = 0.05 over Ia/S = 0.2 through good agreement between simulated and historical runoff at Patiala-Ki-Rao watershed(s). Mriganke (2009) also showed higher coefficient of determination (R^2) and lower root mean square error (RMSE) values in case of Ia/S = 0.05 as compared to Ia/S = 0.2 for the pooled analysis of data in years 2001, 2002 and 2003 (R^2 = 0.998 with Ia/S = 0.05 as compared to R^2 = 0.992 with Ia/S = 0.2 and RMSE = 5.97 with Ia/S = 0.05

Table 5. Coefficient of determination (R^2) and root mean square error (RMSE) between daily historical and predicted runoff depth (S=9.0 cm)

Microwatershed	Ia/S			
	0.2		0.05	
	R^2	RMSE	R^2	RMSE
I	0.78	19.5	0.90	6.5
II	0.85	12.9	0.95	6.4

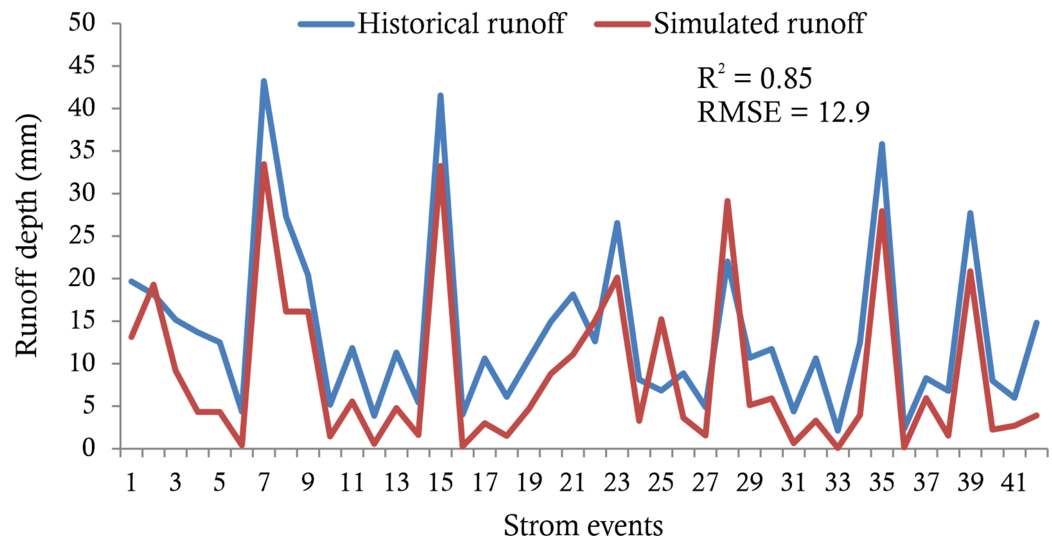

Fig. 3a. Comparison of historical and simulated daily runoff depth with Ia/S=0.2 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed II

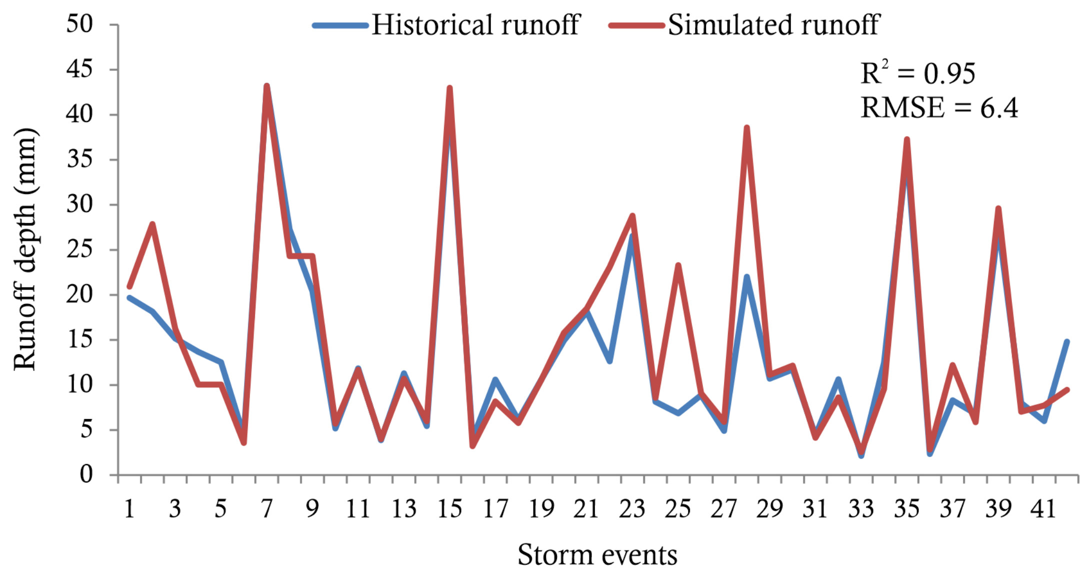

Fig. 3b. Comparison of historical and simulated daily runoff depth with Ia/S=0.05 using soil moisture retention (S) parameter as 9.0 cm for micro-watershed II

as compared to RMSE = 9.87 with Ia/S = 0.2) from an agricultural watershed at village Kokowal-Majari-Jhunewal in district Hoshiarpur Punjab. Similarly the studies by Harbor (1994) and Lim *et al.* (2006) also better predicted the daily runoff depth using Ia/S = 0.05 at Little Eagle Creek watershed in Central Indiana for the years 1961 to 1998.

Later, Geetha *et al.* (2008) developed a new lumped model based on Soil Conservation Service Curve Number (SCS-CN) for long term hydrologic simulation. The model has been tested using the data of 5-catchments from different climatic and geomorphic settings of India. However, on comparing the model of Mishra *et al.* (2005) which was based on Variable Source Area (VSA) concept, the proposed model performed better in all applications. Both the models, however, exhibited a better match between simulated and observed runoff in high runoff producing catchments than that in low runoff producing catchments. The results of the study undertaken suggests testing new lumped models by Geetha *et al.* (2008) and Mishra *et al.* (2005) based on VSA concept.

Determining a robust relationship between rainfall and runoff for a watershed has been one of the most important problems for hydrologic engineers and agriculturists since its first documentation (Mishra and Singh, 2003) about 325 years ago. The process of transformation of rainfall to runoff is highly complex, dynamic, and non-linear and exhibits temporal and spatial variability. This was further affected by many and often inter-related physical factors. However, the understanding of various hydrologic variations (spatial and temporal) over long periods is necessary for identification of these complexes and heterogeneous watershed characteristics. The present study in future can be extrapolated to account for soil physical characteristics that vary with time and space in the watersheds.

The results of the present investigation are at variance with study of Beven and Kirkby (1979), wherein it suggested a conceptual model that can simulate the VSA. This could be used for long term water yield estimation which incorporates soil moisture replenishment, depletion and redistribution for the dynamic variations of areas during and after the storm contributing to direct runoff.

On the other hand, the Curve Numbers are sensitive to antecedent moisture conditions (Ponce, 1989). The original method does not contain any expression for time and ignores the impact of rainfall intensity and its temporal distribution. There is no explicit provision for spatial scale effects. In addition, the other limitations of the original method are absence of clear guidance of how to vary the antecedent moisture conditions and fixing of initial abstraction ratio of 0.2, pre-empting a regionalization based on geologic and climatic settings (Choi *et al*., 2002). However, in the present study an attempt was made to vary the Ia/S parameter that considered the variability in soil moisture retention parameter rather than using the initial abstraction ratio of 0.2. In addition, instead of using conventional initial abstraction value of 0.2, it may require localized adjustments to better reflect the specific hydrological characteristics of the region or area.

CONCLUSION

Accurate runoff assessment is essential for developing effective flood management strategies, planning and designing hydraulic infrastructures as well as water resource management in flood prone areas of submontane Punjab. The runoff depth was better simulated by employing Ia/S = 0.05 than that with Ia/S = 0.2 at low to moderate rainfall depths. However, there is need to consider the effects of the characteristics of rainfall such as peak intensity that can better simulate the runoff in the area. The results of undertaken study suggest that there is need to test new lumped models based on Soil Conservation Service Curve Number approach and Variable Source Area concept approach. These models have performed better in simulating runoff in high runoff producing watersheds at other places in India.

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