Journal of Natural Resource Conservation and Management
Vol. 5, No. 2, pp 180-191, 2024
doi: 10.51396/ANRCM.5.2.2024.180-191

Comparison of historical and simulated sediment yields using two different ratios of initial abstraction to soil moisture retention parameters in two micro-watersheds in north-western tract of India

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Received : September 16, 2024
Revised : December 12, 2024
Accepted : December 13, 2024
Published : December 31, 2024

ABSTRACT

The information on accurate records of runoff and soil loss is essential for designing soil water conservation measures, dams, and water reservoirs etc. Thus, a simulation study assumes significant in this context. Keeping these points in view, a study was conducted to simulate rainfall change effects on soil erosion at Patiala-Ki-Rao watersheds, district Roopnagar. In addition, the objective was also to compare historical and simulated sediment yields of two micro-watersheds in North-western tract of India under semiarid tropical environments**.** Thereby, the Modified Universal Soil Loss Equation (MUSLE) and Revised Modified Universal Soil Loss Equation (RMUSLE) were used to simulate event wise sediment yield for total 42 rainstorms for the historical six years as 1983, 1984, 1986, 1987, 1991 and 1994 for Patiala-Ki-Rao watershed(s) I and II. The simulated and historical event wise soil losses (min to max) were in close agreement for both MUSLE and RMUSLE for the micro-watershed I. The per cent error for simulated sediment yield for MUSLE (min to max) varied from -4.6 per cent to -26.9 per cent. However, per cent error for simulated sediment yields for RMUSLE (min to max) varied from -3.5 per cent to -27.6 per cent. The results revealed that simulated event-based sediment yields for RMUSLE (min to max) were in better agreement with historical values than that with simulated sediment yield for MUSLE (min to max). The coefficient of determination (R^2) between historical and simulated soil loss observed was 0.97 for MUSLE and 0.99 for RMUSLE. For micro-watershed II, the simulated and historical soil losses (min to max) were in close agreement for both MUSLE and RMUSLE. The per cent error for simulated sediment yield for MUSLE (min to max) varied from +5.4 per cent to -28.3 per cent. However, per cent error for simulated sediment yield for RMUSLE (min to max) varied from +7.1 per cent to -24.9 per cent. The simulated event-based sediment yields for RMUSLE (min to max) were in better agreement with historical values over simulated sediment yield for MUSLE (min to max). The coefficient of determination (R^2) between historical and simulated soil loss was 0.87 for MUSLE and 0.96 for RUSLE. However, the event wise soil loss for RMUSLE was better correlated between simulated and historical values than that with MUSLE, wherein the rainfall-runoff factor better estimated the sediment yield.

Keywords: USLE, RMUSLE, Empirical models

INTRODUCTION

In order to evaluate the effects of rainfall change on runoff and soil erosion, a modeling approach can be employed. The different modeling approaches followed are empirical, semi-empirical, process-based approach, abstract, conceptual, graphical, or mathematical (Hadda and Sidhu, 2024). It provides a way to read elements easily which have been broken down to a simpler form. However, general circulation models are often used in theoretical approach to match past climatic data, make future projects that link causes and effects in rainfall changes and how it could affect runoff and sediment loss.

The above literature pointed out that most of the models employed at different places requiring large data set and complex in nature. Therefore, complete understanding of the simulation studies is important for planning and management of soil erosion and for maintaining maximum level of agricultural production at a place. In the submontane Punjab, there is little information on the accurate runoff and soil loss records in the watersheds which cover sufficient duration of rainy season to enable accurate assessment of runoff. But, on the other hand, daily rainfall records representative of most of the watersheds are generally available. Theses could find utility in assessing runoff and sediment yields in the area. In this connection, a few empirical relationships on watershed basis can be developed to estimate runoff and soil loss or sediment yields in the tract.

Bennett (1974) has given concepts of mathematical modeling of sediment yield. According to him a sediment yield model should mathematically approximate the behavior of the two distinct phases of the phenomenon, the upland phase and the low land channel phase. In both the phases, research was needed to explain the effects of unsteadiness and flow non-uniformities on transport

Walling (1974) developed a grey-box model relating sediment yield to storm runoff, peak surface runoff, total surface runoff and the day of year. The best example of grey box models is the Universal Soil Loss Equation (USLE) which was developed by Wischmeier and Smith (1962) based upon the works of Zingg (1940), Musgrave (1947), and Smith (1958).

William (1975) modified the USLE to estimate sediment yield for individual runoff events and the modified equation is known as MUSLE. The channel and gully erosion or deposition in impoundments are accounted for separately and added to or subtracted from the equations estimate (William 1978).

Knisel (1980) overviewed various erosion and sediment transport models and revealed that the USLE is the basic element of most models. Foster *et al.* (1981a) proposed several sets of metric conversion factors for the USLE. A nomograph was presented for determining annual erosivity factor (R) and soil erodibility factor (K) in SI units. Foster and Lane (1981 b) concluded that the use of small plots for verifying the USLE are inappropriate, because soil erodibility factor (K), slope length (L) and slope steepness factor (S) cannot be applied to small plots because of the absence of sufficient length to begin rill erosion and other runoff processes related to detachment and transport of soil particles.

Johnson *et al.* (1985) tested the MUSLE for intermountain North West United States for rainfall and snow melt conditions. The MUSLE underestimated sediment yields for the largest storm events and overestimated for the smaller events. The equation given below, which is fitted to data show application of the MUSLE to areas with rainfall and snow melt runoff and sediment yield.

$S_Y = 11.3\ (V^*q_P)^{0.75}\ K\ L\ S\ C\ P$

V is runoff volume, qp is peak runoff rate and other notations such as KLSCP are the known factors of the Universal Soil Loss equation.

William and Berndt (1972) modified the USLE for predicting sediment yield from watersheds. All factors of the equation, except the rainfall factors were modified to increase computational efficiency. In addition, the erosion control practice factor was expanded to include the separate effect of grassed waterways.

William and Berndt (1977) predicted daily, monthly, and annual sediment yield fairly accurately by attaching a sediment yield model to water yield model based on SCS curve numbers. A soil moisture index is used to predict daily runoff volumes and hydrological yield model is used to determine peak flow rates. Shirley and Lane (1978) derived a sediment equation from the partial differential equations for overland flow with rill and interrill erosion on a plane. Derived sediment yield equation incorporates hydraulic resistance, rill and interrill erodibility terms, watershed area and runoff volume. Calculated yields compared favorably with observations. The derived equation is an improvement over the USLE, because it accounts for decreasing yield with increasing watershed area.

Foster *et al.* (1980) developed a simulation model which incorporates fundamental principles of erosion, deposition and sediment transport mechanics and concluded that this model gives improved estimates over the Universal Soil Loss Equation. Foster *et al.* (1981a) developed a model for field sized areas to evaluate sediment yield under various management practices. The model incorporates fundamental principles of erosion, deposition, sediment transport and concluded that model produces reasonable estimates of erosion, sediment transport and deposition under a variety of conditions common to field sized areas.

Murphree and Mutchler (1981) derived relationships between sediment yield and runoff with rainfall using data from two adjacent watersheds in the Mississippi Delta. These relationships can be used for predicting sediment yield from flatland watersheds at locations where climate, cropping and arid management conditions are similar to those in this experiment.

Hetrick and Travis (1988) compared surface runoff and sediment yield from the coupled sediment yield and soil erosion (SESOIL and EROS) model to measured data from three watersheds taken as two cornfield watersheds and one grassland watershed. The watersheds differed in their management practices, soil type, ground cover, and meteorology. Overall, SESOIL and EROS model predictions on an annual basis are in fair to good agreement with observed data from three watersheds.

Lane *et al.* (1988) developed a new generation water erosion prediction technology and it is expected to replace the USLE as the primary erosion prediction tool used by action agencies. Bingner *et al.* (1989) compared the simulated results from the models CREAMS, SWRRB, EPIC, ANSWERS and AGNPS with measured data of runoff and sediment yield on an annual and storm rainfall event basis. They concluded that no one model worked well in every situation of runoff and sediment yield on the watersheds. Overall CREAM and SWRRB produced results that were close to measured values more often than the other models, even though SWRRB required simpler inputs.

Rani (1991) developed two computer programs: SOIL LOSS and GENRAIN in FORTRAN 77 language. SOIL LOSS model for predicting runoff, peak runoff rate and soil loss on event basis at Patiala-Ki-Rao watersheds. Runoff and peak runoff rates were determined by Curve Number method and procedure suggested by U.S. Soil Conservation Services (SCS, 1972) method. Modified Universal Soil Loss Equation (MUSLE) was used to compute soil loss on event basis. Using simulated precipitation, annual soil loss from watersheds was determined. The maximum and minimum percentage difference in historical and simulated runoff depths were -116.75 and -0.08 for micro-watershed (III) and -67.77 and 2.08 for micro-watershed (II) of Patiala-Ki-Watershed, Roopnagar.

However, all the above referred studies varied with objectives, availability of infrastructure and instrumentation, and advancement in the knowledge domain etc. Therefore, keeping these points in view, the present investigation was undertaken with the objective to compare historical and simulated sediment yields of two micro-watersheds in North-western tract of India under semiarid tropical environments

MATERIALS AND METHODS

Description of the watersheds

Four adjoining watersheds known as Patiala-Ki-Rao watersheds situated in foothills of the Shiwaliks ('Kandi' area) in district Roopnagar (Punjab) have been regularly monitored for hydrological measurements. Of these, two watersheds, micro-watershed I and II were considered for estimating sediment yields, as these varied in size, shape, slope, vegetation characteristics and applied treatments. These were contiguous to each other. These are situated at an elevation of 415 m above the mean sea level in the Shiwaliks of Punjab. The instruments installed for measurement and monitoring of runoff and sediment loss were the Parshall Flume in watershed I and V-notch (120^0) in watershed II, automatic stage level recorders and sediment samplers. 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 thermometers etc. However, afforestation, fencing and engineering treatments were applied in the watershed I but 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 (Table 1).

In addition, the information on daily rainfall, runoff volume, peak discharge rate, soil loss and other meteorological parameters of the selected watersheds have been obtained from the office of the Director, Dr DR Bhumbla Zonal Research Station

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)

for Kandi Area, Ballowal Saunkhri, district Shaheed Sukhdev Singh Nagar.

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 monsoon (Kharif) season and 20 per cent during the winter (Rabi) season. However, the rainfall received during the summer months is of major concern due to its harvesting and subsequent use in winter season crops. The monsoon rainstorms (summer season) received in the area varied 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 (Kukal *et al.,* 1991). In the pre- monsoon months of May and June, high temperatures and 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 is very sparse on the ground (Kukal *et al.,* 2000). These factors and receipt of high intensity and short duration rainstorms cause large-scale runoff and soil erosion 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 shales along with pseudo-conglomerates of Middle Miocene to Helvetian age. The exact information on the age of these deposits is lacking. However, 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.

However, the computations and determinations of other parameters are described below.

Peak runoff rate

The peak runoff rate computed by employing the rational formula is listed below.

$$Q_p = CIA/360$$

Where, Q is peak runoff rate in m^3/s; C is runoff coefficient; I is rainfall intensity in mm/hr for a period equal to the time of concentration in minutes and A is watershed area in ha which can be measured from topographic map.

Runoff coefficient (C)

It is defined as the ratio of the runoff to the rainfall. Value of 'C' depends upon watershed characteristics like vegetation cover, slope, infiltration rate and soil texture etc. The different values of 'C' are given in Appendix-C by Singh (2014). For the Patiala-Ki-Rao micro-watersheds I and II, the value of 'C' was selected as 0.30 and 0.35 respectively.

Rainfall intensity (I)

It is the average intensity of rainfall (mm/hr) considered when rainfall is distributed uniformly over the entire watershed for storm duration equal to the time of concentration. The relevant information is obtained from rainfall charts and its computation procedure has been discussed by Singh (2014).

Time of concentration

It is the time required for the runoff water to flow from the most remote-point of the watershed area to its outlet (Tc). When the duration of a storm equals the time of concentration, it is assumed that all parts of the watershed are contributing simultaneously to the discharge outlet. The time of concentration for the selected micro-watersheds was computed using the following empirical formula given by Kirpich (1940) as follows:

$$Tc = 0.0195\ L^{0.77}\ S^{-0.385}$$

Where, Tc is time of concentration in minutes; L is maximum length of flow in m and S is average slope of the area in m/m which is determined by contour length method as given by Wentworth (1930).

The computed Tc for Patiala-Ki-Rao micro-watershed I and II were as 4.0 and 4.21 respectively.

However, after calibration, Rational method was modified for the Patiala-Ki-Rao micro-watersheds as suggested by Duggal *et al*. (2000) and listed below.

$Q = CIA^{0.55}$ for low intensity storms i.e. intensity less than or equal to 5 cm/hr

$Q = CIA^{0.95}$ for high intensity storms i.e. intensity more than 5 cm/hr

The equation proposed is discussed below.

Duggal (1992) used two computer models 'SEDIMENT and MSEDIMENT' in Fortran 77 language. The SEDIMENT program was used to determine erosivity index R and sediment yield by replacing the rainfall factor with a runoff factor for a storm. It was used to determine event based sediment yield. The equation proposed is discussed below.

$$Sy = 11.8\ (V^*q_p)^{0.56}\ KLSCP$$

Where, Sy is sediment yield from an individual storm in m tons; V is storm surface runoff depth in mm; q_p is peak runoff rate in m^3/s; K is soil erodibility factor; LS is topographic factor; C is crop cover management factor and P is conservation practice factor.

However, after calibration, MUSLE was modified for the Patiala-Ki-Rao micro-watersheds by Duggal *et al.* (2000) and listed below:

$$Sy = 8.0\ (V_{Ia/S=0.2}{}^*q_p)^{0.56}\ KLSCP$$

Where, $V_{Ia/S=0.2}$ is storm surface runoff depth computed by SCS-CN method using (initial abstraction ratio (Ia/S) = 0.2 and MSEDIMENT computer program was used to predict event-based sediment yield (Sy) using MUSLE.

Rational method

The relevant equation is revised by considering the mean value of $V_{Ia/S=0.05}{}^*q_p$ of 6 years 1983, 1984, 1986, 1987, 1991 and 1994 having total 42 rainstorms, the revised MUSLE is described below

$$Sy = 8.0\ (V_{Ia/S=0.05}{}^*q_p)^{0.56}\ KLSCP$$

where, $V_{Ia/S=0.05}$ is storm surface runoff depth computed by SCS-CN method using initial abstraction ratio of Ia/S as 0.05.

Erosivity factor

The different erosivity indices such as EI_{15}, EI_{30}, EI_{45} and EI_{60} were compared and of these, EI_{60} was found to be the best that correlates with soil loss for Patiala-Ki-Rao micro-watersheds I and II in the district Roopnagar. MSEDIMENT programme was used to determine peak runoff rate by Rational method, runoff depth by SCS-CN method and event-based sediment yield by Modified Universal Soil Loss Equation (MUSLE) for micro-watershed II and III. Simulated peak runoff rate, runoff depth and event-based sediment yield were in close agreement with their observed values at Patiala-Ki-Rao micro-watersheds, Roopnagar.

Erodibility factor

This is expressed as tons of soil loss per hectare per unit of rainfall erosion index (K) for a slope of specified dimensions (9 per cent, and 22.1 m long) under continuous cultivated, fallow without the influence of crop cover. Values of K were obtained from Wischmeier *et al*. (1971) nomograph. The inputs used in this nomograph were per cent organic matter (Table 2), soil texture (Table 3), soil structure grade and permeability etc.

Table 2. Organic matter content (per cent) of soils for two micro-watersheds at Patiala-Ki-Rao

Soil sample	Soil depth (cm)	Micro-watershed I	Micro-watershed II
1	0-15	0.38	0.66
	15-30	0.42	0.56
2	0-15	0.99	0.58
	15-30	0.81	0.46
3	0-15	0.29	0.54
	15-30	0.33	0.59
4	0-15	0.68	0.37
	15-30	0.33	0.33

Table 3. Particle Size distribution of Soils for two micro-watersheds at Patiala-Ki-Rao

Soil depth (cm)	Watershed (I) per cent			Watershed (II) per cent		
	Sand	Silt	Clay	Sand	Silt	Clay
0-15	60.4	24.5	14.9	46.5	35.2	18.2
15-30	51.5	31.2	17.2	59.4	28.1	12.4
0-15	63.4	22.1	14.4	75.9	14.5	9.4
15-30	64.0	23.0	12.8	82	9.5	8.4
0-15	86.2	6.0	7.7	62	24.7	13.1
15-30	84.4	6.8	8.6	65.9	19.9	14.0
0-15	80.9	9.3	9.7	34.5	41.0	24.1
15-30	80.9	10.0	9.0	32.4	44.5	22.9

Depending upon soil texture, per cent organic matter, soil structure and permeability, the erodibility factor (K) was obtained by using nomograph of Wischmeier *et al*. (1971). However, the K-factor was as 0.18 and 0.20 of micro-watershed I and II respectively. The texture of soils of these watersheds I and II are sandy loam to sandy clay loam.

Topographic factor

The slope length factor is the ratio of soil loss from any length of slope to that from the slope length specified (22.1 m generally) for a given soil erodibility value. The topographic factor LS as suggested by Smith and Wischmeier (1962) is as follows:

$$LS = (L/22.11)^{m} (0.065 + 0.0454S + 0.0065S^2)$$

Where, m is 0.5 for slopes > 3 per cent; and m is 0.3 for flatter slopes', L is slope length in m and S is slope steepness in per cent.

Slope length

Slope length (L) is the average overland flow length for the watershed. Consider a rectangular watershed with one channel in the center, extending the length of watershed. The watershed width is equal to area divided by the channel length. As the channel is located in the centre of watershed, the overland flow length is half the width. Therefore, length can be computed as follows:

$$L = 0.5\ DA / LCH$$

Where, L is length of overland flow or slope length; DA is drainage area of watershed in m^2 and LCH is total length of channels in the watershed in m.

Slope steepness

Mean watershed slope (S) was determined by contour length method as suggested by Wentworth (1930)

$$S = L*M/A$$

Where, S is mean watershed slope in per cent; L is total length of contour lines within the watershed in m; M is contour interval in m and A is the watershed area in m^2.

Slope length of the micro-watershed I and II was 73.5 m and 107.4 m respectively and mean watershed slopes determined were 38.1 and 34.1 per cent for micro-watershed I and II respectively. Topographic factor determined was 20.5 and 20.2 for micro-watershed I and II respectively.

Crop cover management factor

This is defined as the ratio of soil loss from land cropped under specified conditions to corresponding soil loss from continuous fallow on identical soil, slope, and rainfall conditions. Value of Crop Cover Management Factor (C) employing for each watershed was determined from Wischmeier and Smith (1978) and the same is reported by Singh (2014) in Appendix-A.

The cover management factor (C) was computed from Appendix-A, suggested range is 0.08 and 0.038 for percentage ground cover varying from 40 to 60 per cent and brushes with average drop fall height of 2 meter with 50 per cent cover under heading "G" (cover at surface is grass, grass like plants, decaying compacted litter at least 5 cm deep). The value of C was considered as 0.06 for both the micro-watersheds.

Conservation practice factor

The Conservation Practice Factor (P) is the ratio of soil loss for a given practice to that for up and down the slope farming. Value of P for each

Table 4. Parameters of modified universal soil loss equation

Factorwatershed	K	LS	C	P
Micro-watershed I	0.18	20.56	0.06	0.95
Micro-watershed II	0.20	20.24	0.06	0.95

watershed was determined based on the recommendations of USDA (1978).

Since no conservation practice other than providing some gully check dams and plantation were used, therefore, the value of P was considered as 0.95 in the micro-watersheds. Parameters of modified universal soil loss equation in micro-watershed I and micro-watershed II is given in Table 4.

Statistical analysis

The simulated and historical values of runoff depth and event-based sediment yield 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 Arthur (1984).

RESULTS AND DISCUSSION

Comparison of historical and simulated event-based sediment yield in micro-watershed I

The information on historical and simulated event-based sediment yield (min to max) during the years 1983, 1984, 1986, 1987, 1991 and 1994 is presented in Table 5 for Patiala-Ki-Rao micro-watershed I. The historical sediment yield (min to max) varied from 17.5 tons to 178.7 tons, simulated sediment yield for MUSLE (min to max) varied from 21.7 tons to 195.7 tons and simulated sediment yield for RMUSLE (min to max) varied from 24.8 tons to 168.5 tons which was less than that simulated sediment yield for MUSLE. The per cent error for simulated sediment yield for MUSLE (min to max) varied from -4.6 per cent to -26.9 per cent. However, per cent error for simulated sediment yields for RMUSLE (min to max) varied from -3.5 per cent to -27.6 per cent. Thus, the overall per cent error varied within 30 per cent error limit. It showed that simulated event-based sediment yields for RMUSLE (min to max) were in close agreement with historical values than that in simulated sediment yield for MUSLE (min to max).

The information on historical event wise sediment yield and simulated event wise sediment yield for total 42 rainstorms of the years 1983 to 1994 has been presented in Appendix-H by Singh (2014). The overall per cent error varied within 30 per cent error limit (Appendix-H; Singh, 2014). Higher coefficient of determination ($R^2 = 0.99$) between historical event wise sediment yield and simulated event wise sediment yield for RMUSLE than that with simulated event wise sediment yield for MUSLE ($R^2 = 0.97$) indicated that simulated event-based sediment yields for RMUSLE were in better agreement with historical values over simulated sediment yield for MUSLE (Table 5 and Figure 1). The information on descriptive statistics for historical and simulated event wise sediment yield for MUSLE and RMUSLE for micro-watershed I are presented in Table 6. The information through mean, ±SD, CV and R^2 indicated that simulated event wise sediment yield with RMUSLE better related with historical event

Table 5. Relationships between historical and simulated event based sediment yield (tons) on different Julian days for micro-watershed I

Year	Julian day(s)	Sediment yield historical (Min to Max)	Sediment yield simulated for MUSLE (Min to Max)	Sediment yield simulated for RMUSLE (Min to Max)	Per cent error for MUSLE (Min to Max)	Per cent error for RMUSLE (Min to Max)
1983	28 to 253	27.9 to 146.4	33.6 to 133.5	31.2 to 168.5	-15.4 to -26.7	-13.3 to -24.9
1984	40 to 261	17.5 to 137.7	21.7 to 171.7	25.3 to 158.6	-4.6 to -26.9	-4.2 to -27.6
1986	174 to 272	25.0 to 143.3	29.6 to 169.2	31.5 to 162.3	-14.8 to -24.4	-12.6 to -22.9
1987	207 to 248	40.7 to 178.7	44.4 to 195.7	43.5 to 185.9	-6.9 to -9.5	-6.4 to -8.9
1991	213 to 259	22.2 to 142.4	24.7 to 175.3	24.8 to 166.5	-8.1 to -23.1	-7.7 to -19.6
1994	184 to 245	23.1 to 88.2	29.1 to 92.1	26.7 to 89.2	-4.6 to -22.6	-3.5 to -21.6

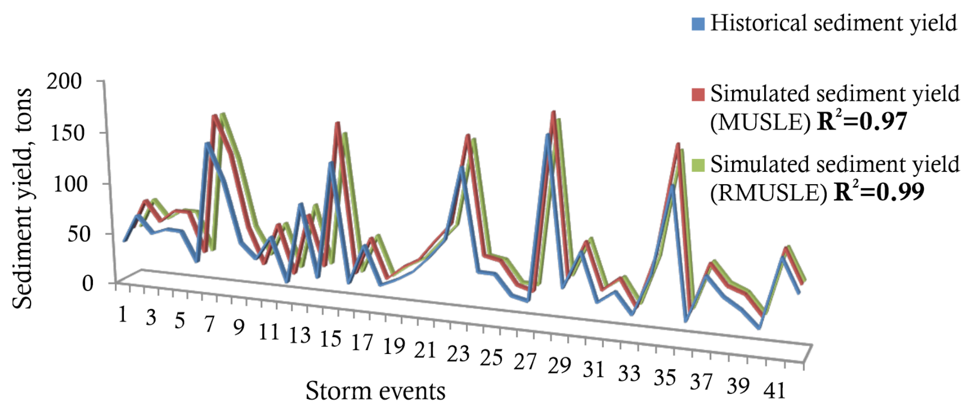

Fig. 1. Comparison of historical and simulated event-based sediment yield for micro-watershed I

Table 6. Descriptive statistics for historical and simulated event-based sediment yield for MUSLE and RMUSLE for micro-watershed I and II

Descriptive statistics	Micro-watershed I Simulated			Micro-watershed II Simulated		
	Historical	MUSLE	RMUSLE	Historical	MUSLE	RMUSLE
Mean (tons)	60.2	69.3	66.7	91.8	119.6	108.8
±SD (tons)	39.5	45.9	43.7	58.4	87.2	80.5
CV (%)	65.6	66.2	65.4	63.6	72.9	73.9
R^2		0.97	0.99		0.87	0.96

wise sediment yield over simulated sediment yield with MUSLE.

Statistical analysis

The results of statistical analysis are presented in Table 6. The smaller values of coefficient of variation and larger values of coefficient of determination signified that data was more consistent using RMUSLE than that with MUSLE, i.e., less variable, and highly correlated.

Comparison of historical and simulated event-based sediment yield of micro-watershed II

The information on historical and simulated event-based sediment yield (min to max) during the years 1983, 1984, 1986, 1987, 1991 and 1994 is presented in Table 7 for Patiala-Ki-Rao micro-watershed II. The historical sediment yield (min to max) varied from 32.6 tons to 300.3 tons, simulated sediment yield for MUSLE (min to max) varied from 37.2 tons to 362.4 tons and simulated sediment yield for RMUSLE (min to max) varied from 32.5 tons to 341.6 tons which was less than that simulated sediment yield for MUSLE. The per cent error for simulated sediment yield for MUSLE (min to max) varied from +5.4 per cent to -28.3 per cent. However, per cent error for simulated sediment yield for RMUSLE (min to max) varied from +7.1 to per cent to -24.9 per cent. Thus, the overall per cent error varied within 30 per cent error limit. It showed that simulated event-based sediment yields for RMUSLE (min to max) were in close agreement with historical values over simulated sediment yield for MUSLE (min to max).

The information on historical event wise sediment yield and simulated event wise sediment yield for total 42 rainstorms during the years 1983 to 1994 has been presented in Appendix-I by Singh (2014). The overall per cent error varied within 30 per cent error limit except Julian day 250 (per cent error = -112.7), 206 (per cent error = -62.7) and 253 (per cent error = -83.6) for years 1983, 1984 and 1991 respectively (Appendix-I; Singh, 2014)). Higher coefficient of determination (R^2 = 0.96) between historical event wise sediment yield and simulated event wise sediment yield for RMUSLE than that with simulated event wise sediment yield for MUSLE (R^2 = 0.87) indicated that simulated event-based sediment yields for RMUSLE were in better agreement with historical values over simulated sediment yield for MUSLE (Table 7 and Figure 2). The information on descriptive statistics for historical and simulated event wise sediment yield for MUSLE and RMUSLE for micro-watershed II is presented in Table 6. The information through mean,

Table 7. Relationship between historical and simulated event-based sediment yield (tons) on different Julian days for micro-watershed II

Year	Julian day(s)	Sediment yield historical (Min to Max)	Sediment yield simulated for MUSLE (Min to Max)	Sediment yield simulated for RMUSLE (Min to Max)	Per cent error for MUSLE (Min to Max)	Per cent error for RMUSLE (Min to Max)
1983	28 to 253	49.6 to 192.6	62.0 to 315.3	52.9 to 278.1	-20.1 to -28.3	-17.7 to -24.6
1984	40 to 261	37.1 to 190.9	45.4 to 318.7	32.5 to 290.1	-20.6 to –27.8	-17.3 to -25.8
1986	174 to 272	42.0 to 245.1	50.3 to 313.4	43.1 to 297.4	+5.4 to -27.8	+7.1 to -24.3
1987	207 to 248	68.5 to 300.3	75.4 to 362.4	69.3 to 341.6	-9.9 to -20.2	-7.9 to-16.9
1991	213 to 259	38.1 to 166.1	45.1 to 319.4	38.8 to 309.9	-16.1 to -22.8	-14.6 to -24.9
1994	184 to 245	32.6 to 97.4	37.2 to 102.2	33.9 to 94.6	-7.3 to -20.6	-5.7 to -17.9

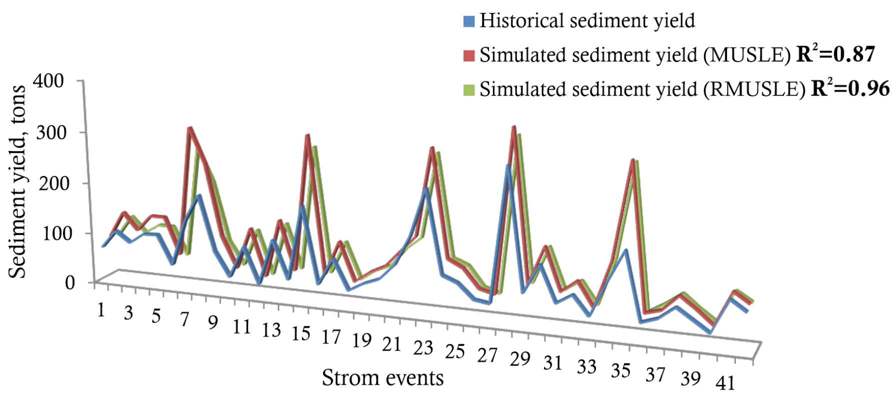

Fig. 2. Comparison of historical and simulated event-based sediment yield of micro-watershed II

±SD, CV and R^2 indicated that simulated event wise sediment yield with RMUSLE better related with historical event wise sediment yield over simulated sediment yield with MUSLE.

Duggal *et al.* (2000) observed that there was good agreement between simulated and historical event wise sediment yield using MUSLE with coefficient of determination (R^2) = 0.95 and 0.84 and per cent error limit was within 30 per cent error limit for two Patiala-Ki-Rao micro-watersheds. Johnson *et al.* (1985) tested the MUSLE for intermountain North West United States and showed that the MUSLE underestimated sediment yields for the largest storm events and overestimated for the smaller events. It thus suggested that the empirical equation proposed for a watershed suffers from several drawbacks. This needs to be improved by incorporating new factors which were not accounted for in the proposed empirical equation.

Potential Changes in simulated event wise sediment yield with rainfall-runoff factor

The information on potential changes in simulated sediment yield with rainfall-runoff factor is presented in Figures 3 and 4 for both the micro-watersheds I and II respectively. For micro-watershed I, simulated sediment yield as a function of rainfall-runoff factor was evaluated by employing linear, power, and exponential functions. Of the evaluated functions, power function (R^2 = 0.81) for simulated sediment yield and rainfall-runoff factor showed significantly larger variation over linear function (R^2 = 0.80) and exponential function (R^2 = 0.60). Similarly, for micro-watershed II, of the evaluated functions, linear function (R^2 = 0.91) for simulated sediment yield and rainfall-runoff factor showed significantly larger variation over power function (R^2 = 0.81) and exponential function (R^2 = 0.68). This suggests that for micro-watershed I, power function may be employed as dependent variable for simulating event wise sediment yield with independent variable as rainfall-runoff factor. Similarly, for micro-watershed II, linear function may be employed as dependent variable for simulating event wise sediment yield with independent variable as rainfall-runoff factor.

Impacts of rainfall change on soil erosion and surface runoff have also been evaluated by considering changes in rainfall intensity. The changes in mean rainfall have been assumed to take

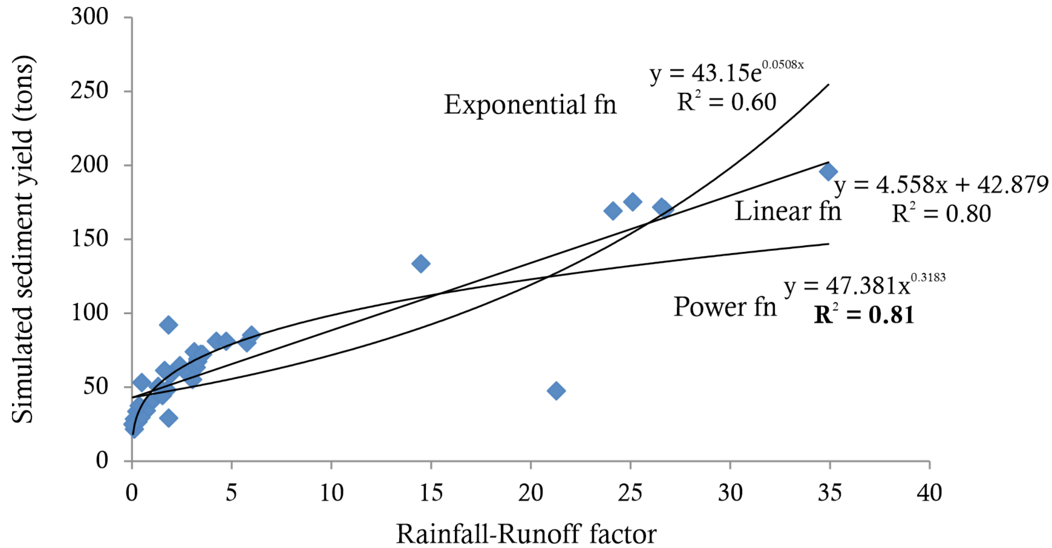

Fig. 3. Potential Changes in simulated event wise sediment yield with rainfall-runoff factor using Ia/S=0.05 of micro-watershed I

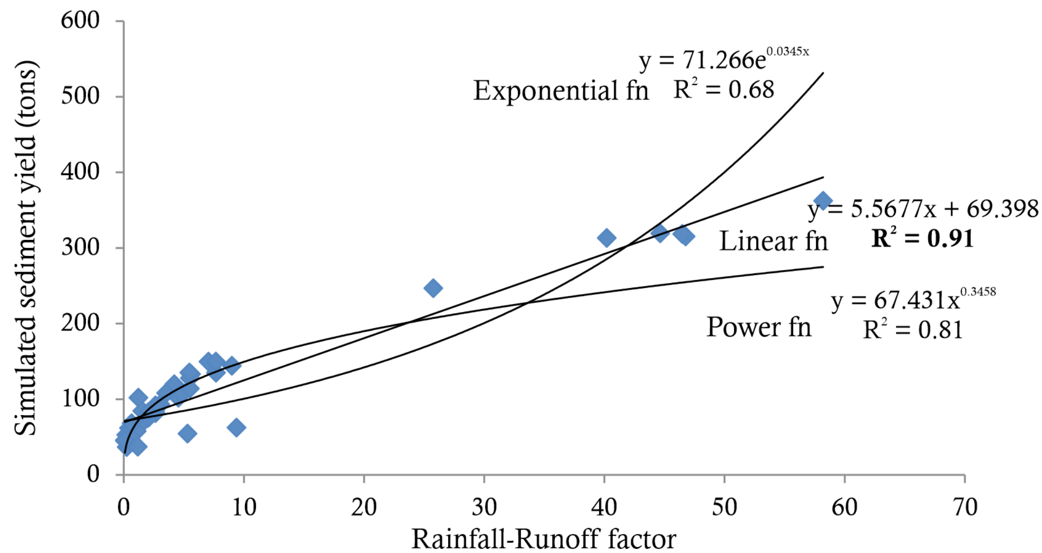

Fig. 4. Potential Changes in simulated event wise sediment yield with rainfall-runoff factor using Ia/S=0.05 of micro-watershed II

place by a change in storm frequency alone, intensity alone or a combination of two (Favis-Mortlock *et al.,* 1991; Pruski and Nearing, 2002a and 2002b). Pruski and Nearing (2002a) compared the effects of changes in storm frequency alone or intensity by allocating mean rainfall changes to change in storm frequency alone or changes in both. They found that change in rainfall amount and intensity had much greater effect on soil erosion and runoff generation than a change in storm frequency. Specifically, a 1 per cent change in rainfall resulted in 2.4 per cent change in soil loss and 2.5 per cent change in runoff for change in rainfall amount and intensity that accounted for most of change. It resulted in 0.9 per cent change in soil loss and 1.3 per cent change in runoff for a change in frequency account for all the change. Other studies in the U.S. (Savabi *et al.,* 1993) and Great Britain (Favis-Mortlock *et al.,* 1991) showed that average soil erosion increased by 2 to 4 per cent for 1 per cent increase in rainfall if the change in storm intensity is accounted for all the increase.

Regarding soil erosion and conservation concerns, the results indicated a possibility for increasing erosion despite the predicted decrease in annual rainfall during the last decade in the area. This is due to predicted increase in rainfall particularly of large events reflected by greater variability of daily rainfall depth during the critical period when summer monsoon rainfall to commence, surface cover is low, and soils are more prone to soil erosion (Hadda and Sur, 2001; Hadda *et al.,* 2002). It is also known that increase in rainfall intensity rather than rainfall amount could cause more erosion and ultimately affect the sediment yield.

CONCLUSION

The submontane Punjab covers 9.5 per cent of total geographical area of the state. In the area, about 75-80 per cent of annual rainfall occurs in the months of June to September. However, 20-25 per cent of the rainfall occurs in October to March months. About 40-45 per cent of the rainfall is lost as surface runoff. Also, 25-225 tons/ha/yr soil losses occur on a small to large watershed in submontane Punjab. Some evidence showed that 55 to 90 per cent chance of occurrence of drought in the area. Thus, there is acute shortage of water for sowing of crops during post monsoon period due to prevalence of drought. Thus, rainwater excess can be harvested during summer monsoon months and stored in water reservoirs, ponds, and tanks etc. As each watershed is unique in its characteristics, thereby it becomes labour intensive, time consuming to install gauging station to monitor runoff and soil loss in a watershed. The information on accurate records of runoff and soil loss is essential for designing soil water conservation measures, dams, and water reservoirs etc. Thus, a simulation study assumes significant in this context. Keeping these points in view, it is imperative to better understand soil hydrology with respect to runoff and soil erosion in submontane Punjab. Keeping these points in view, a study was conducted to simulate rainfall change effects on soil erosion at Patiala-Ki-Rao watersheds, district Roopnagar. In addition, another rationale was to compare historical and simulated sediment yields of two micro-watersheds in north-western tract of India under semiarid tropical environments

The Modified Universal Soil Loss Equation (MUSLE) and Revised Modified Universal Soil Loss Equation (RMUSLE) were used to simulate event wise sediment yield for total 42 rainstorms for the historical six years as 1983, 1984, 1986, 1987, 1991 and 1994 for Patiala-Ki-Rao watershed(s).

For micro-watershed I, the simulated and historical event wise soil losses (min to max) were in close agreement for both MUSLE and RMUSLE. The per cent error for simulated sediment yield for MUSLE (min to max) varied from -4.6 per cent to -26.9 per cent. However, per cent error for simulated sediment yields for RMUSLE (min to max) varied from -3.5 per cent to -27.6 per cent. The results revealed that simulated event-based sediment yields for RMUSLE (min to max) were in better agreement with historical values than that with simulated sediment yield for MUSLE (min to max). The coefficient of determination (R^2) between historical and simulated soil loss observed was 0.97 for MUSLE and 0.99 for RMUSLE. For micro-watershed II, the simulated and historical soil losses (min to max) were in close agreement for both MUSLE and RMUSLE. The per cent error for simulated sediment yield for MUSLE (min to max) varied from +5.4 per cent to -28.3 per cent. However, per cent error for simulated sediment yield for RMUSLE (min to max) varied from +7.1 per cent to -24.9 per cent. The simulated event-based sediment yields for RMUSLE (min to max) were in better agreement with historical values over simulated sediment yield for MUSLE (min to max). The coefficient of determination (R^2) between historical and simulated soil loss was 0.87 for MUSLE and 0.96 for RMUSLE.

The event wise soil loss for RMUSLE was better correlated between simulated and historical values than that with MUSLE, wherein the rainfall-runoff factor better estimated the sediment yield.

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