Article

Simulation Accuracy of EROSION-3D Model for Estimation of Runoff and Sediment Yield from Micro-Watersheds

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Abstract: The present study was conducted to test the efficiency and applicability of the EROSION-3D (Jürgen Schmidt, Berlin, Germany) model in the lower *Shivaliks* of Northwest India. Two similar micro-watersheds in terms of soil characteristics and land use were selected for calibration and validation of the model. The model was calibrated using the data from seven rainstorms of micro-watershed A and validated using data from 11 rainstorms in micro-watershed B. After calibration, the overall statistical parameters, namely RMSE (0.44 mm), percent error (4.92), correlation coefficient (0.94) and model efficiency (88%), clearly indicate that the model simulated runoff quite well in conditions prevalent in *Shivaliks*. For sediment yield, the overall statistical parameters, namely RMSE (0.365 Mg ha⁻¹), percent error (12.71), correlation coefficient (0.97) and model efficiency (88.32%), clearly indicate that the model simulated sediment yield also quite well. During the validation process, for runoff, RMSE (1.72 mm), percent error (19.19), correlation coefficient (0.94), and model efficiency (81.25%) and, for sediment yield, RMSE (0.19 Mg ha⁻¹), percent error (17.16), correlation coefficient (0.97), and model efficiency (74.48%) clearly demonstrate the reasonable accuracy of the EROSION-3D model to predict runoff and soil loss from micro-watersheds located in *Shivaliks* of Northwest India. Therefore, the EROSION-3D may be used as decision support system for soil conservation management decisions in the lower *Shivaliks* of India.

Keywords: EROSION-3D; runoff; sediment yield; Shivaliks; watersheds

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1. Introduction

Land degradation is the decline in the productivity potential of the soil [1]. Land degradation results in soil compaction, salinization, acidification and soil loss from wind and water erosion [2]. The land degradation should be perceived in the context of policy, socio-economic conditions and the environment, as it has implications on many policy issues, including climate change, food production and security, flood and drought management, etc. [3,4]. Land degradation has long been recognized as having a negative influence on agricultural and food production. Soil erosion is identified as the chief cause of land degradation [5]. Soil erosion results in decreased soil quality thereby decreasing the crop yields [6]. Soil erosion also results in the formation of rills and gullies which render the arable lands unfit for the cultivation. Soil erosion generates huge quantity of sediments which result in siltation of downstream water reservoirs including lakes and

dams [7]. The siltation of water reservoirs results in reduction in the storage capacity which affects the supply of water for different water demands [8]. More than half of all fertile, food-producing soils globally are now classified as degraded [9]. It has been estimated that about 1964.4 million hectares (M ha) of the global soils are affected by anthropogenic degradation out of which, 1903 M ha is affected by water erosion [10,11]. In India, about 36.7% (120.7 M ha) of the total land suffers from various forms of degradation with water erosion being its chief contributor (68.4%) [12]. The gross erosion is estimated as 5.11 Gigatons per year ($1559 \text{ Mg km}^{-2} \text{ year}^{-1}$) out of which 34.1%, 22.9% and 43.0% are discharged in reservoirs, oceans and rivers, respectively [13]. About 74 million tons of nutrients are lost annually due to erosion resulting in the monetary loss of about one billion dollars [10,14]. Although soil erosion can be observed in all major types of ecosystems, in India, its most disastrous effects are being witnessed by the fragile ecosystems such as the *Shivalik* foothills. The *Shivalik* foothills are the lowermost part of the Himalayan Mountain chain covering an area of 2.14 M ha in five states of India. In Punjab, *Shivalik* foothills cover an area of about 0.39 M ha which is locally known as the *Kandi* area. The *Shivalik* foothills are considered as the most fragile and vulnerable ecosystem in the Himalayan region and are facing the most dangerous effects of climate change [15]. These foothills are formed of erodible and weakly cemented sandstones with inter-bedded clay and silt strata. During the monsoon season, heavy rainstorms cause significant erosion and peak flash flows [16]. This region is characterized by erratic behavior of rainfall, undulating topography, steep slopes and lack of vegetation which results in high soil erosion [17,18]. The average annual soil loss in the *Shivalik* foothills is $16 \text{ Mg ha}^{-1} \text{ year}^{-1}$ and, in some watersheds, it is more than $80 \text{ Mg ha}^{-1} \text{ year}^{-1}$ [19]. Sheet and rill erosion is the most common type of erosion prevalent in the agricultural fields while gully erosion is predominantly found at higher elevations [15]. The agriculture in this region is mostly rainfed, as the crop security depends entirely on the monsoon rainfall.

Therefore, there is need to understand the process of runoff and soil erosion so as to estimate its extent in the *Shivalik* region for planning and implementation of the conservation strategies to stop the ecological degradation. The data of runoff and soil erosion are pre-requisite to plan and implement the various activities of watershed management. Moreover, in rainfed areas, as prevailing in the *Shivalik* regions, the prediction and assessment of runoff and soil erosion from a watershed are important for evaluation of watershed management practices and development of water resources. However, manual monitoring of hydrological data in all the watersheds is difficult due to complexities in data requirement, inaccessibility of the watersheds, high expenditure and extensive requirement of trained personnel and automated apparatuses [18]. The hydrological data monitoring stations are in decline due to number of constraints including monetary constraints and lack of technical staff [20,21].

Runoff and soil erosion are highly complex phenomena as the processes are affected by many factors, including climate, soil type, topography and land use which makes its simulation extremely difficult [22]. The application of data-driven modelling methods to deliver improved runoff and sediment yield estimates has received considerable attention in recent years [23,24]. Hydrological models have been used to study and understand the complex runoff and soil erosion processes. The application of hydrological models has made it easier to estimate the runoff and soil erosion from the watersheds. Among the various types of available hydrological models, the distributed watershed models are very helpful in understanding the process behind runoff and soil erosion. These models have proved to be very useful for simulation of various processes related to the management of water, including water quality, sediment yield, groundwater flow etc., however, for their proper implementation, calibration and validation of these models is extremely important [25]. These models have been used worldwide for simulating runoff and soil erosion processes and some of the models have also been tested in the *Shivaliks* of India [26]. Most of the hydrological models are site-specific in nature and, hence, their efficiency and applicability need to be tested before using them as the decision support systems for

simulation of best management practices. EROSION-3D is a physically-based distributed hydrological model which simulates runoff and soil erosion from the watersheds. As the EROSION-3D model is a raster-based model, it requires a grid-cell presentation of the watershed. EROSION-3D needs fewer input soil parameters as compared with other hydrological models such as Watershed Erosion Prediction Project (WEPP), European Soil Erosion Model (EUROSEM), etc. There are many advantages while using EROSION-3D. For instance, the modeling approach has unlimited transferability to other situations, single event modeling is permitted, simulations generated by the model contain a high spatial and temporal resolution, sediment particle transport and sedimentation can be simulated for sediment budget estimation, and a detailed parameter database is available for the input used by the model based on extended field results for various types of soils and land uses. Moreover, a limited number of parameters are used in this model and it is compatible with the GIS software [27]. This model has been tested at various locations [28–31] and predictions were reliable but it has not been tested in the conditions prevailing in the lower *Shivaliks* of India. Keeping this in view, the present study was undertaken to determine the simulation accuracy and applicability of the EROSION-3D model to estimate runoff and sediment yield from micro-watersheds in *Shivaliks* of Northwest India.

2. Materials and Methods

2.1. Study Areas

In this study, two micro-watersheds named as micro-watershed A (located at Regional Research Station, Ballawal Saunkhri) and micro-watershed B (located at Harwan village, Garhshankar, Hoshiarpur) were selected in the lower *Shivaliks* of Punjab, India (Figure 1). The average annual rainfall observed at micro-watershed A and micro-watershed B was 1051 mm and 1081 mm, respectively. However, more than 85% of the rainfall is observed in three months from July to September during the monsoon period [32]. The characteristics of the micro-watersheds are given in Table 1.

2.2. Hydrological Data

2.2.1. Rainfall

Rainfall data during the study period (2017 and 2018) were measured using the recording type rain gauges installed at both micro-watersheds. The rainfall intensity was calculated for each 7 min of the rainstorms from the cumulative rainfall vs. time graph.

2.2.2. Runoff

The study watersheds were gauged for measurement of surface runoff. An H flume and rectangular weir were installed at the outlet of micro-watershed A and micro-watershed B, respectively. The automatic water level recorders were installed over the gauging stations which continuously measured the head of water flowing over the structures. The head of water was then converted into the daily discharge ($\text{m}^3 \text{s}^{-1}$) which was further converted into runoff depth (mm) using the watershed area and runoff duration.

2.2.3. Sediment Yield

Sediment yield was measured by taking periodic runoff samples in sediment sampling bottles of one liter capacity during rainstorms. Usually, 4–5 runoff samples were collected during an event depending on the duration of the storm. The runoff samples were collected in such a way that these samples represented the rising limb, the peak segment and the recession limb of the hydrograph. The collected runoff samples were oven-dried at 105 °C for 24 h and the dry weight of sediments was noted down. The amount of sediments collected in a sample was multiplied with the volume of runoff from that storm to calculate the total soil loss during a rainfall event.

Figure 1. Location map of micro-watersheds A and B.

Table 1. Basic characteristics of selected micro-watersheds.

Sr. No.	Description	Micro-Watershed A	Micro-Watershed B
1.	Latitude	30.40° to 32.30° N	31.36° to 31.38° N
2.	Longitude	75.30° to 75.48° E	76.48° to 76.49° E
3.	Elevation (m)	355	497
4.	Slope%	6.98	1.75
5.	Catchment area (ha)	1.86	1.52

2.3. Erosion-3D Model

The EROSION-3D model is a physically-based hydrological model mainly developed for simulating runoff and soil erosion processes on arable lands. The EROSION-3D is a raster-based model and hence represents the watershed in the form of grids/cells. The model mainly consists of two sub-models, viz. infiltration and erosion sub-models. The erosion sub-model represents erosion process in the form of detachment, transport and deposition of soil particles. The erosion sub-model calculates erosion using the momentum flux approach. The infiltration sub-model determines the infiltration rate based on modified

the Green and Ampt equation [33]. The readers are referred to [27,34,35] to get the detailed information about model processes.

2.4. Preparation of Model Input Files

2.4.1. Climate File

The rainfall data for each rainstorm during the study period were recorded using the self-recording rain gauges installed near both the study watersheds. The rainfall intensity of each rainstorm was calculated for every 7-min interval. Rainfall charts from recording type rain gauges were analyzed in order to calculate the rainfall intensity.

2.4.2. Soil File

Soil sampling was carried out from 0–15 cm and 15–30 cm depths using standard procedures [36]. The air-dried samples were ground and passed through a 2-mm sieve for analysis of various physical and chemical characteristics, viz. soil texture, bulk density, initial moisture and organic carbon. The data obtained after the analysis were used to prepare the soil input file for the model.

Various other parameters required by the model, such as skin factor, resistance to erosion and surface roughness were taken from a study conducted in October 2017 at Regional Research Station, Ballawal Saunkhri [37]. The skin factor, resistance to erosion and surface roughness are calculated using the following formulae [37]:

$$S_f = -10.1057 + 0.0048 \times \text{Bulk} + 3.2865 \times \text{Corg} + 0.1487 \times \text{Moist} - 0.2657 \times \text{Cl} - 0.0291 \times \text{Si} \quad (1)$$

$$E = -0.0074 + 5.2 \times 10^{-6} \times \text{Bulk} + 0.00632 \times \text{Corg} - 0.063 \times \text{Rough} - 3.52 \times 10^{-4} \times \text{Cl} - 8.2 \times 10^{-5} \times \text{Si} \quad (2)$$

$$n = V_q^{-5/3} \times q_0^{2/3} \times S^{1/2} \quad (3)$$

where, S_f is skin factor (-), E is resistance to erosion (N m^{-2}), n is surface roughness ($\text{s m}^{-1/3}$), Bulk is bulk density (kg m^{-3}), C_{org} is organic carbon (%), Moist is soil moisture (%), Rough is surface roughness ($\text{s m}^{-1/3}$), Cl is clay content (%), Si is silt content (%), S is slope inclination (m m^{-1}), q_0 is mean runoff flow rate from overflow phase $\text{m}^3(\text{s}^{-1}\text{m}^{-1})$ and V_q is runoff velocity (m s^{-1}).

2.4.3. Relief/Slope

The total station survey was carried out for both the watersheds to prepare the digital elevation models of 1×1 m resolution. The average elevation of the micro-watershed A was 355 above the mean sea level, whereas it was 497 m for micro-watershed B (Figure 2A,B).

2.4.4. Land Use

The land use was evaluated by surveying the study micro-watersheds during the monsoon season and the information was recorded field-wise. The information was digitized as a layer in GIS. The micro-watershed A was inhabited by maize, moong, mash and perennial grasses, whereas micro-watershed B was dominantly occupied by maize only (Figure 3A,B).

Figure 2. (A) Digital elevation model of micro-watershed A. (B) Digital elevation model of micro-watershed B.

Figure 3. (A) Land use map of micro-watershed A. (B) Land use of micro-watershed B.

2.5. Calibration and Validation of EROSION-3D Model

Calibration is the important step to increase the reliability of the model in that particular soil, climate, land use management practices in that watershed. The manual calibration based on a trial-and-error procedure was used in the study [38]. The model was calibrated for seven rainstorm events observed at micro-watershed A. Skin factor, resistance to erosion and surface roughness were used to calibrate the model against observed runoff and soil loss. Several simulations were performed adjusting the parameter values until the deviation between observed and simulated data was minimum. The model was validated with runoff and sediment yield data available from eleven rainstorms recorded at micro-watershed B. The model performance was statistically analyzed by calculating the percent error, root mean square error (RMSE), correlation coefficient (r) and Nash–Sutcliffe model efficiency [39].

3. Results

3.1. Rainfall Characteristics

During the monsoon season of 2018, 33 and 34 rainy days were observed at micro-watershed A and micro-watershed B, respectively. Out of these rainy days, only seven and eleven rainfall events resulted in runoff at micro-watershed A and micro-watershed B, respectively. The I_{30} (30 min maximum rainfall intensity) varied from 101.1 to 197.7 mm hr⁻¹, whereas the kinetic energy of the rainfall events varied from 1.06 to 18.19 MJ ha⁻¹ at micro-watershed A (Table 2). The I_{30} was in the range of 59.4 to 496.2 mm hr⁻¹, whereas the kinetic energy of the rainfall events was found in the range of 7.16 to 82.40 MJ ha⁻¹ at micro-watershed B (Table 3).

Table 2. Rainfall characteristics at micro-watershed A.

Event No.	Rainfall (mm)	Rainfall Duration (min)	$I_{7.5}$ (mm hr ⁻¹)	I_{15} (mm hr ⁻¹)	I_{30} (mm hr ⁻¹)	Total KE (MJ ha ⁻¹)
1	55.2	210	28.2	51.9	101.1	8.46
2	71.8	84	91.8	149.7	197.7	13.99
3	34	42	53.9	91.6	186.9	3.46
4	34.8	63	79.8	126.6	190.8	1.06
5	63.1	112	67.3	98.4	139.3	5.03
6	76.2	210	40.2	80.4	146.4	7.49
7	139.6	194	57.9	86.1	120.3	18.19

Table 3. Rainfall characteristics at micro-watershed B.

Event No.	Rainfall (mm)	Rainfall Duration (min)	$I_{7.5}$ (mm hr ⁻¹)	I_{15} (mm hr ⁻¹)	I_{30} (mm hr ⁻¹)	Total KE (MJ ha ⁻¹)
1	35.2	147	42.0	54.4	92.8	7.77
2	38.5	118	79.2	141.3	232.8	14.43
3	51.2	172	166.2	298.2	496.2	35.20
4	24.2	70	36.0	73.5	127.5	7.16
5	16.2	28	59.4	59.4	59.4	9.11
6	47.2	116	52.8	91.2	112.8	10.71
7	12.2	42	24.0	46.5	67.5	82.40
8	57.7	160	48.0	92.4	92.4	12.47
9	85.3	103	33.8	76.1	129.3	14.42
10	82.0	178	40.2	74.5	117.0	17.70
11	91.4	161	37.6	82.3	139.2	18.36

3.2. Model Calibration

The EROSION-3D model was calibrated to simulate runoff and sediment yield using the data from seven rainstorm events at micro-watershed A during the monsoon 2018. Initially, simulations were performed without calibration to assess the model's ability to simulate runoff and sediment yield. The values of skin factor, resistance to erosion and

surface roughness at which the best fit was obtained during the model calibration are given in Table 4. The calibrated values of skin factor, resistance to erosion and surface roughness were found close to those obtained in the rainfall simulation experiments conducted at RRS Ballawal Saunkhri [37].

Table 4. Calibrated values of skin factor, resistance to erosion and surface roughness.

Land Use	Skin Factor (-)	Resistance to Erosion (N m^{-2})	Surface Roughness (s m^{-1})
Maize	0.0057	0.0007	0.024
Moong and Mash	0.138	0.006	0.075

The storm-wise observed and simulated runoff and sediment yield along with the corresponding rainfall are given in Figures 4 and 5. It can be seen that the observed and simulated runoff and sediment yield are in close accordance with each other. Out of the total seven rainstorms at micro-watershed A, the simulated runoff was higher for three rainstorms as compared to observed values, whereas for four rainstorms, the simulated runoff was lower as compared to observed values. Similarly, model overestimated the sediment yield for three storms and underestimated for four storms. The scatter diagrams show close agreement between observed and simulated runoff and sediment yield as most of the points are close to the 1:1 line indicating reasonable accurate simulation by the model (Figures 6 and 7).

The total simulated runoff and sediment yield during the calibration period were 131.2 mm and 9.0 Mg ha^{-1} against the observed values of 143.6 mm and 7.93 Mg ha^{-1} , respectively. The deviation of the simulated runoff and sediment yield from the observed values was highest in high rainfall event of 22 September, in which the model slightly underpredicted the runoff but overpredicted the sediment yield. The model performance statistics during its calibration are given in Tables 5 and 6. The model simulated runoff and sediment yield with reasonable accuracy as is reflected from low values of percent error (4.92 and 12.71), RMSE (0.44 mm and 0.36 Mg ha^{-1}) and high values of correlation coefficient (0.94 and 0.97) and Nash–Sutcliffe model efficiency (88.0% and 87.3%).

Figure 4. Observed and simulated storm-wise runoff during model calibration.

Figure 5. Observed and simulated storm-wise sediment yield during model calibration.

Figure 6. Comparison between observed and simulated storm-wise runoff during model calibration.

Figure 7. Comparison between observed and simulated storm-wise sediment yield during model calibration.

Table 5. Test statistics for runoff simulation by the EROSION-3D model during the calibration period at micro-watershed A.

Statistical Parameters	Observed Runoff (mm)	Simulated Runoff (mm)
Total	143.57	131.21
Maximum	44.38	35.65
RMSE (mm)		0.44
Mean Percent error		4.92
Correlation Coefficient		0.94
Model efficiency (%)		88.0

Table 6. Test statistics for sediment yield simulation by the EROSION-3D model during the calibration period at micro-watershed A.

Statistical Parameters	Observed Sediment Yield (Mg ha ⁻¹)	Simulated Sediment Yield (Mg ha ⁻¹)
Total	7.93	9.0
Maximum	3.18	3.84
RMSE (Mg ha ⁻¹)		0.365
Percent Error		12.71
Correlation Coefficient		0.97
Model Efficiency (%)		88.32

3.3. Model Validation

After calibration, validation is an important step in which performance of the calibrated model is judged using a different dataset. In the present study, the model which was calibrated using data from micro-watershed A, was validated using 11 rainstorm data observed at micro-watershed B. The results of validation are given below:

The storm-wise observed and simulated runoff and sediment yield along with the corresponding rainfall during the model validation period are given in Figures 8 and 9. The observed and simulated values of runoff and sediment yield are in close agreement indicating good simulation by the model. The scatter plot diagrams show observed and simulated values are close to the 1:1 line (Figures 10 and 11).

Figure 8. Observed and simulated storm-wise runoff during model validation.

Figure 9. Observed and simulated storm-wise sediment yield during model validation.

Figure 10. Comparison between observed and simulated storm-wise runoff during model validation.

The total simulated runoff (91.85 mm) and sediment yield (12.35 Mg ha⁻¹) during the validation period were higher than the observed runoff (80.69 mm) and sediment yield (10.66 Mg ha⁻¹). The lower values of percent error (21.63 and 17.16) and RMSE (1.65 mm and 0.19 Mg ha⁻¹) and higher values of correlation coefficient (0.96 and 0.97) and Nash–Sutcliffe model efficiency (82.8% and 74.5%) indicate the reasonably accurate simulation of runoff and sediment yield by the EROSION-3D model (Tables 7 and 8).

Figure 11. Comparison between observed and simulated storm-wise sediment yield during model validation.

Table 7. Test statistics for runoff simulation by the EROSION-3D model during the validation period at micro-watershed B.

Statistical Parameters	Observed Runoff (mm)	Simulated Runoff (mm)
Total	80.69	91.85
Maximum	12.59	15.94
RMSE (mm)		1.65
Percent Error		21.63
Correlation Coefficient		0.96
Model efficiency (%)		82.77

Table 8. Test statistics for sediment yield simulation by the EROSION-3D model during the validation period at micro-watershed B.

Statistical Parameters	Observed Sediment Yield (Mg ha ⁻¹)	Simulated Sediment Yield (Mg ha ⁻¹)
Total	10.66	12.35
Maximum	1.72	1.96
RMSE (Mg ha ⁻¹)		0.19
Percent Error		17.16
Correlation Coefficient		0.97
Model Efficiency (%)		74.48

4. Discussion

It was noted that the model overestimated the higher values of soil erosion. It might be because of the fact that the model failed to take into account the contribution made by the erosion control practices while estimating the same. Furthermore, the efficiency of the model also decreased subsequently as the magnitude of soil loss increases. Nemetova et al. [40] also reported the same problem of overestimation of the soil erosion rate when the magnitude of the sediment yield was higher.

The soil erosion map (Figure 12) shows the spatial distribution of soil erosion in the study watershed. It can be seen that maximum soil erosion was recorded from that part of the watershed which was under maize cultivation. Maize being a widely spaced and thus erosion permitting crop caused a high amount of soil erosion from the watershed. Maize is

usually grown on ridges in the *Shivalik* foothills at the spacing of 60 cm. The inter-row space between the maize rows in sloping fields may act as channel through which runoff can flow easily resulting in higher soil erosion. The calibrated values of surface roughness and resistance to erosion for maize is relatively less than the corresponding values for moong and mash which shows that the soils under maize cultivation are more susceptible to soil erosion. At the commencement of the monsoon season, the area under moong and mash cultivation was found to be erosion prone. However, in the later stages, mash and moong proved to be beneficial in controlling soil erosion which may be attributed to the fact that the mash and moong quickly establish a good canopy cover which dissipates the rainfall impact thereby resulting in lower runoff and soil erosion [41]. Nemetova & Kohnova [42] also observed the maximum soil loss from scenario of fallow land. Gao et al. [43] also reported that the runoff and soil loss were more in maize cultivation as compared to the soyabean crop. Therefore, the agricultural practices and land cover conditions play an important role in describing the soil erosion process. Hence, these factors must be properly taken into account while studying the soil erosion process [44].

Figure 12. Soil erosion map by the EROSION-3D model.

The study also revealed that the presence of permanent grasses in the watershed as zone of deposition. Furthermore, the region where soil erosion control practices such as contour bunding or conservation tillage were practiced, seemed to be helpful in controlling soil erosion. Similar observations regarding the effect of land use on rate of soil erosion were made by Nemetova et al. [40]. As the area under perennial grasses proved to be helpful in controlling erosion rates and found to be a deposition zone, an increase in the area under its cultivation will be a good measure to check soil erosion. Similar recommendations were also made by Routschek et al. [33]. Dass et al. [45] and Singh et al. [46] also reported that perennial grasses when grown as vegetative barriers reduce the runoff and soil erosion and increase the crop productivity. The comparison between contribution of perennial grasses and agronomic measures for erosion control shows that the former proved to be much more effective in soil erosion control as compared to the latter. Although, a combination of both may be the best management practice to curb the threat of soil erosion. Schob et al. [29] tested different erosion control measures and recommended the combination of pasture and agronomic measures as the most appropriate method for effective erosion control. Yousuf et al. [47] simulated the impact of erosion control structures (sedimentation basins and check dams) and reported that runoff and sediment yield decreased by 72% and 90% due to the implementation of these structures. Yaekob et al. [48] also reported that soil and water conservation structures reduced the sediment yield by about 74%.

Although model predictions regarding runoff estimation were very much acceptable, yet, one important trend was observed in the runoff estimation. It was the model's inability to simulate runoff for high magnitude rainstorms precisely which may be due to the surface sealing phenomenon wherein soil particles clog the soil pores decreasing the infiltration rate. This process may not be well accounted by the model while simulating the runoff. In the EROSION-3D model, the surface sealing phenomenon is represented by the skin factor, hence this parameter needs to be calibrated more precisely. Another reason could be that during high-magnitude storms, the runoff may follow different pathways to the streams so that the watershed behaves differently. During the validation period, the model slightly overestimated the sediment yield values of high magnitude. It might be because of the model's inability to take into account the role of tillage practices while simulating the erosion rate. Keeping in view the complex nature and heterogeneity of the rainfall-runoff-erosion process, the performance of the EROSION-3D model has been satisfactory for simulation of runoff and sediment yield from watersheds located in the Shivalik foot-hills of Northwest India.

5. Conclusions

Quantification of runoff and sediment yield is pre-requisite for implementation of conservation measures at the watershed scale. The present study was undertaken to evaluate the performance of the EROSION-3D model to simulate runoff and sediment yield from micro-watersheds located in the *Shivalik* region of Northwest India. The model was calibrated by adjusting the three soil-related parameters, skin factor, resistance to erosion and surface roughness. The results of the study indicate that the simulation accuracy of the EROSION-3D model is reasonably good for simulation of runoff and sediment yield. However, the model efficiency for runoff was better than sediment yield which could be due to the more complex and heterogeneous nature of the erosion process than the runoff generation process. The wide-row crops such as maize resulted in higher soil erosion as compared to the crops having less row-to-row spacing and high foliage such as moong and mash. The inclusion of perennial grasses in a watershed proved beneficial, however, sole perennial grasses may not be economically suitable, so a combination of perennial grasses with cash crops may be adopted better. Therefore, the EROSION-3D may act as base for selection of suitable crops and management practices for the policy makers. Hence, the EROSION-3D model is a very effective tool for quantifying runoff and sediment yield in the *Shivalik* region of India and may serve as a decision support tool for soil and water management decisions owing of its low input data requirements and reasonable accuracy.

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