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RUNOFF QUANTIFICATION FROM SMALL NON-ARABLE RANGELAND WATERSHED IN *SHIVALIK* FOOT-HILLS USING WEPP MODEL

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ABSTRACT

Mathematical hydrologic models are useful tools for quantifying runoff to design and evaluate alternate land use, and best management practices, implementation of which can help in reducing the damaging effects of runoff on land productivity, quality and life of water bodies. Water Erosion Prediction Project (WEPP) model having the most mechanistic runoff flow component, is one of these models suitable for simulation and quantification of runoff from small watersheds. In this study, the WEPP watershed model has been applied on a small rangeland watershed having an area of 15.55 ha located in Shivalik foot-hills of Punjab. The watershed area was divided into 33 hillslopes and 14 channel segments. Climate file was generated by CLIGEN software using observed data on daily rainfall, maximum and minimum temperatures. For each hillslope and channel, soil, slope and land use management files were prepared. The sensitivity analysis of the model shows that it is highly sensitive to hydraulic conductivity of the soil. The model was calibrated and validated using the observed runoff data, each of four years (1994-1997 and 1998-2001) duration. The overall statistical model performance parameters for the validation period (1998-2001), namely percent error of 4.9%, RMSE of 0.56, correlation coefficient of 0.93 and model efficiency of 81%, indicate reasonably accurate simulation of runoff at the watershed scale. The performance of WEPP model further improved (correlation coefficient = 0.99, model efficiency = 97%) when simulation runs were conducted without two extreme events of rainfall greater than 100 mm.

Keywords: *Hydrologic models, WEPP model, Rangeland watershed, Runoff simulation, Runoff quantification.*

INTRODUCTION

In the state of Punjab, there is about 5.38 lakh hectare of land which falls in the *Shivalik* foot-hills and comprises of 53 small watersheds, is locally known as *Kandi* area. The land in the area is undulating and steeply sloping. Surface soils are low in organic matter, easily dispersible and highly erodible. The whole area is ecologically degraded. The forest cover varies from 1.5- 5.5% only. Rainfall constitutes the major source of water. Average annual rainfall in the area varies from 800 - 1250 mm. The rains are erratic and ill distributed in time and space. More than 80% of rains occur during monsoon months. Rains of high intensity and short duration are common. A large portion of monsoon rainfall (35-45%) goes as runoff in the torrents causing large scale erosion and flash floods in the downstream areas. A soil conservation policy is therefore needed urgently in the area, in which management decisions are based on physical principles and sound scientific concepts. For this, it is essential to quantify runoff, being a transporting medium for sediments, in a spatially distributed form to design and implement conservation efforts and to evaluate them at the watershed scale. In addition, since most of the area in *Shivalik* foot-hills is rain-fed, and ground water is too deep to exploit economically, prediction and assessment of runoff on watershed basis is important for water resources development (Bhardwaj and Kaushal 2009). A reasonable prediction/quantification of runoff not only provides useful information for management of water resources, but also reduces losses to life and property caused by extreme events. However, the hydrology of a watershed is complex, involving many natural processes and numerous hydrologic interrelationships. Comprehensive field studies to monitor watershed response in the form of runoff are limited. The considerable expense, collection difficulties, substantial land area requirements, field personnel and automated equipment requirements often make repeated runoff measurements unfeasible. Faced with this limitation, mathematical hydrologic models are powerful alternatives to quantify storm runoff to design and evaluate alternative land use and best management practices, implementation of which can help in reducing the damaging effects on land productivity and water bodies (Bhardwaj and Kaushal 2009).

There are many hydrologic models capable of simulating runoff at watershed scale. Stanford Watershed Model (Crawford and Linsley 1966), CREAMS (Knisel 1980), ANSWERS (Beasley *et al.* 1982), SWRRB (Arnold *et al.* 1990), AGNPS (Young *et al.* 1989), EPIC (Sharpley and Williams 1990) CASC2D (Ogden and Julien 2002), MIKE SHE (Refsgaard and storm 1995), WEPP (Flanagan and Nearing 1995) and SWAT (Arnold *et al.* 1998) are few a among these models and probably the most widely used hydrologic models. These physical process based models, often with an explicit attempt to describe runoff are better equipped to evaluate the impacts of management interventions and help to make management decisions aimed at preserving land productivity and environment quality (Yu and Rosewell 2001). Runoff components of these models use the SCS–CN method to predict runoff (Bingner 1990; Schroder 2000). Among these models only SWAT, AGNPS and ANSWERS are the distributed parameters physically based watershed scale models mostly used for low slope conditions (Arnold *et al.* 1998; Bingner *et al.* 1992; Schroder 2000). According to Borah and Bera (2003), mathematical bases of a watershed model play an important role in determining the problems, situations or conditions for which the model is most suitable, the accuracies and uncertainties expected, its full potential use and limitations. Most of these models are site specific and have been developed for the climatic conditions prevalent in Europe.

The comparison of these models showed that no single model worked well in every situation for simulating runoff at watershed scale (Bingner *et al.* 1989). Also they are not

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readily adaptable to different situations. Most of these models have been developed for simulating hydrologic processes in large watersheds. However, WEPP (Water Erosion Prediction Project) watershed model, which is an extension of WEPP hillslope model, is capable of simulating runoff in addition to other hydrologic processes from small watersheds (Nearing *et al.* 1989; Laflen *et al.* 1991). It has the most mechanistic runoff flow and sediment transport component and can simulate various best management practices including agricultural practices, ponds, terraces, culverts, vegetative filters and check dams (Kalin and Hantush 2003). The model was used successfully worldwide (Yu and Rosewell 2001; Huang *et al.* 1996; Amore *et al.* 2004; Pieri *et al.* 2007; Baigorria and Romero 2007; Shen *et al.* 2009; Shen *et al.* 2010) for estimating runoff from different land use and crop management practices. The WEPP model was compared with the ANSWERS (Bhuyan *et al.* 2002), EPIC (Bhuyan *et al.* 2002) and SWAT (Shen *et al.* 2010). The performance of the WEPP model was at par with the ANSWERS and better than the EPIC and SWAT in simulating different management scenario. The WEPP model provides several advantages over existing hydrologic models. It reflects the effects of soil surface conditions due to agriculture, range and forestry practices on storm runoff (Savabi *et al.*1995).

However, for Indian conditions only a few studies have been conducted for quantification of runoff using WEPP model (Pandey *et al.* 2008; Ramsankaran *et al.* 2009; Singh *et al.* 2009), wherein the model was calibrated and validated using the historical hydrologic data of a small agricultural watershed with medium slope, but none under the conditions those prevailing in *Shivalik* foot-hills. Hence, the performance of the WEPP model needs to be evaluated for simulating runoff under the conditions those prevailing in *Shivalik* foot-hills, for its future application in the area. So, the present study was undertaken to test the applicability of the WEPP model for quantification of runoff from small non-arable rangeland watershed in *Shivalik* foot-hills.

OVERVIEW OF WEPP MODEL

The Water Erosion Prediction Project (WEPP) watershed model (Flanagan and Nearing 1995) is an extension of the WEPP hillslope model (Laflen *et al.* 1991). The WEPP is a physically based distributed parameters model and is considered to possess the state-of-the-art knowledge of the erosion science, and has become an important analytical tool for runoff and soil loss estimation (Lane *et al.* 1997). The distributed input parameters for the model include rainfall amount and intensity, soil texture, plant growth parameters, residue decomposition parameters, effects of tillage implements on soil properties and residue amount, slope shape, steepness and orientation, and soil erodibility. The WEPP works in continuous as well as single-storm simulation mode. The hillslope version of the model had nine components: climate generation, winter processes, irrigation, hydrology, soil, plant growth, residue decomposition, hydraulics of overland flow, and erosion. Three components: channel hydrology and hydraulics, channel erosion, and impoundments were added in the watershed version. The detailed description about all these components can be found in the model documentation (Flanagan and Nearing 1995). Infiltration is computed using the Green-Ampt Mein-Larso equation. Overland flow is routed using either an analytical solution to the kinematic wave equations or regression equations derived from the kinematic approximation. Peak runoff rate at the channel or watershed outlet is calculated by two methods: (1) the method used in the CREAMS model (Knisel 1980); and (2) a modified rational equation used in the EPIC model (Sharpley and Williams 1990). The user has to select the method for the simulations. The model considers interrill and rill erosion process in hillslopes as well as in channels. The movement of suspended sediment in rill, interrill, and channel flow areas is calculated using steady state continuity equation at peak runoff rate. Watershed sediment yield is calculated considering soil detachment from hillslopes and channels, transportation, and deposition of sediment in hillslopes and channels. Sediment deposition and sediment discharge from impoundments is modeled using conservation of mass and overflow rate concepts.

DESCRIPTION OF STUDY WATERSHED

A small gauged watershed having an area of 15.55 ha at Patiala-Ki-Rao, Distt. Ropar (Punjab) was selected as the study watershed. It is located between 30˚.48’ North latitude and 76˚.51’ East longitude in *Shivalik* foot-hills of Punjab, as shown in Fig. 1.

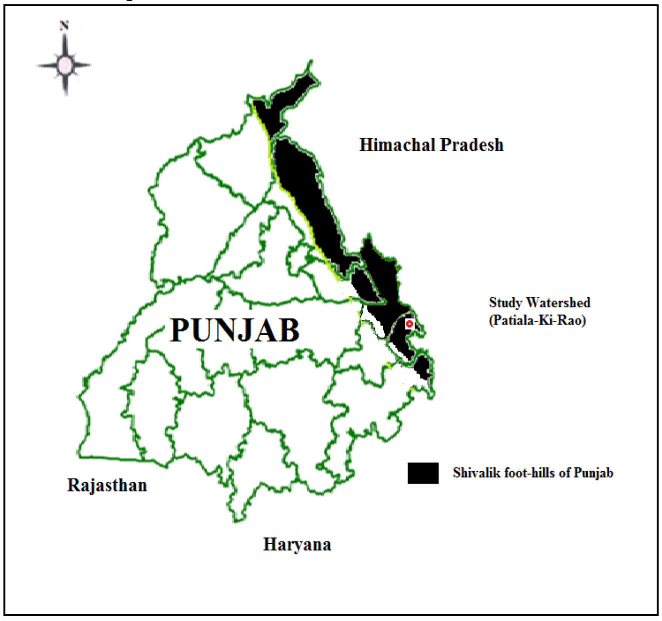

Fig. 1: Location map of the study watershed at Patiala-Ki-Rao in Punjab

Watershed Characteristics

Climate

Mean annual rainfall of the area is 910 mm, of which 80% is received from late June to mid-September. However, a few light showers due to westerly depressions are also received from December to March. In general, summers are hot and winters are cool. The maximum temperature (41-42˚C) is recorded in first fortnight of June, whereas the minimum temperature (5-6˚C) is recorded in the month of January. Relative humidity is around 73% during monsoon season.

The annual variation of rainfall and runoff producing rainfall is shown in Fig. 2. The mean monsoon rainfall from 1982 to 2002 was 925.7 mm with maximum of 1614.2 mm in 1988 and minimum of 387.8 mm in 1987. The runoff producing rainfall is 74.7 percent of mean annual rainfall.

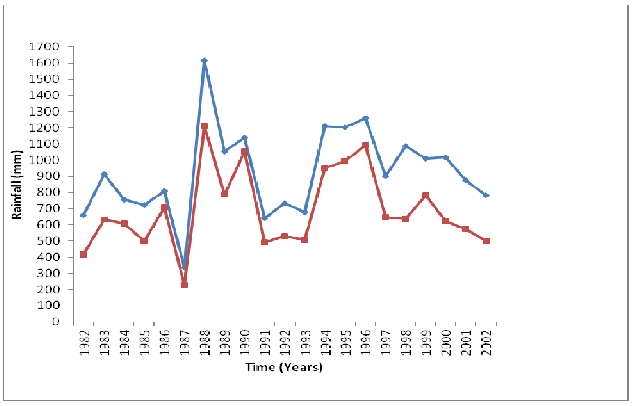

Fig. 2: Annual variation of rainfall and runoff producing rainfall at Patiala-Ki-Rao watershed

Topography

The topographic map of the watershed is shown in Fig. 3 and the geomorphic characteristics have been summarized in Table 1. The mean slope of the watershed is 36.9%. Watershed geomorphology refers to the physical characteristics of the watershed. Certain physical properties of watershed significantly affect the characteristics of runoff and as such are of great interest in hydrologic analyses. The geomorphic characteristics of the study watershed (Table 1) show the watershed is slightly elongated, drainage network is less developed, length of overland is moderate, but average watershed slope (36.9%) is quite high, resulting quick concentration of storm runoff at the outlet.

Table 1: Geomorphic characteristics of the study watershed

S.N.	Geomorphic Characteristics	Values
1	Watershed area	15.55 ha
2	Perimeter	1668 m
3	Length of watershed	566 m
4	Total length of stream	1046 m
5	Shape factor	2.06
6	Form factor	0.49
7	Compactness coefficient	1.19
8	Elongation ratio	0.79
9	Circularity ratio	0.70
10	Rotundity factor	1.62
11	Drainage density	67.27 m/ha
12	Average length of overland flow	74.33 m
13	Watershed relief	116.00 m

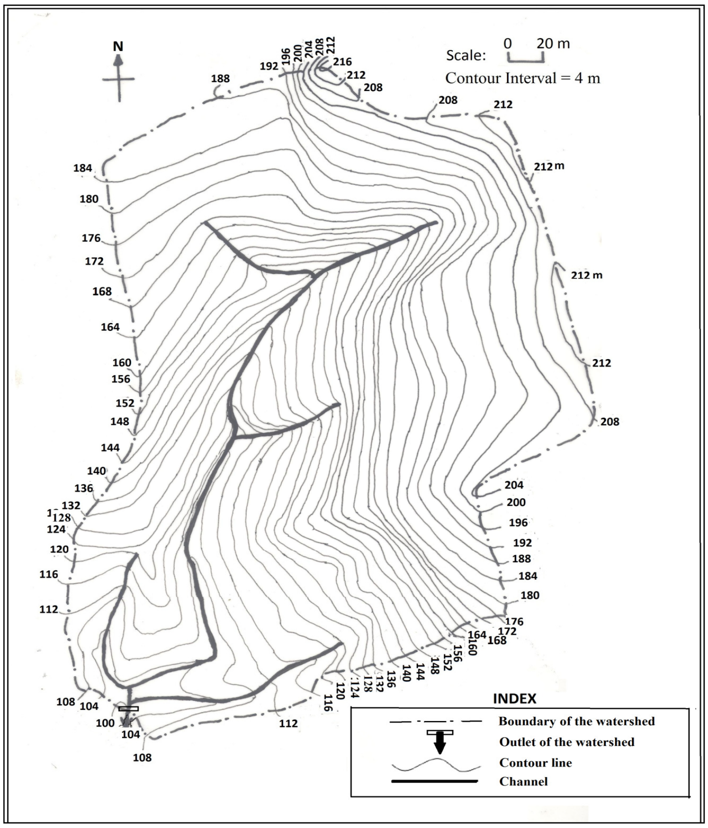

Fig. 3. Topographic map of the study watershed

Soil Characteristics

The major soils of the study watershed varies from loamy sand to sandy loam with low to medium moisture retention capacity. The soils, in general, are light textured and erodible. The hydraulic conductivity of these soils was found to vary from 25.90 to 29.10 mm/hr. Particle size distribution and the organic matter present in the top 30 cm soil layer is shown in Table 2.

Data Collection

The selected study watershed was being monitored by the PAU Zonal Research Station for Kandi Area, Ballowal Saunkhari under the world bank funded "Kandi Area Watershed Development Project". In addition to runoff gauging station at the outlet, a meteorological observatory had been established near to the watershed. Hence, data on daily rainfall, maximum and minimum temperature and storm wise runoff for the period 1994 to 2001 i.e. 8 years was collected from the station.

Table 2: Particle size distribution and percent organic matter in the top 30 cm soil layer

Sample No.	%Clay	%Silt	%Sand	%Coarse Sand	%Silt + VFS*	%Organic Matter
1	16.50	10.60	72.90	34.75	48.75	0.56
2	17.75	10.80	71.45	34.90	47.35	0.75
3	18.60	11.05	70.35	35.80	45.60	0.68
4	17.00	11.30	71.70	36.00	47.00	0.80
5	28.85	23.90	47.25	22.25	48.90	0.45
6	15.76	10.70	73.54	36.20	48.04	0.50
7	25.20	21.15	53.65	29.46	45.34	0.65
8	18.67	10.25	71.08	29.5	51.48	0.40
9	20.90	14.60	64.50	28.50	50.60	0.65

* VFS: Very fine sand

Land use and management practices

The selected watershed is a non-arable rangeland watershed. The land surface of the watershed is covered with grasses, brushes and scattered trees with an overall vegetative index of 0.60. The watershed is fenced and exposed to minimum grazing. Some temporary loose boulder check dams have been installed/constructed on the drainage line of the watershed to reduce the channel gradient and conserve soil and water.

METHODOLOGY

Runoff gauging station

The runoff is observed at the Runoff Gauging Station (RGS) established at the outlet of the watershed. RGS consists of a broad crested rectangular weir of size 3.56 meter having a discharge capacity of 3.0 cumec as shown in Fig.4. An Automatic water stage recorder installed upstream of the weir over the stilling well continuously records the stage hydrograph.

Fig. 4: Runoff gauging station at the outlet of the watershed.

Preparation of Input Files for WEPP Watershed Model Application

Preparation of input files forms the base of any hydrologic model. Number of input files required for WEPP model depends on the application for which it is being applied. However, the major input files for WEPP watershed model application for simulating runoff are climate, soil, slope, cropping/management and channel files. Input file builders are provided in the model for all input data files except the climate input file where a program called CLIGEN is provided in the model which can be used to generate data series of any length.

First step in the preparation of data input files for the application of WEPP is to divide the study area into a number of hillslopes and channels. Each hillslope is made up of one or more overland flow elements (OFE). OFE is an area of uniform cropping, management, and soil characteristics. The current version of WEPP allows simulation of upto 10 OFE on individual hillslope. The input files are prepared for each hillslope. Soil, slope and management parameters for each OFE on the hillslope profile are provided in the input files. The model run done for individual hillslopes, and runoff is calculated at the foot of the hillslope, which is then routed through channels and the quantities are calculated at the outlet of the watershed.

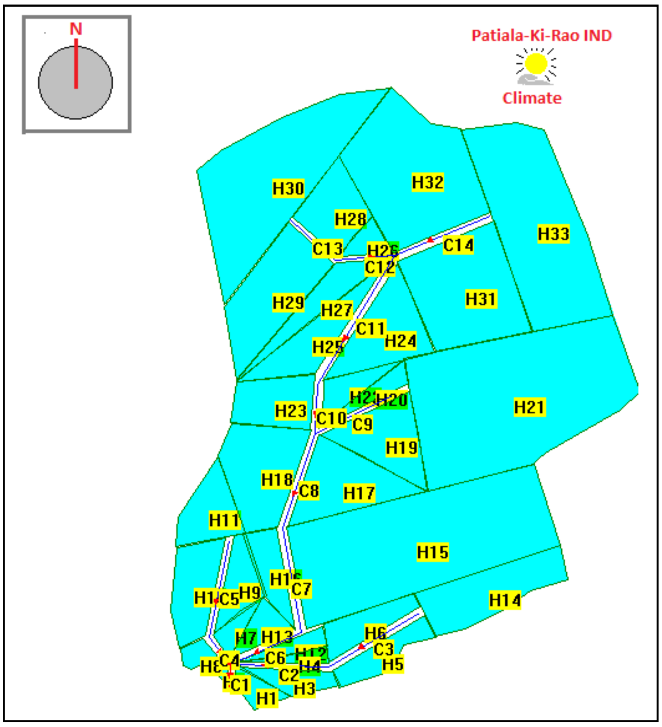

Fig. 5: Map of the study watershed showing all the hillslopes and channels.

For the application of WEPP model, the watershed has been subdivided into hillslopes, each of which are having one combination of soil, slope and land cover characteristics. A total of 33 such hillslopes (H1-H33) and 14 channel segments (C1-C14) were identified and each of these slope have been divided into one OFE, as shown in Fig. 5. Climate, slope, soil and management data input files were created for each of these hillslopes.

Climate input file

In climatic input file, it is possible to provide either single storm event or a continuous rainfall series. Actual data can be supplied, or where only rainfall statistics are available, a program called CLIGEN, a stochastic weather generator that produces daily time series estimates of precipitation, temperature, dew point, wind, and solar radiation for a single geographic point, based on average monthly measurement for the period of climatic record, like means, standard deviations, and skewness can be used. Daily observed precipitation, maximum and minimum temperature for past eight years (from 1994 to 2001) were used in CLIGEN software to generate all the climatic data i.e. duration of precipitation, ratio of time to rainfall peak/rainfall duration, ratio of maximum rainfall intensity/average rainfall intensity, daily solar radiation, wind velocity, wind direction and dew point temperature.

Using CLIGEN program and average climatological parameters for the study area, climate file was generated for Indian conditions by adding a new international station, named as “Patiala-Ki-Rao”. Data on daily rainfall, maximum temperature, and minimum temperature as observed in the studied watershed was used. Two climatic files have been generated, each of 4 year duration, using CLIGEN, one for calibration and another for validation of the model.

Soil input file

Soil characteristics for each hillslope, including type of soil, hydraulic conductivity, soil albedo, intial saturation, number of soil layers, thickness, bulk density, sand, clay and organic matter percentage, etc. have been provided in soil input file. Information on soil properties to a maximum depth of 1.8 meters (upto 8 different soil layers) can be used as input to the model through soil input file.

Slope input file

The distance - elevation data was generated segment-wise for each hillslope from the topographic map of the watershed. The slope of each hillslope segment was calculated using the following formula:

$$\text{Percent slope} \quad S = \frac{E_2 - E_1}{L} * 100 \qquad (1)$$

Where E_1 = elevation of lower point (m) , E_2 = elevation of higher point (m) and L = segment length (m).

The slope input file was prepared. Slope profile is plotted between distance and elevation. In the model, the slope file builder has the added advantage of allowing the user to graphically preview the slope profile.

Land use and management practices input file

The land management input file contains all the information needed by the WEPP model related to plant parameters (rangeland plant communities and cropland annual and perennial crops), tillage sequences and tillage implement parameters, plant and residue management, initial conditions, contouring, subsurface drainage, and crop rotations. The management file builder contains a large number of built in cropping pattern and management practices, which can be easily brought into our data file to suit the prevailing conditions of *Shivalik* foot-hills on each overland flow elements within a hillslope.

Channel input file

Channel properties such as width and depth of channel, hydraulic properties, channel bank management details, soil characteristics, etc. has to be given as input data in channel input file. Channel soil, channel slope and management files were prepared for each channel segment. Procedure for preparation of channel input files is exactly the same as that for hillslope.

Model Sensitivity Analysis

Sensitivity analysis help to identify those parameters which affect the model response to a great extent. Hantush and Kalin (2005) described the sensitivity analysis as measure of how a relative perturbation of the parameter is propogated into the relative perturbation of the prediction. Sensitivity analysis provides a quantifiable response of a model output over a range of input parameters. The hydrological models are most sensitive to weather and soil parameters (Nearing *et al.* 1990; Baffaut *et al.* 1997). When the weather parameters are generally recorded by precisely calibrated automatic weather station, there is no chance of manual error in the measurement. Therefore, sensitivity analysis of weather parameters are omitted. Thus, in this study, sensitivity analysis of the model was carried out to assess the variations in the model output with change in soil parameters only. The model's sensitivity to an input parameter was determined by varying parameter, while keeping other parameters constant, and comparing the corresponding predicted runoff. The soil input parameters considered for sensitivity analysis were effective hydraulic conductivity, slope and land-use and management. The values of these parameters varied by ±50% of the actual observed values during the analysis. To quantify the impact of change in the values of input parameters on the outputs, the following relative sensitivity equation (McCuen and Snyder, 1983) was used:

$$S_r = \frac{(P_2 - P_1)/(P_{12})}{(I_2 - I_1)/(I_{12})} \quad (2)$$

Where, I_1 and I_2 are the smallest and largest values of the input used, I_{12} is the average of I_1 and I_2 ; P_1, P_2 and P_{12} are the corresponding values for the output.

WEPP Model Performance Evaluation – Calibration and Validation

Precise calibration of the WEPP model is essential in the study conditions for accurate simulation results (Pieri et al. 2007). Split sample calibration approach was adopted for model's performance evaluation. Eight years data set pertaining to 1994 to 2001 was split into two parts. The data from 1994 to 1997 were used for model calibration and data from 1998 to 2001 for model validation. The manual calibration based on trial-and-error procedure (Sorooshian and Gupta 1995) was used in the study. Previous studies on the WEPP model (Nearing *et al.* 1990; Bhuyan *et al.* 2002; Pandey *et al.* 2008; Singh *et al.* 2011) indicated that the model is very sensitive to soil input parameters in simulation of runoff. Hence, soil parameters such as: effective hydraulic conductivity, slope, and land-use/management were considered for calibration in the present study. The values of parameters were chosen within the prescribed range. Several simulation were performed adjusting the parameters values until the discrepancies between observed data and model prediction were minimum.

After calibration proper validation is equally essential for model testing before it could be used for varying conditions. During validation, the performance of the calibrated model was judged without any change in the input files except the climate file. The model was validated for daily runoff using data from 1998 to 2001.

Performance evaluation parameters

Statistical analysis provides facts in a precise and definite form using numerical figures. American Society of Civil Engineering (ASCE) Task Committee on criteria for evaluation of watershed hydrologic models (1993) recommended that both visual and statistical comparison between model-computed and measured quantities be made whenever data are presented. In this study, the observed and predicted values of runoff on daily basis were compared by calculating statistical parameters namely: mean (Kirnak and Gowda 2001), standard deviation (Kirnak and Gowda 2001), percent error (Martinec and Rango 1989), coefficient of correlation/coefficient of determination (Bansal *et al.* 1991), root mean square error (Thomann 1982), and Nash-Sutcliffe model efficiency (Nash and Sutcliffe 1970), for calibration and validation of the model using 4 years data, respectively.

RESULTS AND DISCUSSION

Sensitivity Analysis

The WEPP model required large quantum of data as input for simulation. Accuracy in simulation depends upon quality of data. The user should know the parameter, which should be calibrated precisely to improve the performance of the model. Thus, it is pertinent to do sensitivity analysis to know about the parameters, which affect the output of the model to a larger extent, with slight variation in their values. Sensitivity analysis not only help to identify the influence parameters but also quantify their influence on outputs. Moreover, for the purpose of model application, sensitivity analysis also determines the level of accuracy or precaution needed in determination of these parameters. For examples, if modeling is performed for water resources development, hydraulic conductivity is to be determined more precisely and while considering non-points source of pollution, erodibility of the soil is to be determined more precisely.

In the present study, model sensitivity to hydraulic conductivity of soil (K_e), watershed slope (S), land use and management was studied. Several model runs were made using climate file of calibration period by varying these parameters one at a time and keeping the others fixed at the actual values. Variations of ±50 were considered in the values of the tested parameters.

The results of sensitivity analysis revealed that among the parameters considered, the change in effective hydraulic conductivity mainly affected the predicted runoff with a sensitivity ratio of -0.371. Rainfall infiltration increases with the increase in K_e and decreases with decrease in K_e. Hence, runoff volume decreases when K_e is increased, and increases when K_e is decreased. However, change in runoff volume ranges between 17-18.5 percent with ±50 variation in the values of K_e (Table 3). This shows that WEPP model is highly sensitive to effective hydraulic conductivity.

Table 3: Model sensitivity to different input parameters

Parameter	Measured values	Range of test value		Change in runoff (%)	Sensitivity ratio (S_r)
		-50%	50%		
Hydraulic conductivity (mm/hr)	26.2	13.1	39.3	17-18.5	-0.371
Slope (%)	36.9	18.45	55.35	6.5-7.1	0.182

The table 3 also shows the sensitivity of WEPP model to ±50 percent variation in the slope of the watershed. It is observed that the change in the output of the model i.e. runoff volume ranges between 6.5 to 7.1 percent. This change in predicted runoff is significant with a sensitivity ratio of 0.182. In this study, as the study watershed is a rangeland watershed, three management scenarios: low grazing, medium grazing and higher grazing were tested for sensitivity. The effect on the total runoff volume was found to be insignificant on the output of the model with respect to other parameters. Effective hydraulic conductivity is more dominant in runoff generation process as compared to other parameters, which is evident from the values of sensitivity ratio in runoff simulation (Table 3). The results obtained are in agreement with the reported results of previous studies (Nearing *et al.* 1990; Baffaut *et al.* 1997; Bhuyan *et al.* 2002; Brunner *et al.* 2004; Pandey *et al.* 2008; Singh *et al.* 2011). Therefore, it can be inferred that more precise estimation of hydraulic conductivity is essential for accurate prediction of runoff and hence these parameters were calibrated/adjusted during simulation of runoff from the watershed by using WEPP model.

Calibration of the Model

WEPP model has been calibrated using 4 years of rainfall and runoff data (1994 to 1997) with 81 rainy days. Initial simulations using WEPP model were performed without calibration to assess the model's ability to predict daily runoff storms. The objective of the model calibration was to minimize prediction error for runoff events. Calibration parameters namely hydraulic conductivity, slope and management practices of watershed were selected based on the sensitivity analysis carried out and the previously cited literature. The values of the model parameters were adjusted by trial and error basis. The performances/reliability of the model was evaluated statistically by comparing observed and simulated values of runoff. The calibrated value of hydraulic conductivity which gave statistically the best results was 23.25 mm/hr. The daily observed and predicted values of runoff are plotted as hydrographs for the calibration period in

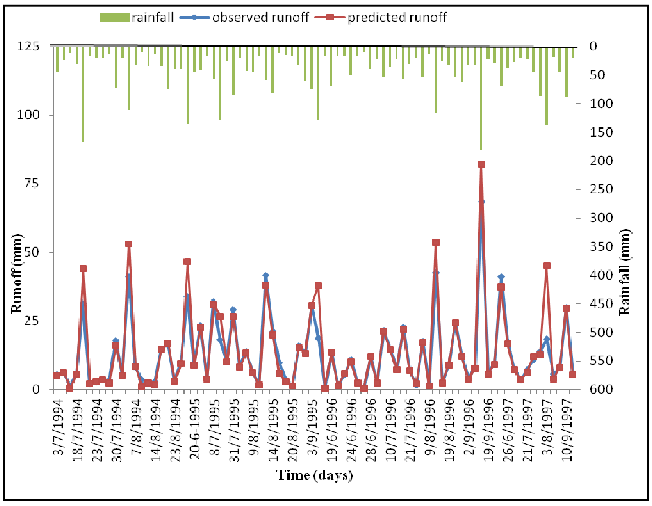

Fig. 6: Observed and predicted daily runoff hydrographs for model calibration period (1994-1997)

Fig. 6, which shows that the simulated values of runoff respond well to the rainfall values. However, for the higher values of rainfall, the values of runoff are over-predicted by the model.

Scatter plot of the daily observed and predicted runoff (Fig. 7) show that the majority of data points are evenly distributed about the 1:1 slope line. It is evident from the figure that a few rainfall-runoff events show a large deviation from 1:1 slope line. These events are extreme runoff events from rainfall storms greater than 100 mm. There were eight such extreme events during the calibration period. However, high value of R^2 (0.91) indicate that both the observed and predicted values of runoff are closely related to each other. The average percent error during the calibration period is 7.68. There is larger deviation between observed and predicted runoff values in case of extreme rainfall events. The percentage error in predicted runoff for these extreme cases ranges from 20.12 to 144.93%. This clearly indicated that for extreme cases of rainfall the model prediction is not that accurate.

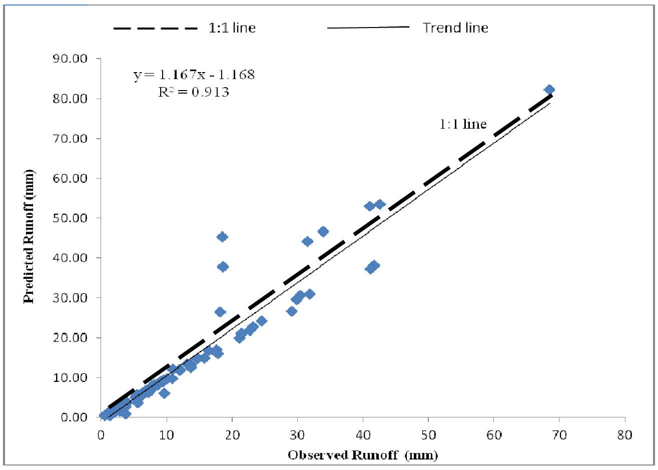

Fig. 7: Comparison between observed and predicted daily runoff for model calibration.

The summary statistics of the observed and predicted daily runoff for calibration period are quite close to each other as shown in table 4. Also, year-wise statistical parameters for runoff simulation are given in table 5. The percent error in simulation was higher during the years 1994 and 1997. This may be because of more number of extreme rainfall events during these years. However, the overall value of RMSE of 0.56 mm, correlation coefficient of 0.96, percent error of 7.68 and model efficiency (E_{NS}) of 84% for calibration period indicate reasonably accurate simulation of surface runoff by the model.

Table 4: Summary statistics of observed and predicted daily runoff for model calibration period (1994-1997)

Statistical parameter	Runoff(mm)	
	Observed	Predicted
No. of storms	81	81
Mean runoff	12.91	13.90
Standard deviation	12.50	15.26
Maximum runoff	68.5	82.28
Runoff coefficient	0.28	0.30

Table 5: Statistical parameters for runoff simulation for model calibration

Year	RMSE (mm)	Correlation Coefficient	Percentage Error (%)	Model Efficiency (%)
1994	1.05	0.99	13.5	82
1995	1.09	0.91	3.66	80
1996	0.68	0.99	6.26	99
1997	2.1	0.82	10.07	48
Overall	0.56	0.96	7.68	84

The total amount of rainfall of 3693.30 mm in 81 storms during the calibration period produced 1032.50 mm measured runoff and predicted runoff was 1111.82 mm. For the whole calibration period, it is observed that around 28 percent of rainfall goes as a runoff in this watershed, whereas around 30 percent is the predicted runoff. This further shows that model is capable of simulating runoff quite well and is ready for further validation by field application.

Validation of the Model

After calibration proper validation of the model is equally essential for model testing before it could be applied for developing best management practices in the watershed. During validation, the performance of the calibrated model was judged without any change in the input files except the climate file. The data on rainfall-runoff collected for the study watershed at Patiala-Ki-Rao from the year 1998 to 2001 was used for the validation and quantification of runoff. There were 59 runoff storms during the period which were simulated. The summary statistics of these storms is given in table 4.4. The rainfall amount of these storms ranged from 13.7 mm to 177.1 mm, resulting in 0.74 mm to 59.7 mm runoff at the outlet of the watershed, respectively. The daily observed and predicted runoff hydrographs have been plotted along with corresponding rainfall amount for validation periods (1998-2001) in Fig. 8. It is observed from the Fig. 8 that the trend of the predicted values closely matches the trend of observed values of runoff. The predicted runoff values respond well to the rainfall input. However, for a few higher values of the rainfall, the values of predicted runoff are over-predicted by the model during the validation period.

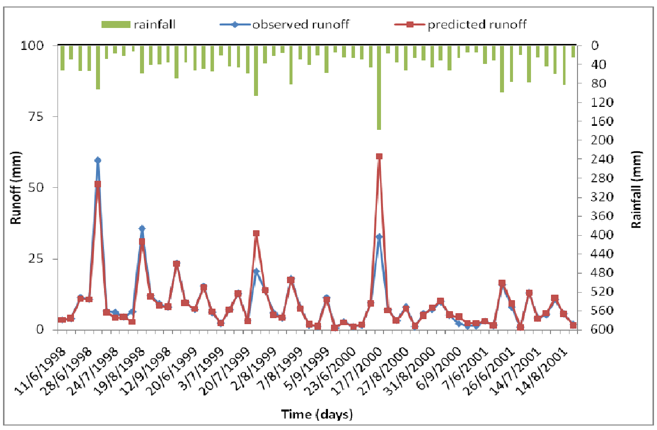

Fig. 8: Observed and predicted daily runoff hydrographs for model validation period (1998-2001).

Scatter plot for the daily measured as well as predicted runoff for validation (Fig. 9) show that the majority of data points are evenly distributed about the 1:1 slope line except a few events which have been over predicted by the model. The position of the trend line also verify the fact of over prediction of runoff.

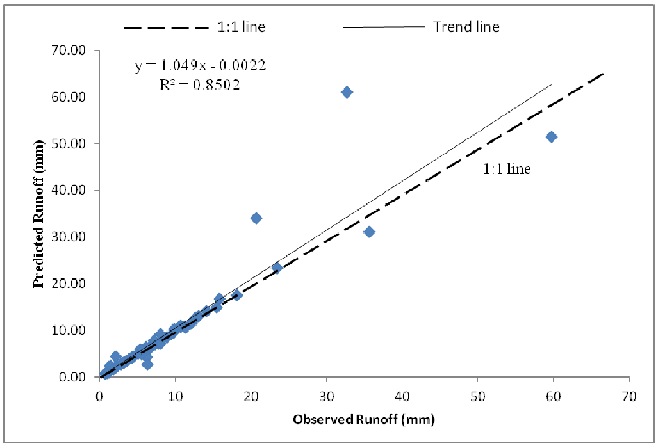

Fig. 9: Comparison between observed and predicted daily runoff for model validation.

The closeness of the observed and predicted values of mean runoff of 8.84 mm and 9.27 mm, the standard deviation of 9.78 mm and 11.12 mm, simulation of maximum runoff of 59.7 mm and 61.1 mm and runoff coefficient of 0.20 and 0.22, respectively (Table 6) shows that the model simulates runoff from the watershed with reasonable accuracy.

The year wise statistical parameters for runoff simulation are sown in Table 7. The value of RMSE ranges between 0.03 and 0.95. The correlation coefficient (0.93-0.99) is quite high for all the years of simulation. The model efficiency and the percent error in the prediction of runoff varies from 47 to 99% and 4.26 to 18.0%, respectively. The minimum value of model efficiency (47%) and the maximum percent error (18.0%), both correspond to the year 2000. This may be because of a few extreme rainstorms (rainfall > 100 mm) that have occurred during the year 2000 and which the model could not simulate with good accuracy. The percent error in the simulation of extreme rainstorms (177 mm and 106.4 mm) ranged between 64 to 87%, which is quite high. However, the overall statistical parameters namely the mean values of observed and predicted runoff of 8.84 mm and 9.27 mm, respectively (Table 6), the RMSE of 0.56 mm, correlation coefficient of 0.93, percent error of 4.88 and model efficiency (E_{NS}) of 81% (Table 7) for validation period indicate reasonably accurate simulation of surface runoff by the model.

Table 6: Observed and predicted daily runoff for model validation period (1998-2001)

Statistical parameter	Runoff (mm)	
	Measured	Predicted
No. of storms	59	59
Mean	8.84	9.27
Standard deviation	9.78	11.12
Maximum	59.7	61.06
Runoff coefficient	0.20	0.22

Table 7: Year wise statistical parameters in runoff simulation for model validation

Year	RMSE (mm)	Correlation Coefficient	Percentage Error (%)	Model Efficiency (%)
1998	0.68	0.98	9.6	97
1999	0.74	0.94	7.45	72
2000	0.95	0.98	18.0	47
2001	0.03	0.99	4.26	99
Overall	0.56	0.93	4.88	81

The statistical parameters (Table 7) in runoff simulation for validation period show that the model does not perform well in simulating the extreme events, when rainfall is greater than 100 mm (percent error = 64 to 87%). There were two extreme events during the validation period (1998-2001). To further study this fact, the model performance was evaluated by conducting simulation runs on the data without the extreme events i.e. considering only the rainstorms with rainfall less than 100 mm. The simulation results have been compared in Fig. 10 and the statistical parameters tabulated in Table 8. The plot between the observed and predicted values of runoff with R^2 = 0.99, evenly and close distribution of data points along 1:1 slope line and the location of the trend line show that WEPP model simulated runoff resulting from the rainstorms of magnitude less than 100 mm with high accuracy. The statistical parameters improved (Table 8) for simulation without extreme events. The error in the prediction of mean runoff reduced from 4.9% to 3.4%, the overall RMSE from 0.56 to 0.19, percent error reduced from 4.88% to 3.5%, model efficiency improved from 81% to 97%. Also, error in prediction of runoff coefficient reduced from 10% to 3%. This shows that the performance of the WEPP model has improved significantly when simulation runs were conducted without the extreme rainfall events and model's inability to simulate extreme events with good accuracy. Past few studies (*Pandey et al.* 2008; Raclot and Albergel 2006; Croke and Nethery 2006; Nearing 1998) also report large deviation in simulation of runoff from extreme rainfall events. This may be due to the limitation in representing the random components of the measured data in the model. Overall, the WEPP watershed model has been found to be quite suitable for simulation of runoff in *Shivalik* foot-hills.

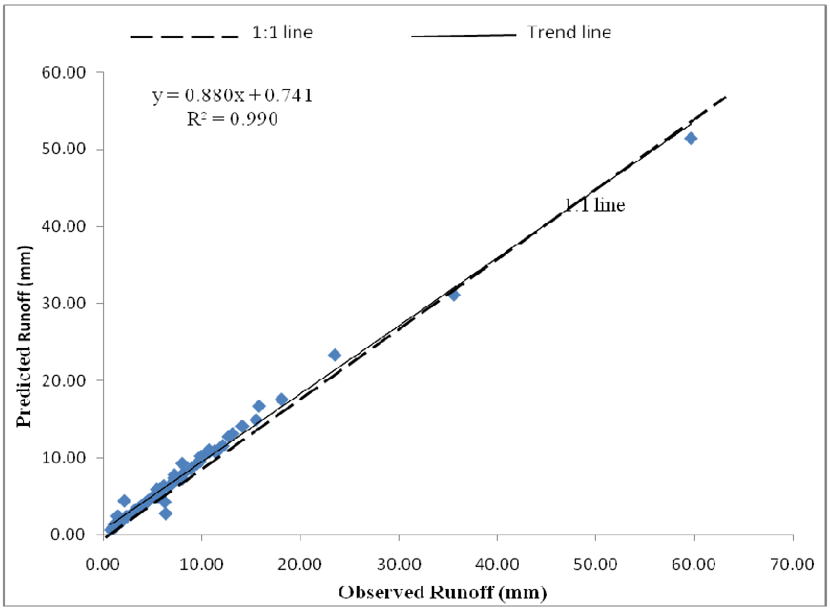

Fig. 10: Comparison between observed and predicted daily runoff without extreme rainfall events for model validation.

Table 8: Statistics of observed and predicted daily runoff without extreme rainfall events (Rainfall > 100 mm) for model validation period (1998-2001).

Statistical parameter	Runoff (mm)	
	Observed	Predicted
No. of storms	57	57
Mean	8.21	7.93
Standard deviation	9.27	8.21
Maximum	59.70	51.44
Runoff coefficient	0.200	0.195
RMSE (mm)	0.19	
Correlation coefficient	0.99	
Model efficiency (%)	97	
Percentage error (%)	3.5	

Annual quantification of runoff using WEPP model has been given in Table 9. During the validation period, annual rainfall varied from 575.10 mm in the year 2001 to 772.30 mm in the year 1999. The observed and predicted runoff ranged from 70.42 mm to 210.80 mm and 73.42 mm to 190.57 mm, respectively. The observed and predicted runoff coefficients ranged from 0.12 to 0.33 and 0.13 to 0.30, respectively. The percent error in prediction of runoff ranged from 4.3% to 32.8% and that for runoff coefficient from 8.3% to 31.25%. The minimum runoff of 70.42 mm was observed in the year 2001, which was predicted by the model with an error of 4.3%. The maximum runoff which was observed in the year 1998, was predicted with an error of 9.6%. Similarly, the percent error in the prediction of minimum runoff coefficient during the year 2001 was 8.3%. However, the model predicted the maximum runoff coefficient during the year 1998 with 100% accuracy. Total amount of rainfall of 2609 mm during the validation period resulted in 521.61 mm of runoff measured at the outlet of the watershed, which was predicted by the WEPP model with an error of 4.9%. Overall, the WEPP model predicted the mean annual runoff (130.40 mm) with an error of 2.1% and the mean annual runoff coefficient with an error of 10.0%. Keeping in view the variability of various hydrologic parameters within a natural system, the prediction error in the quantification of annual runoff is quite low and within the acceptable limits.

Table 9: Annual quantification of runoff through WEPP model application

Year	Annual Rainfall (mm)	Annual Runoff (mm)		Runoff Coefficient	
		Observed	Predicted	Observed	Predicted
1998	638.80	210.80	190.57	0.33	0.30
1999	772.30	142.89	153.54	0.20	0.22
2000	622.80	97.50	129.52	0.16	0.21
2001	575.10	70.42	73.42	0.12	0.13
Total	2609.00	521.61	547.05	-	-
Mean	652.25	130.40	133.15	0.20	0.22

CONCLUSIONS

In this study, the WEPP watershed model has been applied to simulate and quantify runoff from a small rangeland watershed having an area of 15.55 ha located in *Shivalik* foot-hills of Punjab. The results of the study show that the model is highly sensitive to hydraulic conductivity, followed by slope. The overall statistical model performance parameters namely percent error of 4.9 % in the prediction of mean runoff, RMSE of 0.56, correlation coefficient of 0.93 and model efficiency of 81% indicate reasonably accurate simulation of runoff at watershed scale. The performance of WEPP model improved significantly when simulation runs were conducted without the extreme rainfall events (rainfall > 100 mm). The error in the prediction of mean runoff reduced from 4.9% to 3.4%, the overall RMSE reduced from 0.56 to 0.19, percent error reduced from 4 88% to 3.5%, correlation coefficient improved from 0.93 to 0.99 and model efficiency improved from 81% to 97%. This shows WEPP model's inability to simulate and quantify extreme events with good accuracy. Overall WEPP model has demonstrated its capability to simulate and quantify runoff from small rangeland watersheds on continuous basis with reasonable accuracy for planning environmental management practices.

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