Environment & Ecology 29 (2A) : 739—744, 2011
 ISSN 0970-0420

Prediction of Runoff and Sediment Yield of Ninga Watershed Sone Catchment

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Abstract

Deterministic geomorphic modeling is the basic tools for prediction of any hydrological behavior of a basin. The magnitude of sediment transported by rivers in major concern for the water resources planning and management. Proper scientific planning and management require detailed data to make reliable predictions. In present paper multivariate statistical technique was applied to develop dimensionally homogeneous and statistically optimal models for predicting the annual runoff and sediment production rate from a small watershed of Sone catchment. The parameters of model ware calculated by multiple regression method using measured runoffs and sediment yield data. The model parameters were determined by five years (1999—2003) data. The performance of model was evaluated by performing the quantitative tests on measured and estimated data. The developed models can be conveniently used to predict the runoff and SPR of small ungauged watershed of Sone catchment and also other region having similar physiographic characteristics.
Key words : Watershed, Runoff, Sediment yields.

Land degradation has become a global issue due to soil erosion by various erosion agents are highly alarming. It is probable that one sixth of the world populations are currently affected by land degradation. The report says that about 328.7 million ha of geographic area of India, some 167 million ha have been suffering from different types of degradation, such as wind erosion (50 million ha), water erosion (90 million ha), salinity and alkalinity (7 million ha) and flooding (20 million ha). The report says that about 175 m ha of the total geographical area is suffering from different degradation and 65 m ha area severely degraded land in India. West Bengal state is the highest suffering from water erosion and Rajasthan is the highest suffering from wind erosion. India is losing about 8.2 million tones of soil nutrients annually as a result of soil erosion. The per capita availability of cultivated land has decreased from 0.48 hectares in 1951 to 02 ha in 1980-81 and the projected estimates that it will further decline to 0.1 ha by 2010 AD. Many of the reservoirs built at huge cost have been silting at a rate faster than anticipated due to poor land and water resources management in the catchments. Due to indiscriminate deforestation there is an accelerated degradation of land and water resources of the catchment. It is understood that agriculture pollution problems are related to soil loss and water movement. Hence for achieving sustainability in agricultural production and productivity it is imperative to develop holistic management practices which can prevent soil loss and assist in efficient use of water. It is not possible to collect the actual silt runoff data from all the watersheds. Such as attempt will not only be expensive but also time consuming. Thus we need a mechanism to locate watersheds susceptible to erosion by way of developing suitable models which can help in predicting the runoff and sediment yield and thereby deciding the priority. Rainfall, runoff and sediment yield of different watersheds have been analyzed and published by different scientists within and outside the country (1, 2). Various models and techniques have been developed in the past, in India and abroad, based on climatological characteristics. Most of these models are location specific. In view of the nature of hydrological data it is problematic whether the attempts to reduce the systematic error, arising from non-linearity by the use of non-linear analysis is warranted (3) and so linear

Table 1. Observed and estimated weekly runoff (mm).

	Years									
	1999		2000		2001		2002		2003	
Weeks	Obs	Est	Obs	Est	Obs	Est	Obs	Est	Obs	Est
26	2.42	4.47	1.84	1.77	0	-2.91	6.4	7.93	4	4.59
27	0.56	0.74	2.02	2.18	2	2.13	8.4	10.29	17.15	16.43
28	41	40.34	131.36	127.62	11.5	13.55	29.4	25.27	0	-2.5
29	15.39	16.13	0	-2.46	26.13	25.83	24.85	22.23	8.09	9.67
30	2.14	2.84	15	23.64	72.88	67.87	11.9	13.28	0	-2.1
31	2.05	2.95	1.4	2.08	5	6.44	0.9	0.72	17.27	18.29
32	14.43	15.91	10.15	12.45	0	-1.79	0.75	0.69	20.13	20.99
33	56.03	57.28	32	26.39	0	-1.54	4.68	7.38	29.12	26.75
34	2.88	4.48	11.9	14.05	0	-1.32	19.95	19.79	20.96	22.75

models have practical advantages in case of application and are mathematically much more convenient to handle than the non-linear models. Considering these reasons an attempt was made to develop the models which simulate the process of runoff and sediment yield on weekly basis for the Ninga watershed of sone catchment.

Methods

The study was undertaken in the Ninga watershed in Sonebhadra district of Uttar Pradesh of India. It falls between the 24⁰24′ to 24⁰28′ N latitude and 82⁰52′ to 83⁰2′ E longitude. The area of the watershed is 2,100 ha. The climate of the area is semi arid with average annual rainfall 1038.30 mm and temperature varies from 4 to 42.5 C. The soils are red and brown. The predominant slope in the hilly portion ranges between 6 to 15% and in the valley portion it varies from almost levels to 5% of the total watershed area 35.3% was under forest and the net sown area was (936 ha) 44.6%. Sheet and gully erosion are common in that area especially near the river. About 80% of annual rainfall is received from July to October during the south-West monsoon period.

Hydrological Data

The Soil Conservation Development of Uttar Pradesh measures the hydrologic data such as rainfall, runoff, sediment yields and SPR at the outlet of the watershed recorded from 1999 to 2003 (Tables 1, 2).

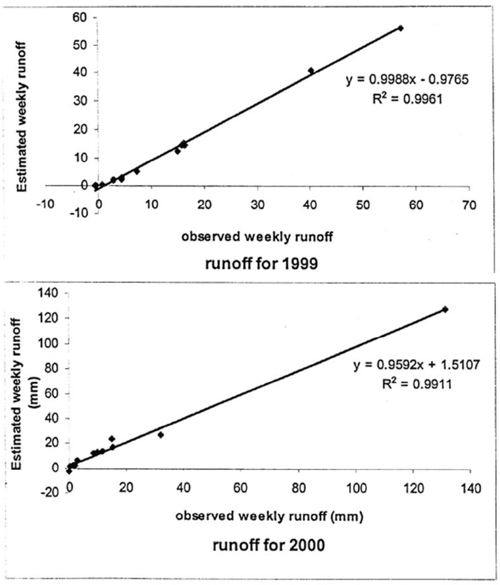
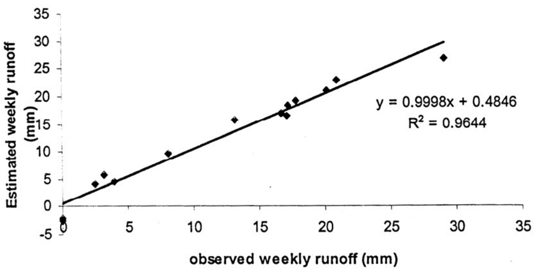


Figure 1. Relation between estimated and observed weekly runoff for 1999 and 2000.



runoff for 2003

Figure 2. Relation between estimated and observed weekly runoff (1999—2003).

Table 2. Observed and estimated weekly sediment yield (tonns).

	Years									
	1999		2000		2001		2002		2003	
Weeks	Obs	Est	Obs	Est	Obs	Est	Obs	Est	Obs	Est
26	665.2	664.85	488.03	487.99	414.06	413.98	669.52	671	613.76	603.01
27	402.63	402.74	525.14	525.79	500.87	501.9	752.07	737.46	714.32	706.11
28	440.37	432.76	719.85	749.28	554.58	580.03	684	683.52	811.12	823.37
29	487.47	486.09	674.04	677.07	501.17	501.92	747.62	732.71	691.44	699.53
30	516	513.66	451.11	451.38	451.73	448.91	618.86	644.93	760.71	764.98
31	506.65	505.64	823.31	819.34	750.76	748.61	431.3	432.87	814.8	798.18
32	683.22	686.08	718.98	726.3	891.71	889.93	420.61	423.43	792.08	813.4
33	712.34	705.69	645.6	644.93	722.2	725.37	615.51	620.24	540.9	514.59
34	650.87	651.31	736.51	737.46	534.5	534.96	752.16	735.93	703.89	702.46

Development of Runoff Model

The following empirical rainfall model, proposed by Ojasvi et al. (4), on aggregate time scale has been applied for the area under study for the estimation of runoff on weekly basis.

$$EWR = \alpha_0 = \alpha_1 r + \alpha_2 API + \alpha_3 NOR + \alpha_4 week \quad ....(1)$$

Where EWR=Weekly runoff volume (mm), r = Weekly rainfall (mm), API = Antecedent precipitation index (mm), NOR = Number of rainy days in the week under consideration, and Week = Calender week number

$\alpha_0, \alpha_1, \alpha_2, \alpha_3$ & α_4 = coefficients

The model described here was modified for the Ninga watershed by determining the values of various coefficients-α. The various parameters used in the above model were determined as per the procedure described in the following sections.

API on any day is equal to R times the index of the day before on any day, then the index after the rain is equal to that before the rain plus amount of the rainfall

$$A'_1 = A_o \cdot (k)^t{}_1 \quad ....(2)$$

Where A'_t=Index after t′ days from the 0 (Zero) day, Called the initial day, A_o = Index on a day called initial index of the basin.

Number of rainy days in a week was obtained by adding the number of days in a week receiving the rainfall.

Determination of Coefficients

The least square technique were used for the estimation of various regression coefficient in the present study by using five years data from 1999–2003.

To simplify the representation, the various variable EWR, r, API, NOR and WEEK in the equation (1) are being represented by R, r, A and W. Thus the equation (1) can now be expressed as

$$R = \alpha_0 + \alpha_1 r + \alpha_2 A + \alpha_3 + \alpha_4 \quad ....(3)$$

The equation for all five years was arranged in matrix form and for any one year was represented in matrix notation as

$$R = X\alpha \quad ....(4)$$

Where R is the random observation vector, α is design matrix of observable parameter, the vector α is a vector of unknown parameter.

The estimation of parameters in the regression equation was done by the method of least square essentially, all possible values for each of the entries in α (=α_0, α_1) are considered and that set for which the sum of squares of the residual was minimum finally chosen.

The solution of equation (3) by the least square was obtained by the following equation-

$$\alpha = X^T R (X^T X)^{-1} \quad ....(5)$$

Where X^T is the transpose of matrix X.

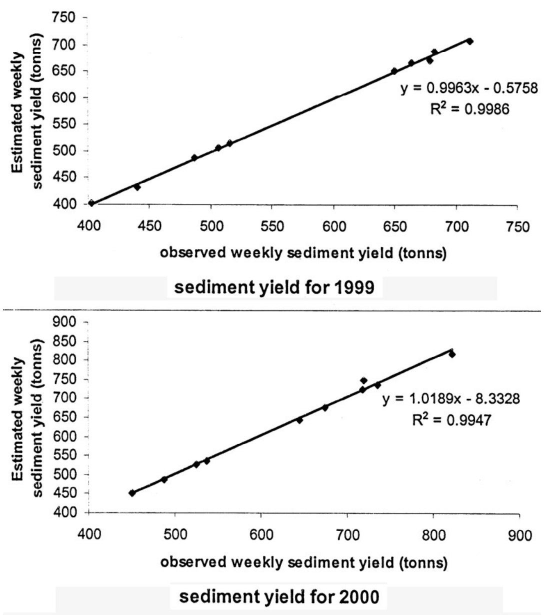


Figure 3. Relation between estimated and observed weekly sediment yield for 1999 and 2000.

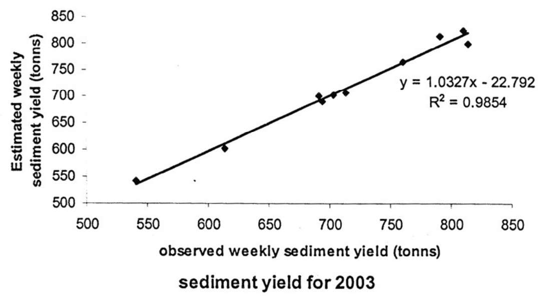


Figure 4. Relation between estimated and observed weekly sediment yield (1999—2003).

Development of Sediment Yield Model

The sediment yield model was development for Ninga watershed by taking the rainfall energy, runoff volume and peak runoff rate as input besides other variable KLSCP of USLE. The model suggested by them is as follows :

$$(ESW)_K = [a\ (EI_{30}) + b\ (Q\ q_p)^c]\ KLSCP \qquad ....(6)$$

Where EWS=Estimated weekly sediment, ET_{30} = The rainfall erosivity index, that is product of weekly total rainfall kinetic energy in tm/ha and rainfall in cm/h, Q=Total weekly runoff volume (mm), q_p=Peak runoff rate (cumecs), K=Erodibility factor, L_s = Slope length and steepness factor, C= Crop management factor, P=Conservation practice factor.

The various variables involved in equation (v) were determined as described in subsequent paragraphs.

Rainfall Energy Factor (EI_{30})

The following relationship was adopted for this study

$$EI_{30} = 0.6235r + 12.3 \qquad ....(7)$$

Runoff volume (Q). Daily runoff values observed during week days were added to obtain weekly runoff volume.

Peak Runoff Rate (q_p)

The daily peak discharge and the runoff volume at the gauging station of Ninga watershed were collected from the Soil Conservation Department of Monsoon 1990. The following relationship between the runoff volume and peak flow was obtained

$$Q_p = 2.072\ Q + 0.1376 \qquad ....(8)$$

Where q_p is peak flow (cumecs) and Q is runoff volume (mm)

Values of parameters K, Ls, c and p has been collected from the office of soil and water conservation, Sonebhadra, Uttarpradesh and presented below :

K = 0.08, Ls = 0.28, C = 0.45, P = 1

Determination of Parameters

Different values of C was assumed and the parameters a and b were determined by a simple linear regression analysis applying the least square technique. The values of a and b for assumed value of C which gives the best coefficient of correlation was finally selected.

Quantitative Comparison of Performance of the Models

The acceptability of a model was judged by the goodness of fit between observed and estimated values. For quantitative comparison between observed and estimated values the following statistical measures were employed in the present study.

Absolute Prediction Error (APE)

The APE was determined by the following equation proposed by the World Meteorological Organization (1975)

$$APE = \frac{\sum_{i=1}^{n} O_i - P_i}{\sum_{i=1}^{n} O_i} \times 100 \qquad ....(9)$$

Where APE is absolute prediction error in percentage O_i and P_i are observed and estimated values respectively.

Coefficient of Efficiency (CE)

The coefficient of efficiency for evaluating the model performance has been recommended by several scientists. The CE is defined (5) as the proportion of the initial variance accounted for by that model is determined by the equation

$$CE = \frac{\sum_{i=1}^{n} [O_i - \bar{O}]^2 - \sum_{i=1}^{n} [O_i - E_i]^2}{\sum_{i=1}^{n} [O_i - O]^2} \times 100 \qquad ... (10)$$

Where CE is the coefficient of efficiency in percentage O and E are observed and computed value at corresponding time and $\bar{O}$ is the mean of the observed values.

Results and Discussion

The study was taken up with an aim to develop optimal models for prediction of the mean annual runoff and SPR which could conveniently be used for any watershed having similar physiography to that of Sone catchment of Uttar Pradesh. The observed and estimated values of runoff and sediment yield for Ninga watershed of year 1999 to 2003 are presented in Tables 1 and 2 and Figures 1). The following models are chosen as statistically optimal runoff and SPR prediction model for Ninga to watershed of some catchment.

Weekly Runoff Model

$$EWR=7.8480-10.2477\ r-0.0016\ API + 1.1741\ NOR + 0.1926\ week$$

Weekly Sediment Yield Model

$$EWS = [2560.7\ EI_{30} - 2049.3\ (Qq_p)^{0.131}\ ] \times 0.01$$

Validation of Models

The performance of model was evaluated by performing the quantitative tests on measured and estimated runoff, peak flow and sediment data. The tests indicate that the average absolute prediction errors ranged from 9.38 to 16.08% and 0.59 to 1.39% for runoff and sediment yield models respectively. The coefficients of efficiency ranged from 89.81 to 99.34% and 98.30 to 99.28% for runoff and sediment yield models respectively. The linear regressions of observed and estimated runoff (R^2=0.9369 to 0.9386) and sediment yield (R^2=0.9108 to 0.9986) were strongly correlated. Therefore, it may be concluded that these models developed in this study can be conveniently used to estimated annual runoff and SPR with a fair degree of accuracy.

Conclusion

Rainfall, runoff and sediment yield data were utilized for the development or reliable response models for predicting runoff and sediment yields from Ninga watershed of Sone catchment. In this study two different models were applied but it is clear that for weekly runoff model and weekly SPR model, the linear regression of observed and estimated values were strongly correlated and the absolute prediction error between the observed and estimated values within the acceptable range of 25%. So it can be concluded that these models can be conveniently used to predict runoff and SPR from small ungauged watershed of Sone catchment by knowing the rainfall runoff and sediment yield.

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