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Estimation of runoff and soil loss for a hilly watershed

M. MUTHAMIL SELVAN, K. SUBRAMANIAN V. RAJENDRAN AND K. RANGASAMY

College of Agricultural Engineering, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu

Abstract : Estimation and analysis of rainfall-runoff-discharge data for a watershed would be of great use for optimum planning and managing the watershed. Universal Soil Loss Equation (USLE) was used to estimate the annual soil loss from a hilly watershed in the Nilgiris. A set of linear regression models were developed by relating (1) rainfall and runoff, (2) rainfall and soil loss and they can be used for prediction of the runoff and soil loss for the watershed. Packages of soil and water conservation measures were recommendd for the watershed as the present runoff and soil loss wre found to be enormous.

(*Key words* : Runoff and Soil loss and watershed)

Runoff and soil loss estimation in any watershed is the important criteria to adopt suitable soil and water conservation practices. For a hilly watershed the rainfall-runoff and rainfall-soil loss can be conveniently described by treating them as a deterministic lumped linear system. Several methods have been developed during recent years for runoff and soil loss estimation. Vinodkumar and Rastogi (1989) developed a mathematical model of instantaneous unit hydrograph for a small watershed. A linear time invariant model was developed by Sharma *et al* (1992) for predicting sediment transport in th arid zone drainage basin. Shrivastava and Bhatia (1992) used soil conservation services (SCS) model for runoff prediction. A few other models were also developed in India. Most of them need very detailed input data, which are not available. Hence, an effort was made to predict runoff and soil loss by developing simple liner regression models.

Material and Methods

Study Area

Ebbanad watershed near Ooty town in the Nilgiri hills is a part of the Moyar subcatchment of the Bhavani river basin. The watershed starts from Dottabetta peak in Ooty town and ends at about 14 km near the silt monitoring station of Ebbanad. The watershed area is located between the Dottabetta peak and the Bikkepattimud reserved forest ranges at an average altitude of 2155 m above MSL. The watershed lies between 11°24'N and 11°2a'N latitudes and between 76°46'E and 76°50'E longitudes covering an area of 28.1 sq km. It includes Kendorai, Adashola, Tuneri, Tummanatti, Kuppachi, Kottamad, Muruttala and Thiruchukudi Ebbanad hamlets of Ebbanad and Kakkuchi villages.

Computation of soil loss

For computation of soil loss potential of the watershed, the relevant data such as watershed boundary map, land use map, rainfall, drinage network soil map and contour map were collected from various sources.

The actual runoff and soil loss were observed over the different periods of five year (1990-1995). The soil loss assessment is also done theoretically by using the universal soil loss equation and this theoretical soil loss is compared with th actual soil loss determined in the river valley project scheme.

The universal soil loss equation (USLE) given by Wishmeier and Smith (1965) was used to estimate the soil loss from the watershed. The ULSE computes the soil loss for a given site as the product of six major factors whose most likely value at a particular location can be expressed numerically. Th soil loss equation is given by

A = RKLSCP

where,

A = Computed soil loss per unit area expressed in unit selected for K and for the period selected for R. Usually the unit of A will be in t/acre/year.

R = Rainfall erosivity index. It is worked out based on EI_{30} index.

K = Soil erodibility factor.

L = Length factor, $L = \left[\frac{x}{22.3}\right]^m$

x = Actual length of the field in m

m = An exponent that depends upon the general slope of the field

S = Slope gradient factor

= $0.065 + 0.04_s + 0.0065_s^2$

s = General slope of the watershed

C = Crop management factor. It depends on the crop cover, crop sequence, production level, length of the growing season, cultural practices, crop residue management and distribution.

P = Conservation practice factor. It depends on the conservation practices like contour bunding, terracing, etc. The erosion control practices followed in these watersheds are mainly bench terracing as the slope is greater than 16 per cent so the value of P is picked as 0.18 from the standard table.

Field observations

Simon's ordinary type rain gauges and automatic rain gauges were installed to observe the quantum of precipitation in the rain gauge stations. Stream gauging sites were equipped with automatic stage level recorders for computing the runoff. The sidiment water samples were collected in the upstream side of the measuring weir at a depth of 15 cm from the water surface. The samples were analyzed in the laboratory for coarse, medium and fine sediments of suspended materials. The concentration of each samaple was expressed in terms of g/l. Th average sediment concentration of all the samples collected for the watershed was calculatd for each month. The details of rainfall, runoff and sedimentation rates of watershed are presented in the Fig. 3 and Fig. 4. Calculations of sediment yield are done as shown below.

$$\textit{sediment yield (mt / ha)} = \frac{\textit{Total soil loss}}{\textit{Areas of watershed}}$$

$$\textit{Sediment rate} = \frac{\textit{sediment yield, g/l x run off, m}^3}{\textit{1.4 x 107 x drainage area, sq. km}}$$

A linear equation in th form of Y = a + bx was developed for the watershed by correlating the rainfall data with the other factors. The correlation coefficient (r) was found out.

Results and Discussion

Theoretical and actual soil loss for the Ebbanad watershed from 1990-91 to 1994-95 are presented in the Table 1. The correction factor values were worked out as large variations among these values and this was observed maximum for the year 1992-93. This is due to the urbanization activities like construction of building, roads, etc taken place in the centre of the watershed. The soil loss during the subsequent years could be reduced to some extent, through farmers' adoption of soil and water conservation measures in the watershed area. However, a technically feasible and economically viable and socially acceptable watershed plan should be proposed for the watershed.

Table 1 Estimation of soil loss in Ebbanad watershed

Year	Rainfall intensity (cm/h)	I_{30} (cm/h)	Kinetic energy 210.3+ 89* log I_{10}	Rainfall erosivity index $KExI_{30}/100$ (t/ha)	Theoretical soil loss A=KLSCP (t/ha)	Actual soil loss (t/ha)	Correction factor (Actual SL/ Theo.SL)
1990-91	0.35	0.92	204.018	1.876	1.295	0.0354	0.273
1991-92	1.26	1.49	219.232	3.266	2.255	0.5646	0.250
1992-93	1.36	1.52	222.184	3.377	2.332	11.7975	5.058
1993-94	1.81	1.97	233.230	4.594	3.172	9.1787	3.063
1994-95	1.24	1.41	210.393	2.966	2.048	4.5780	2.235

Discharge rates

The discharge rates are directly proportional to the seasonal rainfall (Fig.1 and Fig.3). However, quantification of discharge with respect to annual and monthly rainfall were done with a linear regression model. The relationships were as follows:

$$Y_a = 3.91\,X_a - 2425.38$$
$$Y_m = 0.0033\,X_m - 0.029$$

where,

Y_a = annual discharge, ha.m X_a = annual rainfall, mm
Y_m = monthly discharge, ha.m X_m = monthly rainfall, mm

Sediment rates

The magnitude of the soil loss at different annual and monthly rainfall for the Ebbanad wate rshed are shown in Fig.2 and Fig.4. The average rate of soil loss of any year was found to be directly proportional to annual rainfall. Annual and monthwise relationship between soil loss and rainfall for the watershed were also developed. The linear relationships were found to be suitable because of good correlation coefficient. The relationships were as follows:

$$Y_a = 686.95 + 70.59\,X_a$$
$$Y_m = 11.46 + 0.78\,X_m$$

where,

Y_a = annual soil loss and X_a = annual rainfall
Y_m = monthly soil loss and X_m = monthly rainfall.

Conclusions

A detailed study on the watershed was carried out for hydrological behaviour. Runoff and sediment yield for the different rainfall values were observed. Universal Soil Loss Equation (USLE) was used to estimate the annual soil loss from the watershed.

A set of linear regression models were developed by relating (1) rainfall and runoff, (2) rainfall and soil loss and they can be used for predication of the runoff and soil loss for the watershed. Annual and monthly variations in runoff and sediment yield were quqite significant and a few selected months may reflect the bulk of the sediment load of that year.

To control heavy runoff and soil loss from the watershed packages of the soil and water conservation measures like contour bunding, contour trenching and bench terraces were proposed. In addition to this. percolation ponds and farm ponds were also proposed to harvest the excss runoff at the selected outlet points.

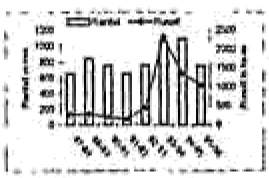
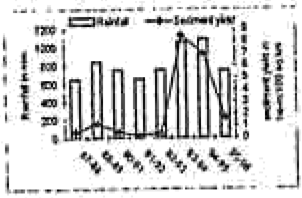


Fig 1 Annual variation of Rainfall and Runoff


2 Annual variation of Rainfall and Sediment yield

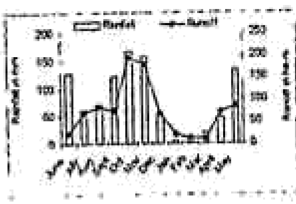
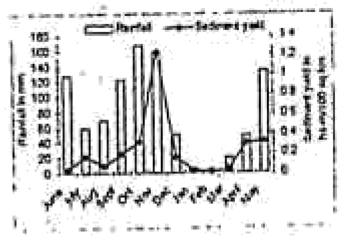


Fig 3 Monthly variation of Rainfall and Runoff


g 4 Monthly variation of Rainfall and Runoff

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