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Applicability of the Universal Soil Loss Equation in mountain watersheds in semiarid and humid regions

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ABSTRACT The mountain watersheds of the Bhavani basin in south India (latitude 10°55'-11°45'N and longitude 75°30'-77°45'E) lie partly in humid and partly in semiarid climatic regions. Due to increased population growth, many of these watersheds are undergoing rapid land use changes especially from forest to agriculture and consequently heavy soil erosion is taking place. Planning for proper development of these watersheds requires estimates of soil loss due to land use change. An attempt is made to predict soil erosion using the Universal Soil Loss Equation and to ascertain the soil erosion rate due to land use change. The computed annual soil loss (t ha^{-1}) agrees fairly well with the observed soil loss data provided by plot studies. The sediment delivery ratios worked out for some of these watersheds compare favourably with those obtained for humid and semiarid areas in other countries.

INTRODUCTION

In many developing countries, the desperate need for food due to a population explosion forces people to over-exploit their soils with the result that they become degraded and unproductive. In India, as in many other parts of the semiarid and humid tropics, there is an urgent need to develop methods for crop production in upland and hilly areas by using scientific land management practices. A major impediment to the development of successful, continuously productive farming systems in the semiarid and humid tropics, is soil erosion which includes both physical removal of surface soil and deterioration of soil physical properties resulting in low productivity. The need for factual, quantitative information to determine soil erosion rates under a variety of climatic, physiographic, land use, and soil management situations led to the establishment of small, test plots in the US early in the century. Today, much factual information exists on the erosion rates and processes because of the improved instrumentation of these field plots.

Data from plot studies on sheet erosion made it possible to develop general relationships that could be used by soil and water resource planners to predict the long term erosion rate for a given field under a variety of land use strategies. Zingg (1940) related steepness and length of slope to soil loss. Smith (1941) and Van Doren *et al.* (1956) considered such factors as soil erodibility and land management. These factors were further evaluated and consolidated and a rainfall parameter added to obtain the empirical equation described by Musgrave (1947). The parameters of the Musgrave equation were not readily adaptable to many of the land use conditions that were encountered. A prediction model that would improve the representation of erodibility and cropping factors and overcome the deficiency of a single rainfall intensity factor that is not closely related to the number of erosive rainstorms per year was needed. The prediction model, known as the Universal Soil Loss Equation was developed to overcome the above mentioned deficiencies by Wischmeier *et al.* (1960).

THE UNIVERSAL SOIL LOSS EQUATION

The Universal Soil Loss Equation (USLE) has the general form

$$A = RKLSCP$$

in which A is the average annual soil loss in t ha^{-1} and R is a factor expressing the erosion potential of average annual rainfall in the locality. R is calculated as the summation of the individual storm products of the kinetic energy of rainfall and the maximum 30 min rainfall intensity for all significant storms, on an average annual basis. K is the soil erodibility factor that represents the average soil loss, in t ha^{-1} per unit of rainfall factor R from a particular soil in cultivated continuous fallow with a standard plot length and a per cent slope arbitrarily selected as 22 m and 9% respectively. S and L are topographic factors for adjusting the estimated soil loss for a specific land gradient (S) and length of slope (L). The land gradient (slope) is measured as a percentage. Slope length is defined as the average distance (m) from the point of origin of overland flow to whichever of the following limiting conditions occurs first: the point where slope decreases to the extent that deposition begins or the point where runoff enters well defined channels. C is the cropping management factor and represents the ratio of the soil quantities eroded from land that is cropped under specified conditions to that which is eroded from clean-tilled fallow under identical slope and rainfall conditions, and P is the supporting conservation practice factor (strip cropping, contouring etc.). For straight-row farming P = 1.0.

DESCRIPTION OF THE BHAVANI BASIN

The Bhavani basin originating in the high Nilgiri Hills in South India (Fig.1) lies partly in humid and partly in semiarid climatic regions (latitude 10°55'-11°45'N and longitude 75°30'-77°45'E). It has four distinct physiographic regions namely, the Western Ghats, the Eastern Ghats, the Plateau regions and the Bhavani valley. The River Moyar coming from the north and the Bhavani from the south are the main tributaries of the river upstream of the Lower Bhavani reservoir. With a drainage area of 6730 km^2, the

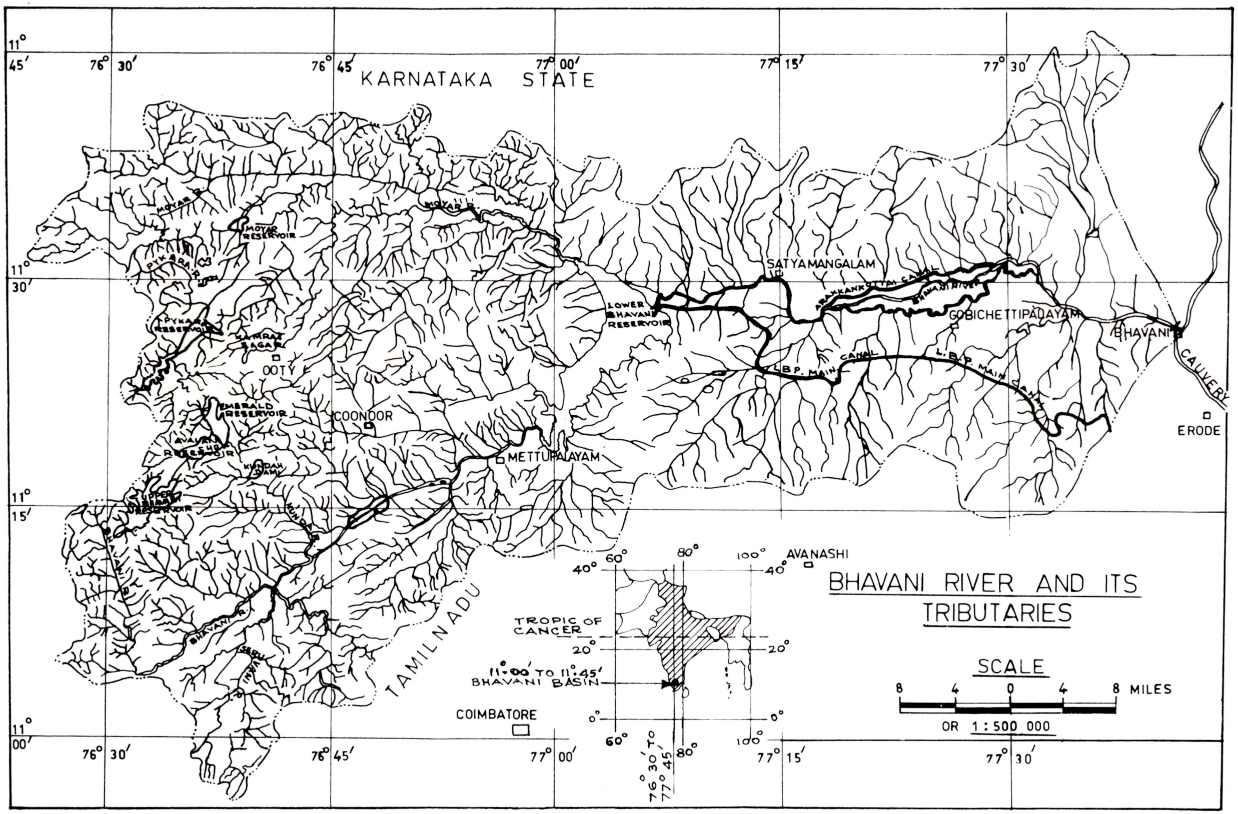

FIG.1 The Bhavani river basin.

basin has a length of 185 km, a width of 80 km in the west and 40 km in the east and consists of 50 subwatersheds. Its elevation ranges from 166 m to 2634 m a.m.s.l. There is a chain of hydroelectric reservoirs in the high hills of Nilgiris, having a total capacity of 481 million m^3. In the plains just downstream of the confluence of the Moyar and the Bhavani, the Lower Bhavani reservoir has been constructed with a storage capacity of 986 million m^3, and this reservoir irrigates an area of 82 400 ha under good crop management. The annual rainfall of the basin ranges from 468 to 6400 mm. Snowfall is absent in this basin and temperatures range from 0°C to 30°C. The rocks of the basin are of Archaean age and consist of granites, charnockites, mixed gneisses and small patches of mylonite. The soils of the basin are varied and exhibit severe erosion hazard and soil limitation. Due to increased population, agricultural and industrial development many subwatersheds of this basin are undergoing rapid land use change from forest to agriculture and urban use resulting in severe soil erosion and pollution. Change in land use affects the hydrology and soil erosion of the basin. Improper land use practices besides resulting in frequent floods, also affect the dry weather flows. In watersheds undergoing such transitions, sediment yields have increased phenomenonally. Two hydroelectric reservoirs, the Kundha and the Pilloor have been silted up by as much as 45 and 25% of their live capacities, respectively. Katery reservoir has silted up completely. The impact of siltation is being taken up almost entirely by the hill reservoirs, whereas the siltation of the Lower Bhavani reservoir in the plains has been only of the order of 2.25% of its live capacity during the last 20 years.

Prediction of soil erosion using the Universal Soil Loss Equation as proposed by Wischmeier has been attempted for these watersheds. The effect of land use change on soil loss has also been studied. The results obtained have enabled us to identify the areas susceptible to erosion.

TEST WATERSHEDS

Sixteen subwatersheds (13 from the hills and 3 from the plains) were selected for the detailed computation of the parameters R, K, L, S, C and P. The rainfall erosion factor (R) is equal to EI/100 where EI is the erosion index value. The energy-intensity product (EI value) of a storm was computed from recording raingauge charts with the help of the energy table developed by Wischmeier *et al.* (1958). The rainfall energy was estimated from rainfall intensity data using an equation developed by Smith *et al.* (1947) and Wischmeier (1965). Using this equation hourly, daily, and monthly rainfall kinetic energies were computed. Maximum intensity of 30 min rainfall for the month was noted from the rainfall recorder chart and multiplied by the monthly rainfall kinetic energy to get the erosion index (EI) for that month. Using a polynomial fit and a chi-square criterion, the monthly erosion index values for each watershed have been correlated with the monthly rainfall. An average EI value was then obtained for each one of the test watersheds based upon the average monthly rainfall. For those watersheds which do not have recording raingauges the polynomial equation developed for the nearest watershed was used and the EI values computed. The average R values computed for hill and plain areas in the Bhavani basin are 886 and 393, respectively.

The factor K is a measure of the erodibility of a given soil and is evaluated independently of the effects of topography (LS), cover and management (C), and supplementary practice (P). When these conditions of independence are met, then LSCP becomes equal to one and K equals A/R. From the results of plot studies a graph is plotted between A and R and K is taken as the slope of the fitted straight line. The values of the K factor for hills range from 0.0001 (forests) to 0.2058 (cultivated and urban) and that of plains from 0.01 (forests) to 0.30 (cultivated and urban). The slope length (L) is determined from the equation, $L = (\ell/22.0)^{0.3}$ where ℓ is the average length of first order channels in the watershed. The slope factor (S) is determined from the following regression equations:

$$S = (0.043 + 0.30G + 0.043G^2)/6.613 \qquad \text{for } G \leq 9$$

$$S = (G/9)^{1.3} \qquad \text{for } G > 9$$

where G is % slope. The Survey of India topographic maps were used to work out the combined LS factor. The combined CP factors has been taken from the literature published by the Indian Council of Agricultural Research (1975). The average CP value for hills ranges from 0.0002 (forest) to 0.1 (cultivated and urban) and for plains from 0.001 (forests) to 0.1 (cultivated and urban). The land use information for the basin was obtained from the land use classification map prepared at the scale of 1:250 000 for the entire Bhavani basin area using Landsat False Colour Composites (FCC) of path 154 to 155 and row 052. With the data collected, the following computations were made using the USLE:

(a) The soil loss in individual subwatersheds (50 in number) for the present land use pattern.

(b) The soil loss in individual watersheds assuming scientific land management is adopted. The scientific management consists of soil and water conservation works in the watersheds involving bench terraces, contour bunds trenches, gully and channel erosion control measures, crop rotation and afforestation, and grassland management practices with adequate percentages of natural and man-made forests.

(c) The soil loss in individual watersheds if 50% of the existing forest in these watersheds is converted into agricultural land with the present as well as scientific land management.

(d) The sediment delivery ratio of a few typical watersheds having sediment yield data.

RESULTS AND DISCUSSIONS

The soil loss in the basin has been broadly subdivided into eight categories namely extremely low, very low, low, moderately low to medium, moderately to high, high, very high and extremely high with the range as indicated in Fig.2. The results for the test

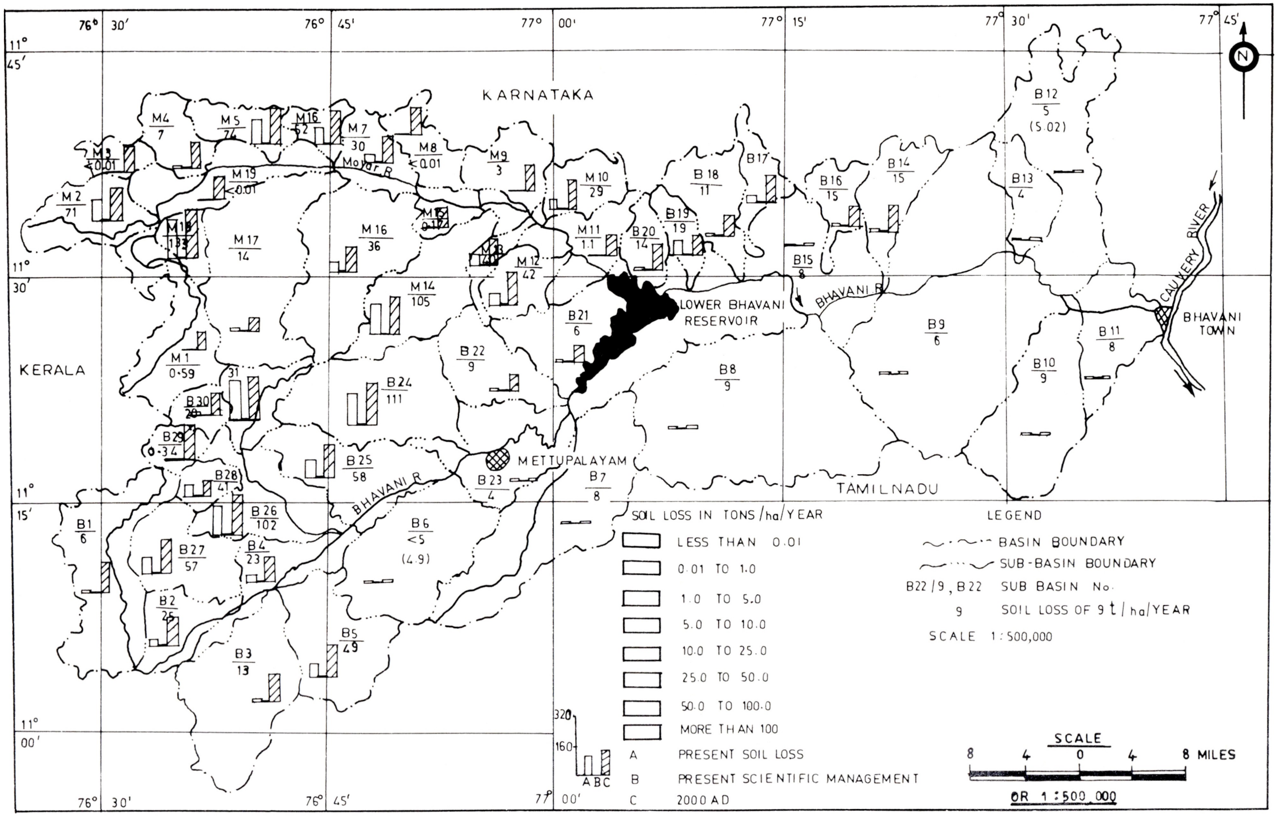

FIG.2 Soil loss in the Bhavani basin.

TABLE 1 Soil loss in test watersheds and the Bhavani basin

Name of subwatershed	*Soil loss (t $ha^{-1}year^{-1}$)*		
	At present: normal	*scientific*	*50% forest converted to farming*
Coonoor	*102.340*	*1.556*	*104.919*
Upper Moyar	*7.491*	*0.311*	*24.192*
Sigur Lower	*17.595*	*0.226*	*23.375*
Katery	*55.556*	*1.422*	*56.711*
Kukkalathorai halla (upper)	*57.243*	*0.875*	*61.637*
Kukkalathorai halla (lower)	*53.194*	*0.779*	*60.778*
Kedarihalla Lower	*8.569*	*0.125*	*11.970*
Alladahalla	*15.807*	*1.342*	*19.938*
Gundagal halla	*68.390*	*1.000*	*145.688*
East Varahapallam	*9.440*	*0.635*	*27.91*
Yemmavipuzha	*0.3835*	*0.376*	*25.993*
Kotagirihalla	*22.174*	*0.851*	*39.926*
Hadothorai halla	*51.477*	*6.669*	*202.900*
Bhavani town	*10.281*	*3.023*	*10.281*
Mettupalayam	*27.831*	*5.827*	*45.767*
Gopichettipalayam	*8.658*	*3.150*	*9.761*
BHAVANI AS A WHOLE BASIN	*27.417*	*1.411*	*62.615*

watersheds are presented in Table 1 and that for whole Bhavani basin in Fig.2.

The study shows that the highly protective natural forest possesses extremely low soil loss followed by mixed, rural and urban watersheds. Predominantly rural and urban watersheds in the Bhavani basin with a very low percentage of forest (0.5-2.5%) are the main areas of erosion. Here the soil loss ranges from 50 to 133 and requires immediate attention. The study has revealed that improper rural and urban management is the root cause of erosion. The present soil loss in the Bhavani basin is 27.4 t $ha^{-1}year^{-1}$ and this can be reduced to 1.4 t $ha^{-1}year^{-1}$ which is within the permissible limit of 1.0-1.5 t $ha^{-1}year^{-1}$ associated with rigid scientific conservation and management practices. If due to population pressure and socio-economic factors, the present forest area is reduced by 50% at a future date, the soil loss with the present land use practices will increase to 62.6 t $ha^{-1}year^{-1}$. If scientific management is adopted, it will drop to 1.79 t $ha^{-1}year^{-1}$. Soil loss data obtained from plot studies closely correlates with the calculated soil loss for certain land uses (Fig.3)

The sediment delivery ratio (DR) = S_y/(sheet erosion + gully erosion + channel erosion) where S_y = sediment yield in t ha^{-1}. The channel and gully erosion have been assumed to be 75% and 50% respectively of the estimates of sheet erosion obtained using the USLE. Sediment delivery ratios for the Coonoor, Katery, Mettupalayam, Pykara, Glenmorgan basins and Bhavani Hills were calculated using the data furnished by the Public Works, Electricity

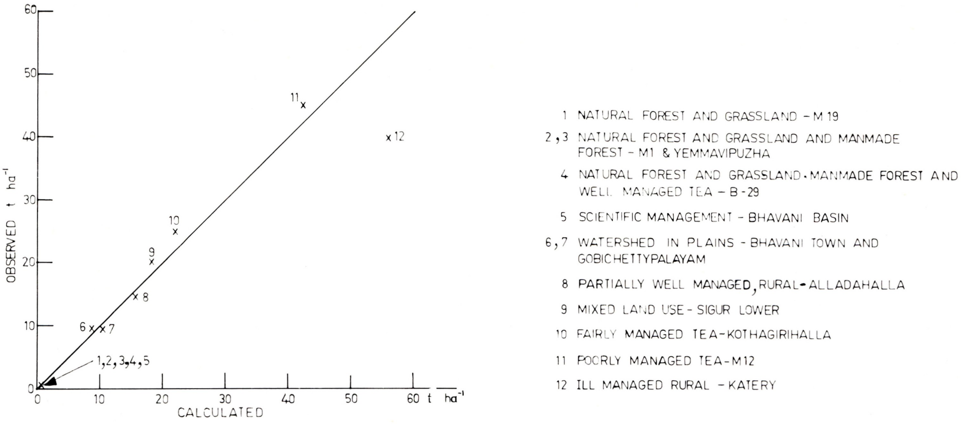

FIG.3 Soil loss observed and calculated.

and Agricultural Departments of the Government of Tamil Nadu and are presented in Table 2.

The delivery ratios obtained for these watersheds are similar to those obtained for humid and semiarid watersheds in other countries (Mutchler, 1976). As regards sediment yields, these are nil under forest land use, followed by mixed land use (3.19), rural (13.95) and urban (19.0). The entire Nilgiri Hills consisting of forest, agriculture, plantations and urban land use has a sediment yield of 5.85 t ha^{-1} and delivery ratio of 0.047.

CONCLUSIONS

From the study, it is concluded that scientific land management with

TABLE 2 Sediment yields and delivery ratios in the Bhavani basin

Subwatershed and land use	*Sediment yield (t ha^{-1})*	*Sheet erosion (by USLE) (t ha^{-1})*	*Channel and gully erosion 75% + 50% (t ha^{-1})*	*Total*	*Delivery ratio*
Coonoor (urban)	*19.00*	*102.3410*	*127.926*	*230.2600*	*0.0825*
Katery (rural)	*13.95*	*55.5560*	*79.550*	*125.0000*	*0.1116*
Mettupalayam (low hills - mixed land use)	*3.19*	*27.7960*	*34.745*	*62.5400*	*0.0510*
Bhavani hills Nilgiris (mixed land use)	*5.85*	*55.3760*	*69.220*	*124.5900*	*0.0470*
Pykara (forest)	*0.00*	*0.5867*	*0.7334*	*1.3201*	*0.0000*
Glenmorgan (forest)	*0.00*	*0.0001*	*0.0003*	*0.0005*	*0.0000*

mixed forest, rural and urban land use is the final answer for erosion control in the Bhavani basin. The Universal Soil Loss Equation can profitably be applied to mountainous regions of tropics for erosion prediction.

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