Assessing soil loss by water erosion in Jamni River Basin, Bundelkhand region, India, adopting universal soil loss equation using GIS

Ram Singh* and V. S. Phadke

Department of Geography, University of Mumbai, Mumbai 400 098, India

The present study uses the universal soil loss equation (USLE) developed by the United States Department of Agriculture, Agriculture Research Service, to predict soil erosion from a watershed. The land cover/landuse data at village level is collected from the Revenue Department, and detailed soil data from the All India Soil and Landuse Survey, New Delhi, are used in USLE for determining soil erosion rate. MapInfo Professional Version 5.5 GIS Software has been used as a platform for spatial data analysis required in the USLE. The potential soil loss has been estimated and mapped. Maps covering each parameter were integrated to generate a composite map of erosion intensity based on advanced GIS functionality. The map is expected to assist in the identification of priority areas of the basin and would thus help in future planning of a watershed and its sustainable development.

Keywords: Erosion, GIS, Jamni River, soil, universal soil loss equation, watershed.

THE soil has been termed by the International Soil Science Society as a 'limited and irreplaceable resource'. Growing degradation and loss of soil means that the expanding population in many parts of the world is pushing this resource to its frontier. In its absence, the biospheric environment of humans would collapse with devastating effects on humanity. Judson[1] was one of the first geologists to assess the world soil erosion. He estimated that the amount of river-borne soil carried into the oceans had increased from 9.9 billion tonnes a year before the introduction of agriculture, grazing and related activities, to the present rate of 26.5 billion tonnes a year. Hydrologists estimated that one-fourth of the soil lost through erosion in a watershed actually makes it to the ocean as sediment[2]. The remaining three-fourths is deposited on foothill slopes, in reservoirs, in river plains and other low-lying areas or in the river-bed itself, which often causes channel shifts. In an overview of global erosion and sedimentation, Pimental *et al.*[3] stated that more than 50% of the world's pastureland and about 80% of agricultural land suffer from significant erosion.

According to information published by the Ministry of Agriculture, Govt of India in 1980, as many as 175 mha constituting 53% of India's geographical area is subject to environmental degradation[4]. About 150 mha has been caught in the vicious circle of erosion by water and wind, the vehicles of erosion. One estimate puts the loss of top soil by water action at 1200 million tonnes every year[5]. This, even at a meagre price of Rs 10 per tonne, works out to a huge loss of Rs 12,000 crores annually. Some attempts have also been made to predict soil loss in India[6]. It may be worth noting that nature takes 200–400 years to build up 1 cm of top soil. It is reported that each millimetre of cultivated soil loss could cost 10 kg of nitrogen and 2 kg of phosphorus per ha.

The dislodgement of soil particles from the surface using energy imparted to it by falling raindrops is a primary agent of erosion, particularly on soils with sparse vegetative cover. The major result of the impulse imparted to the soil surface by raindrops to the deterioration of soil structure is by the breakdown of soil aggregates. The subsequent splashing of soil particles tends to puddle and close the soil surface, and thereby increase surface run-off.

Surface run-off, combined with the beating action of raindrops causes rills to be formed on the soil surface. Rill erosion produces the greatest amount of soil loss worldwide. Sheet erosion takes place between rills and thus is also called inter–rill erosion. If the channels formed on land are so deepened and widened by erosion that their size is greater than those of common rills, then the land is no longer readily usable. These channels carry water during and immediately after rains. Gullies are usually formed by waterfall erosion at the rill head, channel erosion caused by water flowing through the rill, alternate freezing and thawing of the exposed soil banks, and slides and other mass movements in them.

The catchment area of Jamni River, a tributary of the Betwa, is spread over parts of Lalitpur district, Uttar Pradesh (UP), and Tikamgarh and Sagar districts, Madhya Pradesh (MP) in Bundelkhand region (Figure 1). The area is drought-prone and socio-economically backward. It is spread over 4974 km^2 and had a population of about 722,000 in 1991. Erratic rainfall and barren degraded land promote significant surface run-off (34% of the total rainfall with frequency of drought and poor regenerating capacity of vegetation are the natural concomitants). This is further accentuated by pressure of human and cattle populations. Meagre irrigation resources lead to lack of employment opportunity.

In the present study, a well-known model for soil erosion estimation from a watershed, viz. the Universal Soil Loss Equation (ULSE) has been used. Data storage and analysis were carried out using MapInfo Professional Version 5.5 GIS package. Microsoft Excel software was also used for enabling GIS package to prepare maps, as also classification and tabulation of results.

Effective control of soil erosion requires the ability to predict the amount of soil loss which would occur under alternative management strategies and practices. The model

*For correspondence. (e-mail: rrupsing@rediffmail.com)

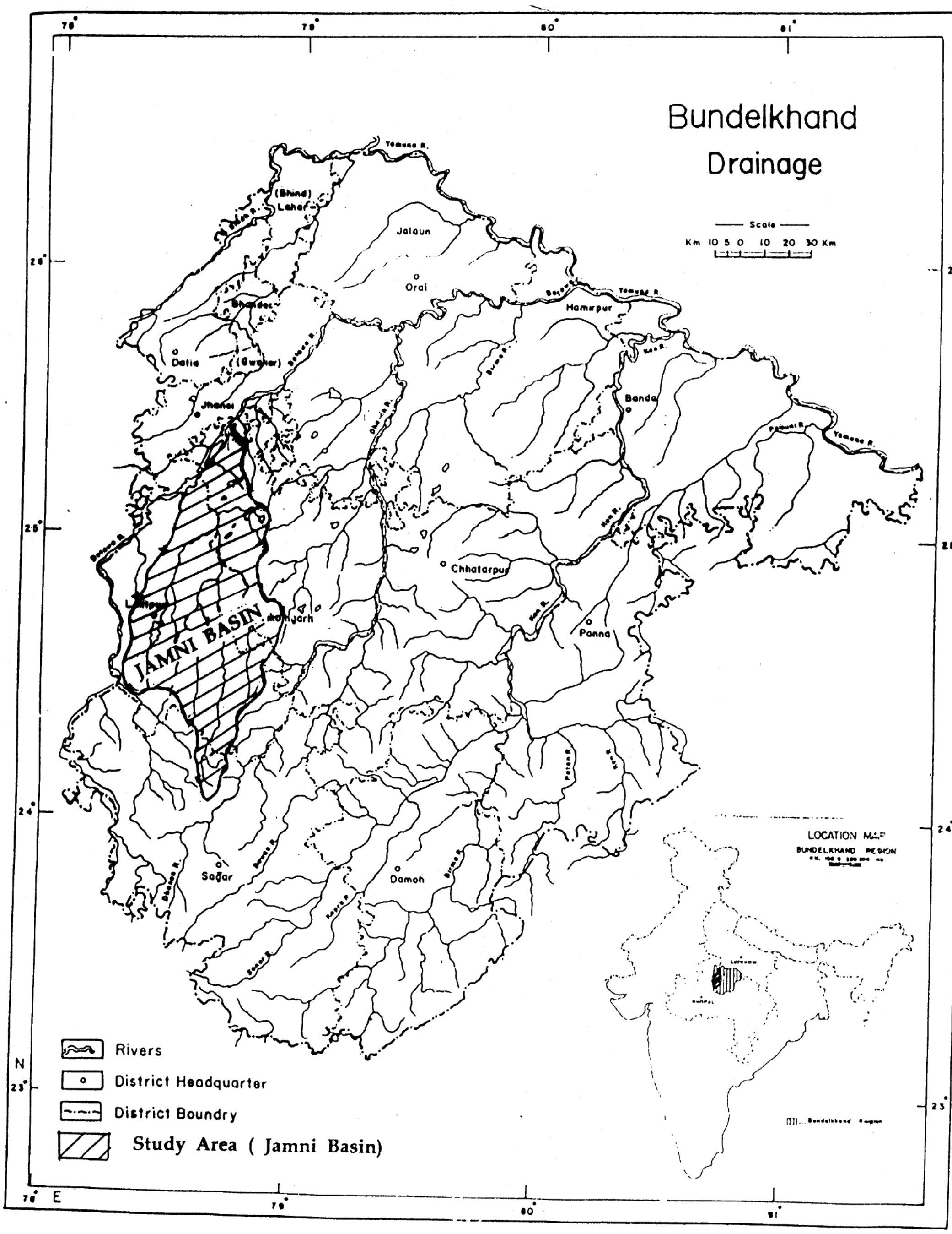

Figure 1. Location map.

having the greatest acceptance and use is the USLE, developed by Agriculture Research Services scientists[7]. USLE was used to determine quantitatively the erosion rate, taking into consideration other possibilities[8]. USLE can be stated mathematically as:

$$U = R \times K \times L \times S \times C \times P,$$

where U is the estimated potential average annual soil loss (tonnes/ha/yr), R the rainfall factor (measure of erosion force of soil which is expressed in tonnes/ha/mm/h), K the soil erodibility factor, L the slope length factor (m), S the slope gradient factor (%), C the cropping/landuse management, and P the soil erosion control practice factor.

$$R = 0.1059abc + 52,$$

where a is the average annual rainfall (mm), b the maximum 24 h rainfall (mm/24 h), and c the maximum 1 h rainfall with recurrence interval of 2 years.

$$K = 0.01292\,[(2.1w^{1.14})\,(12 - x)] + [3.25\,(y - z) + 2.5(z - 3)],$$

where x is the organic matter (%), w the silt (%), i.e. (100 – clay %), y the soil structure code, and z the profile permeability class.

The values of w, x, y and z can be used from a nomograph or the K value can also be calculated. In the present case, a nomograph was used to determine the K value[9].

$$L \times S = (l/22.1^{m})\,(0.065 + 0.045S + 0.0065\,S^2),$$

where S is the slope steepness in %, l the slope length and m depends on slope %.

The value of m is given in Table 1.

An integrated analysis of all the above parameters was performed using MapInfo Professional 5.5 software for each grid cell of 1 × 1 km. Soil loss is estimated for each cell using USLE by estimating the values of individual parameters with the help of Microsoft Excel package, which was then linked to MapInfo to prepare individual as well as composite map. The final results are shown in Table 2.

R values were calculated for six stations, namely Talbehat, Lalitpur, Mahrauni, Tikamgarh, Orchha, Bina and Sagar, within the study area. Mean annual average rainfall value and maximum 24 h and 1 h rainfall readings of the said stations were noted. The said data were fed into their corresponding cell code number in Microsoft Excel software.

The K factor is the same as soil erodibility factor and is directly related to the nomograph. For this factor all field data of the river basin from different sites in each terrain unit were collected by All India Soil and Landuse Survey, New Delhi.

The L and S factors were calculated from Survey of India toposheet (1 : 50,000) in the study area[10]. The toposheet (1 : 50,000) was divided into 1 km × 1 km square grid. According to cell code, slope length and slope gradient, factors were fed into the Microsoft Excel program. Slope length was used with respective slope gradient and used to compute the L factor. The L factor was multiplied by the slope gradient factor (S) to obtain the LS factor.

The C factor was directly obtained from the latest toposheet (1 : 50,000) for the concerned area, grid-wise. This was assigned according to cell code.

The study area comprises undulating piedmont plains, where normal agricultural practices are carried out, except in hills, where cultivation is along hill slopes. Hence these two classes had been used for P factor or soil conservation practice factor.

The data base was converted into a uniform scale (i.e. 1 : 50,000). This was made possible from cell code map. The six components which are spatially distributed all over the area were accurately identified. The cell code map of the river basin was then registered (84 × 181) grids with the grid size 1 × 1 km. Finally, all the cell code units were integrated into one final map. The final output shows spatial variations in the soil erosion rate and its supporting components.

Six potential erosion classes were demarcated in the final output erosion map. The result of each erosion class was shown by a different index. The detailed soil erosion classes along with their slope categories are tabulated (Table 3).

Grid cells falling under each soil loss range were counted and percentage of the basin area under each category was estimated (Table 4).

Other important parameters were then worked out (Table 5).

The pattern of soil erosion intensity in Jamni River Basin brings out a belt of high erosion intensity of over 25 tonnes/ha/yr in the southern part of the catchment area (Figure 2). This area is part of the Narhat Scarps and also stands out as area of steep slopes. High erosion intensity is an expectable feature. When this pattern is superimposed on the slope map, one finds that the area is underlain by steep slopes (>25%), and slope is the most important factor of high erosion intensity here. The pattern of change in forest cover mapped by using census data over two time

Table 1. *m*, *C* and *P* values

Slope %		*m* value
< 1		0.2
1 to 3		0.3
3 to 5		0.4
>5		0.5
C value	Stony/rocky	0.0336
	Forest	0.04
	Built-up land	0.024
	Cropped land	0.58
	Fallow land	0.60
	Water body	0.009
	Scrub	0.55
P value	Farming along hill slopes/hilly regions	0.8
	Farming on alluvial plains/undulating terrain	1.0
	Barren land	1.0
	Dense forest	0.8
	Fallow land	1.0
	Moderately dense forest	0.8
	Open forest	0.02
	River bed	1.0

Table 2. Classes of soil loss

Soil loss	Soil loss range (tonnes/ha/yr)
Very slight	0–4.99
Slight	5–9.99
Moderate	10–24.99
Severe	25–44.99
Very severe	> 45

Table 3. Soil erosion in relation to slope

Soil erosion (tonnes/ha/yr)/slope class (%)	75–100	45–74.99	25–44.99	10–24.99	05–9.99	00–4.99
35–60	07	50	–	–	–	–
20–35	–	10	168	–	–	–
10–20	–	–	133	–	–	–
05–10	–	–	12	66	–	–
01–05	–	–	–	23	15	–
00–01	–	–	–	–	–	4490
Total	07	60	313	89	15	4490

Figure 2. Soil erosion in the Jamni River Basin.

Table 4. Soil erosion rate of the river basin

Soil loss range	Percentage of basin area	Class
00–4.99	90.27	Very slight
05–9.99	0.30	Slight
10–24.99	1.79	Moderate
25–44.99	6.29	Severe
45–74.99	1.21	Very severe
75–100	0.14	Extreme severe

Table 5. Important parameters related to the basin

Minimum rate of soil erosion (tonnes/ha/yr)	0.00
Maximum rate of soil erosion (tonnes/ha/yr)	98.00
Mean	3.22
Standard deviation	± 10.63

periods, viz. 1981 and 1991, does not show deforestation in the area. However, field work by researchers indicated that a large number of trees are daily being cut by the tribals and transported to nearby towns for sale as a fuelwood. Private contractors are also bringing down the forested area. Deforestation is thus also a contributory factor for high erosion intensity. 'Chhutapashu' (roaming cattle) grazing system is another important factor contributing to soil loss, and density of animals here is much more than what the area can support.

Another area with high erosion intensity is found in the northern half of the basin that falls in the lower middle and lower catchment area. The important hills which occur in this area, viz. Kachhana, Nathikhera, Baradang, Tori, Bamori belong to Lalitpur (UP) and Jiraun, Mohangrah, Kumheri and Barapahar belong to Tikamgrah (MP). Here, slope factor plays a less important role compared to deforestation, which is prominent; the area has been finally brought under cultivation.

Rest of the area possesses intensity of less than 5 tonnes/ha/yr, as it is gently sloping. Moreover, there are some attempts at plantation. Being culturable lands, farmers make special efforts towards soil conservation.

The pattern of soil erosion in Jamni River Basin is highly uneven. Rugged physiographic disposition coupled with climatic conditions and human mismanagement are major factors responsible for soil erosion in the north and south. The undulating topography, coarse soil texture, low organic matter, lack of vegetation cover, and dry farming practices are the main factors which have made these soils highly erodible. These areas of the river basin are under a critical condition of deterioration with high rate of potential soil loss. Among the parameters of the USLE, topography is a factor of over-riding importance in determining the rate of soil loss. Variations in soil erodibility also seem to be influenced by soil management factor, especially in central parts of the river basin.

Thus, in the light of the gravity of the problem, the worst affected areas need immediate conservation measures like afforestation, scientific terracing and crop selection, which are important to conserve the land resources for long-term benefits. Otherwise it would result in environmental degradation followed by serious socio-economic consequences in this ecologically vulnerable tract. It should, however, be noted that such measures cannot be applied uniformly and it is necessary to adopt an area-specific approach. On the southern scrap, for example, afforestation would be more effective compared to degraded areas of the north, where measures related to improved cropping practices are sufficient.

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