IMPACT ASSESSMENT OF ALTERNATE LAND COVER AND MANAGEMENT PRACTICES ON SOIL EROSION: A CASE STUDY

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Abstract

Soil erosion is affected by climate, vegetation, topography, and man. Of these, vegetation and soil to some extent are the only factors which man can control. Erosion fills dam reservoirs and reduces dam's economical life. This affects the economy of a country to a large extent. To specify hazard and damage of soil erosion is essential. Among many environmental hazards, checking land degradation is of utmost importance. It also ends up affecting productivity on arable and non arable lands. To prevent the erosion and rapid siltation, management of water, soil cover and vegetation resources on watershed is a must. In the present study, the expected soil loss from Bina river watershed of Betwa river basin has been estimated using USLE model in GIS platform. About 4% of the total geographical area of the Bina watershed was found under very severe erosion with a rate of more than 120 t/ha/year. The average soil erosion for the Bina basin was found to be 8.7 t/ha/year. Impact of alternate land cover management practices have been analysed by hypothetically assigning the alternate land use practices and changing the values of controlling factors of USLE model accordingly. The best management practices to help increase food production and control soil erosion have been suggested.

Introduction

The soil has been defined by the International Soil Science Society as: A limited and irreplaceable resource and the growing degradation and loss of soil means that the expanding population in many parts of the world is pushing this resource to the maximum. In its absence the biospheric environments, man will collapse with devastating results for humanity. Fertile soils by carrying erosion fills dam reservoir and reduces the economical life of dams. To specify hazard and damage of soil erosion is very important for this reason (Choudhary and Nayak, 2003). Among many environmental hazards, checking land degradation is of utmost importance. It is estimated that about 80% of current degradation on agricultural land in the world is caused by soil erosion due to water (Angima et.al., 2003). It is estimated that India suffers an annual loss of 13.4 million tonne in production of major cereal, oilseed and pulses crops due to water erosion equivalent to about 2.6 billion dollars (Sharda et.al., 2010).

Reservoir sedimentation, resulting from degradation of the watersheds in India is on multiple rises as compared to the rate that was assumed at the time the projects. Wang et al. (2006) used the APEX (Agricultural Policy–Environmental eXtender) model developed in the United States to investigate soil erosion effects associated with alternative land uses at the ZFG (Zi-Fang-Gully) watershed in northwestern China. The results indicated that the APEX model could be calibrated reasonably well (615% errors) to fit those areas with .50% slope within the watershed. Wijitkosum (2012) studied the impacts of land use changes on soil erosion in Pa Deng sub-district, adjacent area of Kaeng Krachan National Park, Thailand, were investigated by applying remote sensing technique, geographical information system (GIS) and the Universal Soil Loss Equation (USLE). The study results revealed that land use changes in terms of area size and pattern influenced the soil erosion risk in Pa Deng in the period 1990–2010. The area with smaller land showed high risk of soil erosion.

Bina river, a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh has been selected for the study. In this paper the application of USLE model and GIS has been attempted for determining the quantity of soil erosion in present physical condition of the watershed.

Study Area

Bina river is a major tributary of River Betwa in Bundelkhand region of Madhya Pradesh, which originates from Begumganj block of Raisen district and enters Sagar district at Rahatgarh block and traverses through Khurai and Bina tehsil before confluence with river Betwa near Basoda town in Vidisha district. Presently, domestic water is supplied to Rahatgarh, Khurai and Bina town. Railway requirement at Bina Railway Junction and industrial supplies for Bina Refinery and proposed JP power project is met from this river besides irrigation through direct pumping. "Bina Complex-Irrigation and Multipurpose Project" has been proposed for four dams, the Madia dam and Chakarpur dam-cum-pickup weir on Bina river and one each on Dehra and Dhasan rivers, which are the tributaries of river Betwa. The Index map showing the Bina river watershed up to the confluence with Betwa river is shown in Fig.1. The watershed under consideration falls between 23º18' to 24º15' N latitudes and 78º03' to 78º32' E longitudes having total geographical area of 2817 sq.km.

The average normal annual rainfall of the area is 1329.56 mm, and on an average 28 days of rainfall happens in a year. About 90% of the annual rainfall takes place during the monsoon period. Only 5.5% of annual rainfall takes place during winter and about 4.5% of rainfall occurs during the summer season. During winter, January is the coldest month with the average minimum temperature of 11.5˚C, whereas the hottest month is May with average maximum temperature up to 40.9˚C. The topography of the area is rolling to undulating. The land slope is characterized by flat topped hillocks.

Methodology

In the present study, the well-known model for soil erosion estimation from a watershed, the Universal Soil Loss Equation (USLE) has been used. The thematic maps were prepared using remote sensing imageries and data storage & analysis were done using ILWIS Geographic Information System (GIS).

The Universal Soil Loss Equation Model

In 1958, Wischmeier, a statistician with the Soil Conservation Service, was put in charge of analyzing and collating over 10000 annual records of- erosion on plots and small catchments at 46 stations on the Great Plains. The model with the greatest acceptance and use is the Universal Soil Loss Equation (USLE), developed by Agriculture Research Services (ARS) scientists Wischmeier and D. Smith (1978) to estimate soil erosion from fields. Mathematically the equation is denoted as:

$$\mathbf{A = R * K * L * S * C * P} \qquad (1)$$

A = Annual soil loss (tons/ha/year)
R = Rainfall and runoff erosivity index
K = Soil-erodibility factor
L = Length of slope factor
S = Degree of slope factor
C = Cropping-management factor
P = Conservation practice factor

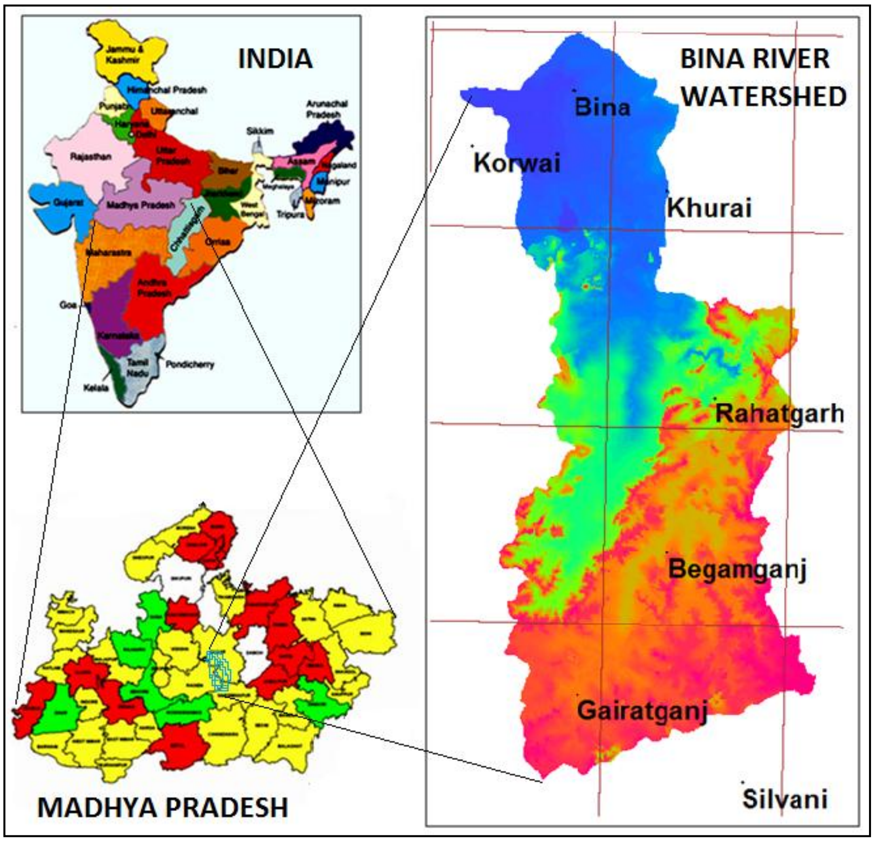


Fig. 1: Index map showing Bina river watershed

Rainfall Erosivity index (R)

R, the rainfall erosivity index,is equal to product of E, the kinetic energy of rainfall, and I_{30} (maximum rainfall intensity in 30 minutes expressed in cm per hour). This index corresponds to the potential erosion threat in a given region where sheet erosion appears on a bare plot with a 9% slope. In India, simple relationship between erosivity index (R) and annual or seasonal rainfall (X) has been developed by Singh et al, 1981 after analyzing the data collected from 45 stations distributed in different rainfall zones throughout the country (Choudhary and Nayak).

$$R_a = 79 + 363.079 * X_a \quad (2)$$
$$R_s = 50 + 389.050 * X_s \quad (3)$$

For this study seasonal rainfall index i.e R_s is used for R value.

Soil Erodibility Factor (K)

The K factor represents both susceptibility of soil to erode by an amount and rate of runoff. K depends on the texture and organic matter content of the soil, its permeability and profile structure. It varies from 0.7 for the most fragile soil to 0.01 for the most firm soil. It is measured on bare reference plots 22.2 m long on 9% slopes, tilled in the direction of the slope and having received no organic matter for three years (http://www.grr.ulaval.ca). It quantifies the cohesive character of a soil type and its resistance to dislodging and transport (particle size and density dependent) due to raindrop impact and overland flow shear forces. K is a function of complex interaction of a substantial number of its physical and chemical properties. A simpler method to forecast K was presented by Wischmeier et al. which includes the particle size of the soil, organic matter content, soil structure and profile permeability (Wischmeier et.al.).

The Topographic Factor (L & S)

SL, the topographical factor, depends on both the length and gradient of the slope. Value varies from 0.1 to 5 in the regular farming lands, and may reach up to 20 in hilly areas. The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by (Wischmeier and Smith 1978).

$$LS = (\lambda/22.1)^{.5} * (0.065 + 0.045\,G + 0.0065G^2) \qquad (4)$$

Where λ = slope length (m) and G = percentage slope gradient. Slope percentage layer was derived from digital elevation model (DEM) of the study area and slope length was assumed to be fixed for each pixel (100 m). The values of G and λ will be derived from DEM.

Cropping Management Factor (C)

The plant cover factor, C, is a simple relation between erosion on bare soil and erosion observed under a cropping system. It is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions. It measures the combined effect of vegetation cover and management variables. It varies from 1 on bare soil to 0.001 under forest, 0.02 under grasslands and cover plants, and 1 to 0.9 under root and tuber crops.

Conservation Practice Factor (P)

The conservation practice factor, P, is the ratio of soil support practice to the corresponding loss with up and down slope culture. Practices induced in this term are contouring, terracing (alternate crops on a given slope established on the contour), strip cropping. P is a factor that takes account of specific erosion control practices such as contour tilling or, contour ridging or mounding. Value varies from 1 on bare soil with no erosion control to about 0.25 with tied ridging on a gentle slope.

Application of ILWIS GIS Tool

The Integrated Land and Water Information System (ILWIS) has the capability of analyzing the Remote Sensing (RS) data as well as Geographic Information System (GIS). ILWIS multiplies the map by overlaying these maps one over another. Hence it becomes very essential for all maps to be rasterized with same pixel size. All the factors required for soil erosion estimation as given in the equation 1 were calculated using ILWIS GIS software and stored as thematic maps in raster format. These maps were then multiplied together to generate the soil erosion map using Map Calculation operation .The approach is made to observe how severe the specific area is by generating a classified map of various erosion class such as 0-10, 10-20, 10-20, 20-40, 40-80, 80-120, >120 etc. The sensitivity analysis will also been done by assigning the barren land as forest cover, agricultural land with good management practices, etc. to see the changes in the quantity of soil erosion from the catchment area. The analysis is helpful for planning the watershed management practices, such as afforestation, contour bunding, gully plugging, etc. Histogram of Erosion map can be used in calculating the total soil erosion of the catchment. The histogram provides total number of pixels falling in each erosion intensity, the number of pixels can be multiplied with the corresponding mid value of erosion intensity to get the total soil loss.

Data Processing & Parameter Estimation

Rainfall Erosivity Factor

Total seven raingauge stations namely Bina, Kurwai, Khurai, Rahatgarh, Begumganj, Gairatganj and Silvani fall in and around Bina river basin. The annual rainfall observed at these stations available for last fifteen years were collected. The seven rain gauge stations were marked on the basin map and stored as point map. The Interpolation operation on the point map was carried out by choosing the Criging interpolation method to get the distributed rainfall map in Raster format. Further, using the MapCalc operation in GIS, the rainfall map was converted into the 'R' Factor map by applying the equation-2 and the output map was named as 'rfactor'. The average annual rainfall observed at seven rain gauge stations and corresponding R-factor values are given in Table-1.

Table 1: Rainfall distribution in Bina river basin

S. No.	Raingauge Station	Av. Annual Rainfall (mm)	R-Factor
1	Bina	1064.1	465.3
2	Korwai	1002.5	442.9
3	Khurai	1193.3	512.2
4	Rahatgarh	1166.9	502.6
5	Begamganj	1209.2	517.9
6	Gairatganj	1183.8	508.7
7	Silvani	1067.3	466.4

Soil Erodibility Factor

The organic matter (O.M.) contents in these soils are reported about 2%. K values was determined based on locally measured soil properties and using soil erodibility factor monograph for great soil groups in India. These values were annual averaged corresponding to homogeneous different soil groups as shown in Figure-2. K values for study area are shown in Table-2.

Table 2: Distribution of soil class and 'K' value

Code	Soil Class	Area	K-Factor
203	Fine sandy loam	9.36	0.35
305	Silty loam	366.02	0.38
311	Silty clay loam	162.82	0.32
314	Heavy clay	203.82	0.17
315	Silty clay	580.64	0.26
317	Clay loam	291.89	0.30
325	Sandy loam	21.85	0.13
342	Coarse sandy loam	14.49	0.07
352	Fine sandy loam	7.68	0.18
355	Sand	24.02	0.02
362	Clay	12.45	0.22
376	Silty clay loam	328.18	0.32
377	Sandy clay loam	395.43	0.20
398	Loamy fine sand	389.43	0.11

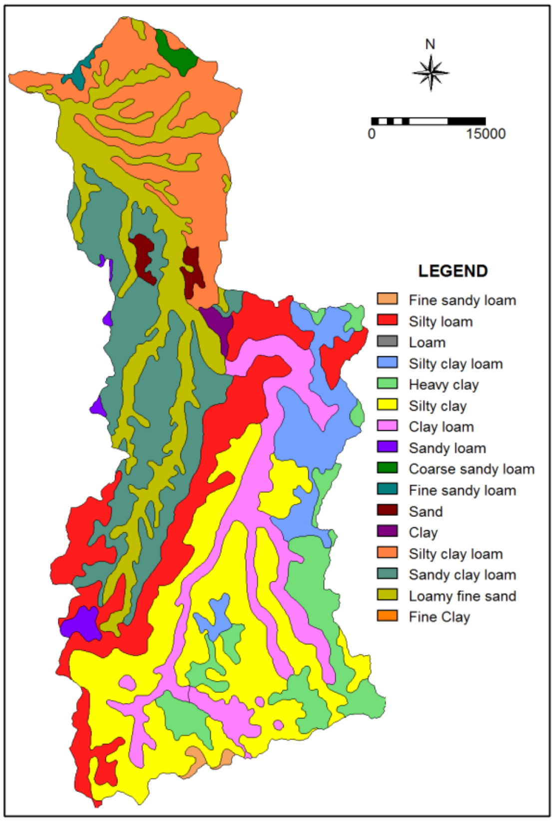


Fig.2: Soil map of Bina river basin

Topography Factor (S, L)

Contour lines given in the Survey of India topographic maps were digitized and the corresponding heights above mean sea level (Contour values) were assigned to each line. The contour lines at 10 m intervals and the spot heights available at some places have also been digitized and stored in vector format as segment/point maps 'isoline'. To create a Digital Elevation Model (DEM) map, interpolation of the segment map 'isoline' was done via the operation InterpolSeg in ILWIS GIS. The DEM map thus generated is a raster map showing the elevation or height above mean sea level at each pixels in the study area as given in Figure-3. Slope length factor map was generated by using the equation no. 4.

Crop Management (Land Use) Factor

The ILWIS GIS software has the capability of Digital Image Processing (DIP) capabilities also. The landuse map was prepared by applying Maximum Likelihood Classifier (MLC) digital classification of multi-date LISS-IV Satellite data acquired from the National Remote Sensing Centre (NRSC), Hyderabad. The land use map of Bina river watershed is given in Figure-4 and spatial distribution of all the five land use classes is given in the Table-3.

Table 3: Landuse map and 'C' factor for Bina river basin

Sl. No.	Landuse Class	Area in Sq.km.	% of Basin Area	'C' Factor
1	Agriculture-1	121.32	4.3	0.25
2	Agriculture-2	786.70	28.0	0.28
3	Current fallow	450.15	16.0	0.30
4	Dense forest	140.61	5.0	0.02
5	Open forest	543.76	19.4	0.05
6	Scrub land	490.28	17.5	0.15
7	Barren land	116.23	4.1	0.45
8	Settlement/ rock outcrop	151.90	5.4	0.20
9	Water body	7.13	0.3	0.001

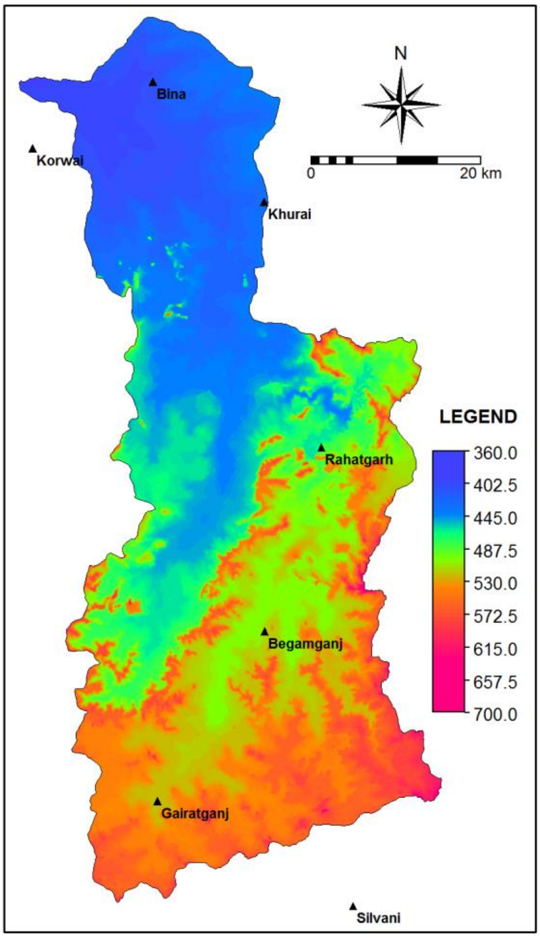
Conservation Practice Factor (P)

The classified slope map slope class was attributed to P factor values to create a raster map of conservation practices factor. The non-agricultural lands (forest, shrubs/bushes and barren/grazing land) were assigned value 1.0 for P factor.

Results and Discussion

Estimation of Expected Soil Erosion

The various maps having the values of factors responsible for soil erosion, i.e. R, K, LS, C and P were brought in the form of raster maps as affirmed previously to obtain the soil loss. Multiplying the R, K and LS maps gave the potential soil erosion of the catchment. The expected soil loss map 'USLE' was obtained by multiplying all the six factor maps. The USLE map was again classified into distinct group of erosion intensities to create the classified expected soil loss and the result has been presented in Table 4. By this assessment it can be clearly observed that almost 4 % of the catchment is prone to very severe erosion condition and 2.3 % is under severe erosion situation.



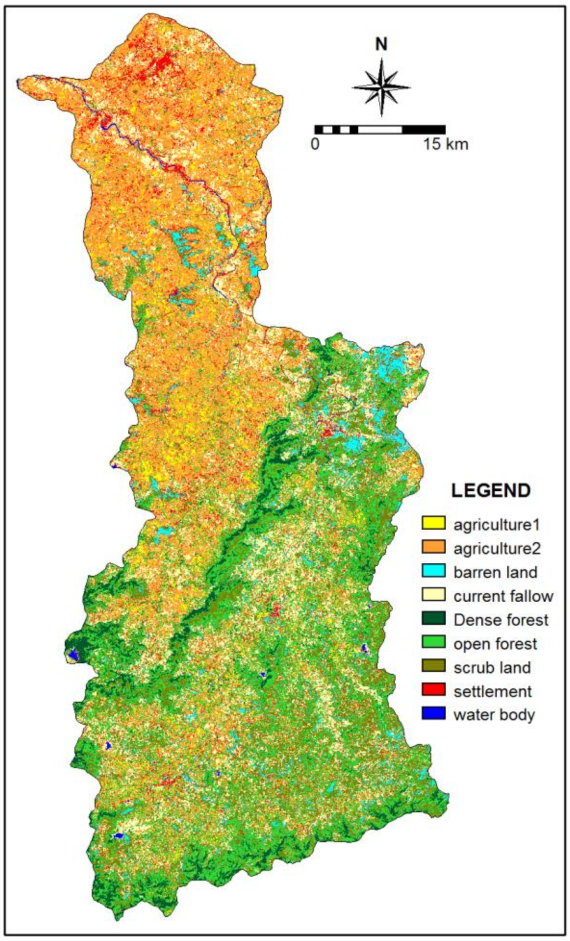


Fig.3: Digital Elevation Model (DEM)

Fig.4: Landuse map of Bina river basin

The quantity of actual soil erosion calculated by USLE model comes out to be 8.72 Million tones/year. This value can be converted in terms of volume by dividing the same with the specific gravity of the sediment load, i.e. 1.1 tones/m^3. Thus, the soil erosion from the Ravishankar catchment will be 7.9 Mm^3/year

Table-4: Potential/Expected soil loss of Bina river basin

Sl. No.	Erosion Class	Erosion Value (t/ha/year)	Potential soil loss		Expected soil loss	
			Area (Sq.km.)	Percent to Total Area	Area (Sq.km.)	Percent to Total Area
1	Very Low	0 – 05	286.50	10.20	1959.90	69.80
2	Low	05 – 10	477.55	17.01	410.16	14.61
3	Moderate	10 - 20	1005.50	35.81	213.55	7.61
4	High	20 - 40	519.53	18.50	94.49	3.36
5	Very High	40 - 80	200.98	7.16	69.43	2.47
6	Severe	80 - 140	88.18	3.14	30.12	1.07
7	Very Severe	> 140	229.85	8.18	30.43	1.08
	Total		**2808.08**	**100.00**	**2808.08**	**100.00**

Alternative Strategies to Reduce Soil Erosion

The impact of land use/land cover changes in the watershed area can be well analysed in GIS. However, the temporal changes can not directly be modeled in the GIS, but the changes in values of different parameters due to change in land use/land cover can be redefined in the GIS. Expected soil loss in a watershed may be estimated by assigning the new values for cropping management practices assuming the alternate land cover. The primary purpose for conducting raster based USLE model simulations is to assist local policymakers to change the land use within the Bina river watershed. One of the major challenges is to identify strategies that reconcile the inherent conflict between food production and soil protection in the area. The proposed alternatives reflect alternative land use practices. Obviously, USLE modeling cannot answer all policy questions, but it may assist with defining: (i) the environmental effects of alternative land uses and (ii) the watershed management practices.

The six land use scenarios simulated include:

- (i) the base,
- (ii) all forest planting in open forest and scrubland,
- (iii) open forest in 50% scrubland and 50% barren land,
- (iv) all grain production in barren land upto 5% slope,
- (v) all grass growth in barren land,
- (vi) all grain production in barren land upto 5% slope, and forest plantations in > 5 % slope & in scrub land.

The USLE model has been run for all the six scenarios and gross annual soil loss in the Bina watershed has been computed for different scenarios. The quantity of annual total soil loss in case of different scenarios has been worked out as shown in Table 5.

Table 5: Expected soil loss in different scenarios assumed for Bina watershed

Scenario	Assumptions on land use changes	Soil loss (t/year)	% change from base
S-I	The base	24.416	Base
S-II	All forest planting in open forest and scrubland	22.137	-9.33
S-III	Open forest in 50% scrubland and 50% barren land	23.289	-4.62
S-IV	All grain production in barren land upto 5% slope	26.444	8.31
S-V	All grass growth in barren land	25.148	3.00
S-VI	Scenario-IV with forest plantations in barren land with more than 5% slope and in scrub land	21.712	-11.07

Discussion of Results

It is seen from the results that the forest plantations in half of the scrub land and barren land is found to be very effective measure for controlling soil erosion. The total expected soil erosion reduced by plantation (S-II) from the present value of 24.416 t/yr to 22.137 t/yr, i.e. by 9.33%. Whereas, the grain production in barren land upto 5 % (S-IV) increases the total expected soil erosion by 8.31%. But, the crop land is necessary to produce food grains for the livelihood of the local population, which increase the soil erosion. In order to keep the total soil loss at minimum, the increase in soil loss due to increase in cropland by converting (barren land into arable land must be counter balance by planting in the high slope barren land (with > 5% slope) and scrub land in the Bina watershed (S-VI), in this scenario, the total soil erosion would be reduced by 11.1%.

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