Proceedings WARMICE-2012
Sudhir Kumar, et al. (eds)
I.A.H., 2012

IV-10

Soil Erosion based Prioritization and Development of CAT Plan for Catchment: A Case Study of Bundelkhand

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Abstract : Comprehensive land development procedures attract special attention in many countries that enable soil and water conservation, better and productive land use and optimum and effective use of available natural resources. The prioritization of watershed helps in taking up soil conservation measures on the priority basis in which recent technology of remote sensing and Geographic Information System (GIS) plays important role because of easy handling and manipulation of spatial information and data. After determining the priority sub-watersheds, the scientifically developed catchment area treatment (CAT) plan may be able to check the movement of eroded particles towards reservoir and also helpful in maintaining the availability of water during summer through conservation structures and preservation of soil moisture for healthy growth of flora and fauna in the region.

In the present study, prioritization of sub-watersheds and development of CAT plan for soil and water conservation were carried out for the catchment of Rangawan reservoir situated in Bundelkhand region of Madhya Pradesh. The Bundelkhand region of M.P. can be characterized with degraded land, undulated topography, frequent drought, limited soil depth susceptible to high rate of erosion. The catchment area of Rangawan reservoir has been divided in to 39 sub-watersheds. Average annual soil loss from the different land forms and land uses of the watershed was estimated using universal soil loss equation (USLE). The average annual soil loss in the sub-watersheds varies between 0.4 and 35.8 tones ha^{-1} $year^{-1}$. On the basis of annual soil loss, priorities of sub-watersheds have been fixed for soil conservation measures. WS-13 has been found the most environmentally stressed sub-watershed where average annual soil loss is 21.94 tones ha^{-1} $year^{-1}$and WS-35 can be taken at the last for soil conservation works where soil loss is 1.59 tones ha^{-1} $year^{-1}$. Overlaying of various thematic maps including drainage, soil, land use, geomorphology and slope, a CAT plan for the priority sub-watersheds have been developed consisting 121 boulder bunds, 9 check dams, 88 gully plugs and 1 percolation tank.

INTRODUCTION

India is basically an agrarian country with a total geographical area of 328.7 Mha and gross cropped area of 177 Mha. Increasing population pressure has resulted in a considerable shift of land use and environmental deterioration leading to a decline in the availability of land. The soil erosion from catchment areas and the subsequent deposition in rivers, lakes and reservoirs are of great concern for two reasons. Firstly, rich fertile soil is eroded from the catchment areas. Secondly, there is a reduction in reservoir capacity as well as degradation of downstream water quality. Sediment particles originating from the continuous process of erosion in the catchment area propagated along the river flow. When this flow accumulates into the reservoir, the sediment that has been carried with the stream gets settled into the reservoir and reduces its capacity. Reduction of storage capacity of a reservoir beyond a certain limit hampers the purpose of the reservoir for which it was designed.

Soil and water conservation are key issues in watershed management and development of catchment area treatment plan. Soil being one of the potential resources of a watershed demands proper conservation and management and it could only be possible if its degree of degradation is assessed properly. Soil conservation strategies are to be planned according to the severity of the extent of the soil erosion problem. The severity of erosion can be evaluated by the priority delineation of the watershed considering many factors, the important fed among them being the annual erosion soil loss and morphometric analysis. The prioritization of watershed helps in taking up soil conservation measures on the priority basis. For the prioritization of watershed remote sensing based inputs in ILWIS (3.6) have been used for analysis of spatial distribution of erosion parameters. For prioritization of sub-watershed, among the several methods, sediment yield index (SYI) method proposed by Bali and Karale (1977) and universal soil loss equation (USLE) proposed by Wischmeier and Smith (1978) are extensively used.

The USLE has been widely applied at a watershed scale on the basis of lumped approach to catchment scale (Jain *et al.*, 2001). Remote sensing provides convenient solution for this problem. Further, voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of Geographical Information Systems (GIS). Renschler *et al.* (1997) used USLE and RUSLE to predict the magnitude and spatial distribution of erosion within a GIS environment using ILWIS software in catchment of 211 km^2 at grid resolution ranging from 200 to 250 m to be more reasonable. Roza (1993) described the advantages of GIS and showed that GIS can be used to study agricultural lands susceptible to soil erosion. The universal soil loss equation (USLE) was the most widely used predictor of soil erosion for agricultural lands. Shinde *et al.* (2010) used universal soil loss equation (USLE) interactively with raster-based geographic information system (GIS) has been applied to calculate potential soil loss at micro watershed level in the Konar basin of upper Damodar Valley Catchment of India. Average annual soil erosion at micro watershed level in Konar basin having 961.4 km^2 areas was estimated as1.68 t/ha/yr. Further, micro watershed priorities have been fixed on the basis of soil erosion risk to implement management practices in micro watersheds which will reduce soil erosion in Konar basin.

STUDY AREA

The catchment of Rangawan reservoir situated in Chhatarpur district in Bundelkhand region of Madhya Pradesh has been selected for prioritization purposes. The Rangawan dam project is a major interstate irrigation project of Madhya Pradesh (M.P.) and Uttar Pradesh (U.P.) situated near village Rangawan in Rajnagar Tahsil of Chhatarpur district. The construction of head work of this project was done by Uttar Pradesh Irrigation Department and was completed in the year 1957. The length of earthen dam is 1.829 km with catchment area is about 731.70 km2. The gross storage capacity of Rangawan reservoir up to F.R.L. is 163.574 MCM with live storage capacity and dead storage capacity are 156.075 MCM and 7.499 MCM respectively.

The watershed boundary of the study area was delineated using SOI toposheets (54p/13, 54p/14, 54p/9, 54p/10, and 54p/6) on 1:50000 scale. The drainage network was also delineated from toposheet. The delineated watershed boundary was further divided into thirty nine sub-watersheds. The sub-watersheds along with the boundary were selected for priority analysis.

DATA USED

For estimation of soil loss for prioritization of sub-watersheds in Rangawan reservoir catchment, toposheets at scale of 1:50,000 from Survey of India were used for creation of thematic maps including drainage, sub-watersheds, contours, digital elevation model etc. LISS III remote sensing data of Indian Remote Sensing (IRS) satellite P6 of path-99 and row-54 of Jan 18 2009 has been used for land use analysis in the study. The daily rainfall data of Chhatarpur district has been used for soil loss estimation and the soil map of All

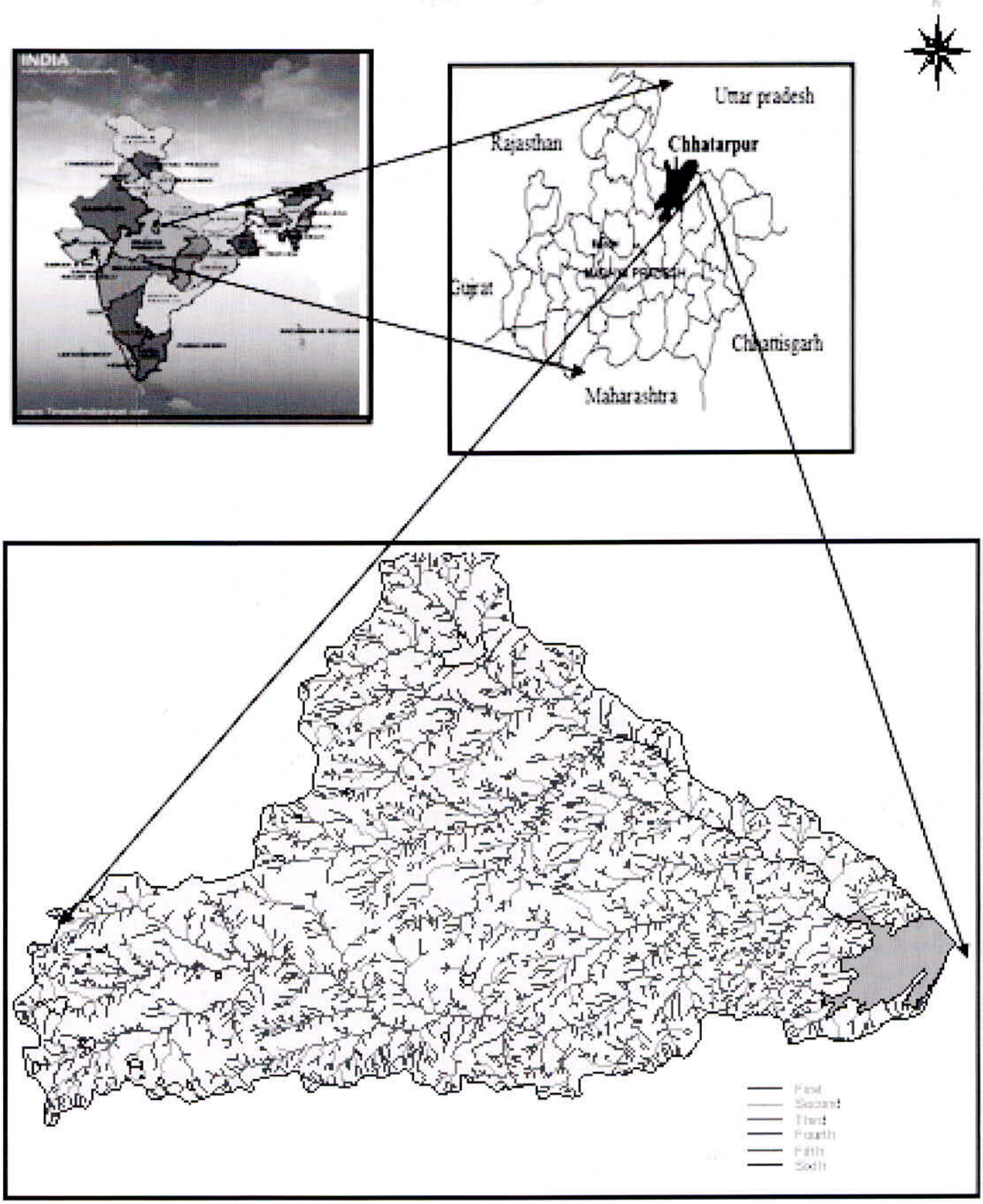

Fig. 1. Location map of Rangawan Reservoir Catchment Area

India Soil Survey and Land use Planning (AISS&LUP), Govt. of India, were used for the soil information of the catchment.

MATERIALS AND METHOD

In the study, the soil loss from sub-watersheds of Rangaan reservoir catchment has been computed using USLE model and CAT plan developed by overlaying of different thematic maps.

USLE Model

Annual soil loss in the form of runoff from different land forms and land uses of the watershed was estimated using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE states that the field soil loss in tones per hectare, A, is the product of six causative factors as given by following Eqn.

$$A=R*K*L*S*C*P \quad (1)$$

Where, A is the computed soil loss caused by sheet and rill erosion ($t\ ha^{-1}\ yr^{-1}$), R is the rainfall erosivity, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover and management factor (dimensionless varies from 0 to1) and P is the support practice factor (dimensionless varies from 0 to1).

Rainfall erosivity factor, R

The R-factor is defined as the product of kinetic energy and the maximum 30 minute intensity and shows the erosivity of rainfall events (Wischmeier and Smith, 1978). Rainfall erosion index implies a numerical evaluation of a rainstorm or of a rainfall pattern, which describes its capacity to erode soil from an unprotected field. The various intensities involved in a specific rain, i.e., antecedent climatic and surface conditions, interaction effects, and extraneous variable all influence the erosion potential of a storm. Keeping the soil and slope parameters constant, studies indicated that the valuable combination of indicators of erosion loss from fallow soil is rainfall energy, a product term which measures the interaction effect of storm energy and maximum prolonged intensity, antecedent moisture index and total antecedent rainfall energy since the last tillage operation.

In India, using 45 stations, distribution in different rainfall zones, simple linear relationship between erosivity index and annual or seasonal rainfall has been developed (Singh et al. 1981).

Annual R factor,

$$Ra = 79+0.363 * P \quad ....(2)$$

Seasonal R factor,

$$Rs = 50 + 0.389 * P \quad ....(3)$$

Where, P is the rainfall in mm.

Soil erodibility factor, K

The K-factor is defined as the rate of soil loss per unit of R-factor on a unit plot (Renard *et al.* 1997). The soil erodibility factor relates the rate at which different soils erode. K is expressed as soil loss per unit of area per unit of R for a unit plot (a plot of 22.3m long with a uniform slope of 9% under continuous fallow and tilled parallel to the slope). Direct measurement of soil erodibility factor is both costly and time consuming and has been feasible only for a few major soil types. This factor was originally determined quantitatively from the runoff plots. Rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Romkens, 1985). The direct measurement of K on unit runoff plots reflect the combined effects of all variables that significantly influence the ease with which a soil is eroded or the particular slope other than 9% slope. The soil loss is adjusted through slope factor S. Therefore, considerable attention has been paid to estimating soil erodibility from soil attributes such as particle size distribution, organic matter content and density of eroded soil (Wischmeier *et al.* 1971).

Slope length & steepness factor, LS

LS are the slope length-gradient factor. The LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22.13 m. The steeper and longer the slope, the higher is the risk for erosion. The value of exponent is variable (0.2 to 0.5) and very rarely 0.9 for different locations and other conditions. The LS-factor can be computed using the following equation:

$$LS = \left(\frac{\lambda}{22}.13\right)^{m} * [0.065 + 0.045G + 0.0065G^2]$$

where, ë is the field slope length, m is the exponent varies from 0.2 for slope less than 1%, 0.3 for slope from 1% to 3%, 0.4 for slope from 3% to 5% and 0.5 for slope more than 5% slope and G is the slope gradient in percent.

Cover and management factor, C

The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978). It measures the combine effect of vegetation cover and management variables. The vegetation cover protects the soil surface from direct impact of the falling raindrops and enhances the degree of infiltration, maintains roughness of the soil surface, slows down surface runoff, binds soil mechanically by root effects and improves physical, chemical and biological properties of soil. The plant cover factor, C, expresses the relation between erosion on bare soil and erosion under cultivation.

Support practice factor, P

The P-factor gives the ratio between the soil loss expected for a certain soil conservation practice to that with up-and down-slope ploughing (Wischmeier and Smith, 1978). Specific cultivation practices affect erosion by modifying the flow pattern and direction of runoff and by reducing the amount of runoff (Renard and Foster, 1983). The amount of soil loss from a given land is influenced by the land management practice adopted. The P-factor considers specific erosion control practices such as contour tilling or contour ridging. The absence of any measures is expressed by a value of 1; the factor is about 0.1 when tied ridging is applied on a gentle slope (Roose, 1996).

Development of CAT Plan

The CAT plan arrest degradation of lands through capture the flow of water on slopes and prevent the transportation of soil from higher level to that of lower level, the water harvesting structures store the water and improve the ground water strata. The CAT plan deals with the preparation of a management plan for treatment of erosion prone area of the catchment through mechanical, biological and agronomic measures. The spatial thematic information was used to develop the Catchment Area Treatment (CAT) plan to optimally utilize the resources for sustainable agriculture in terms of land and water resource development for the Rangawan Reservoir Catchment Area. The CAT plans were prepared digitally by creating the various thematic and base maps using ILWIS (3.6) GIS software. The land use, soil, hydro-geomorphology, slope and watershed themes were built as polygon features, whereas streams and roads were built as line features.

RESULTS AND DISCUSSION

Development of Thematic Map of USLE Factors

Estimation of soil loss from the catchments is necessary for planning of conservation measures in the catchment areas. In the present study, soil loss from the Rangawan reservoir catchment has been estimated using USLE model. ILWIS (3.6) software has been used for generation of various factor maps

Rainfall erosivity (R) factor

The precipitation data from the surrounding meteorological stations namely Bijawar, Chhatarpur and Rajnagar were used for estimating the average annual precipitation (AAP), over the entire watershed with the help of theissen polygon method. The estimated AAP was used for calculation of the rainfall erosivity factor (*R*) in ILWIS (3.6). The *R*-factor varied from 408.41 to 458.93 MJ mm $ha^{-1}h^{-1}$ yr^{-1} as shown a Figure 2.

Soil erodibility (K) factor

The soil erodibility (*K*) factor is a quantitative description of the inherent erodibility of a particular soil type. The K factor reflects the fact that different soils erode at different rates when the other factors that affect erosion remain the same. Soil texture is the principal cause affecting the K-factor, but the soil structure, organic matter content and permeability also contribute. The soil of study area divided into different soil group with varying soil characteristics. Table 1 represents the soil erodibility factor (*K*) of the soil group of study area based on the soil texture class and description of the soil groups. A map for the *K*-factor was produced based on the soil map and soil erodibility texture. The *K*-factor in the present study area varied from 0.200 to 0.340 t ha h ha^{-1} MJ^{-1} mm^{-1} as shown in Figure 2.

Slope length & steepness (LS) factor

The factors of slope length (*L*) and slope steepness (*S*) are combined in a single topographic index termed *LS* factor. Many researchers have used these two *L* and *S* factor as combined *LS* factor. The *LS*-factor in the present study area estimated using the Eqn.4 varied from 0.79 to 0.91 as shown in Figure 2.

Table 1. factor for different soil groups

Soil groups	Description	K factor
227	Slightly deep, well drained loamy soils gently sloping foothills with lower pediments with moderate erosion and slightly stony	0.220
243	Deep, moderately well drained, clayey soils on gently sloping plans with moderate erosion and slightly stony	0.200
489	Slightly deep, well drained loamy soils on moderately sloping residual hills with isolated hillocks with severe erosion and moderately stony	0.240
496	Slightly deep, well drained loamy soil on gently sloping undulating uplands with mounds with moderate erosion and moderately stony	0.240
499	Slightly deep, well drained loamy soil on gently sloping undulating uplands (slightly dissected) with moderate erosion	0.240
507	Very shallow, somewhat excessively drained loamy soils on moderately sloping undulating uplands with valleys with severe erosion and slightly stony	0.340
512	Slightly deep, well drained loamy soil on gently sloping plan lands with moderate erosion and slightly stony	0.240
517	Slightly deep, well drained loamy soil on gently sloping plan lands (slightly dissected) with moderate erosion	0.340

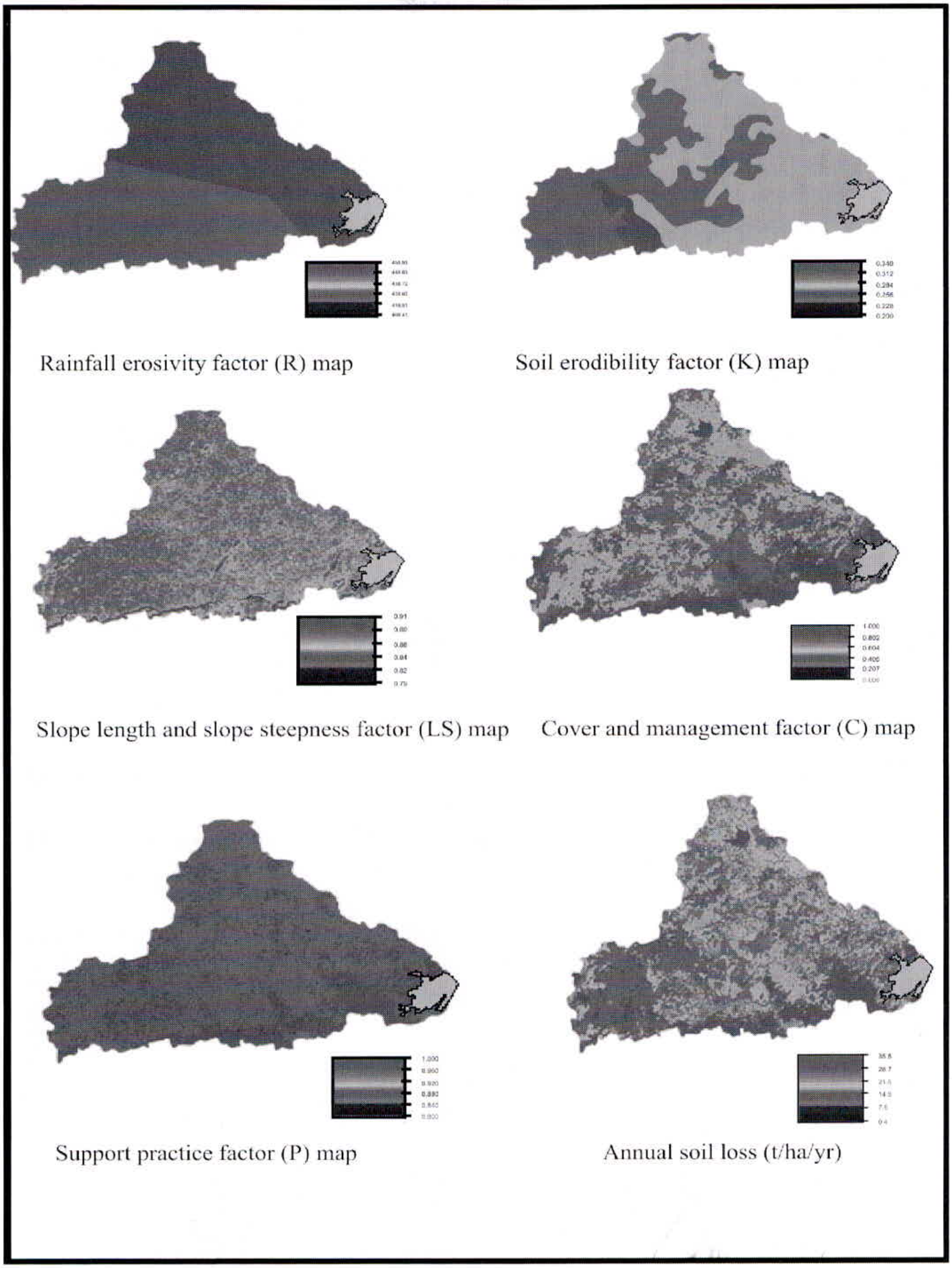

Fig. 2. USLE maps of Rangawan reservoir catchment

Cover and management (*C*) factor

The ratio of soil loss under given crop to that from bare soil is represented as crop management factor *C*. The value of cover and management factor ranges from 1 to approximately 0, where higher values indicate no cover effect and soil loss comparable to that from a tilled bare fallow and while lower *C* means a very strong cover effect resulting in no erosion (Erencin, 2000).The cropping management factor for different land use patterns in the Rangawan reservoir catchment are given in the Table 2. In order to determine C factor, Rangawan reservoir catchment was classified into 6 land uses classes generated from remote sensing image (IRS LISS III) data.

Conservation Practices (P) factor

The P-factor is a ratio between erosion occurring in a field treated with conservation measures and another reference plot without treatment. Therefore, erosion control practice factor is based on the soil conservation practices operated in a particular area. The *P* values range from 0 to 1, whereby the value 0 represents a very good man made erosion resistance facility and the value 1 no man made resistance erosion facility. Table 2 shows the value of conservation practices factor according to the different land use patterns in the Rangawan reservoir catchment area.

Soil Loss Estimation in Rangawan Reservoir Catchment

The R-factor, K-factor, LS- factor, C-factor and P-factor of the watershed of study area varied from 408.41 to 458.93 MJ mm $ha^{-1}h^{-1}$ yr^{-1}, 0.200 to 0.340 t ha h ha^{-1} MJ^{-1} mm^{-1}, 0.79 to 0.91, 0.009 to 1.000 and 0.80 to 1.0 respectively. These factors are combined as a formula in USLE, which returns a single number, the computed soil loss per unit area, equivalent to predicted erosion in tones ha^{-1} $year^{-1}$ (Wischmeier and Smith, 1978). Once all erosive factor maps were generated, these maps were included in a raster operation of multiplication in ILWIS (3.6); therefore a soil loss map was obtained (Figure 2). The annual soil loss predictions range between 0.4 and 35.8 tones $ha^{-1}year^{-1}$. Rangawan reservoir has been divided in to 39 sub-watersheds (WS-1 to WS-39) average annual soil loss in tones ha^{-1} $year^{-1}$ was calculated separately for all the sub-watersheds. The average annual soil loss ranges between 1.5862 and 21. 9763 t/ha/yr for different sub-watersheds (Table 2).

Prioritization of Sub-watersheds

Considering the massive investment in the watershed development program, it is important to plan the activities on priority basis for achieving fruitful results, which also facilitate addressing the problematic areas to arrive at suitable solutions. Prioritization of sub-watersheds was done on the basis of average annual soil loss. All the 39 sub-watersheds in the study area have been prioritized by considering the results of various thematic maps derived from satellite imagery as well as rainfall and soil data. Table 3 indicates distribution of priorities for 39 sub-watersheds of Rangawan reservoir according to soil erosion intensity.

Table 2. C and P factors for different land use

Land use	C value	P value
Agriculture	0.420	1.000
Barren	1.000	1.000
Built up	0.024	1.000
Dense forest	0.011	0.800
Scrubs	0.210	1.000
Water bodies	0.009	1.000

Table 3. Average soil loss for sub-watersheds of the Rangawan reservoir catchment

WS	Area (km^2)	Ave. soil loss (t/ha/yr)	Priority
WS-1	16.1433	13.5914	12
WS-2	14.4986	14.6145	9
WS-3	30.2767	15.981	7
WS-4	20.6237	18.0601	3
WS-5	8.6892	12.5011	19
WS-6	11.3812	10.1683	29
WS-7	11.4454	12.1097	23
WS-8	13.6552	12.6022	17
WS-9	12.1844	16.5015	6
WS-10	10.5886	18.9724	2
WS-11	6.7249	11.0539	28
WS-12	17.2491	17.1878	4
WS-13	15.6483	21.9763	1
WS-14	12.8013	12.2858	21
WS-15	7.6553	12.3405	20
WS-16	10.8305	11.7565	25
WS-17	10.9735	11.8303	24
WS-18	8.6464	12.8613	14
WS-19	7.0902	12.2474	22
WS-20	10.0325	14.3787	10
WS-21	5.6299	17.1611	5
WS-22	11.2079	12.6627	16
WS-23	9.5038	15.9372	8
WS-24	9.8653	11.674	26
WS-25	15.8589	12.8416	15
WS-26	48.8628	5.9076	35
WS-27	37.7835	9.9146	30
WS-28	16.5577	14.0669	11
WS-29	14.8281	13.332	13
WS-30	14.7496	3.9883	38
WS-31	27.1564	8.907	31
WS-32	24.3308	12.5457	18
WS-33	21.6648	5.562	37
WS-34	9.2489	11.1872	27
WS-35	4.2292	1.5862	39
WS-36	13.3891	7.9868	32
WS-37	10.726	6.1786	34
WS-38	7.2872	5.6749	36
WS-39	8.6971	6.3838	33

CAT Plan for Rangawan Reservoir Catchment

A treatment plan for development of soil and water conservation has been suggested for Rangawan reservoir catchment based on the spatial information obtained from remote sensing and GIS on land use pattern, soil, slope, drainage network, contour lines etc. Non-perennial streams can be exploited by constructing gully plugs, check dams, percolation tanks etc., which improve the ground water conditions and help to bring additional lands under assured irrigation. In order to reduce the velocity of runoff, soil erosion and to increase the infiltration which helps in increasing in-situ moisture conservation, a series of measures like contour bunding, contour framing, graded bunding, vegetative barriers, ridges and furrows, inter bund land management and surplus runoff arrangement to drain excess water from fields were suggested.

The catchment area treatment plan developed for soil and water conservation in Rangawan reservoir catchment area is spatially depicted in Figure 3 and soil and water conservation structures/ measures for the catchment is presented in Table 4. In the catchment, soil and water harvesting structures like boulder bunds (121), check dams (9), gully plug (88), percolation tanks (1), soil conservation practices like contour farming, strip cropping and vegetative barriers etc., were suggested.

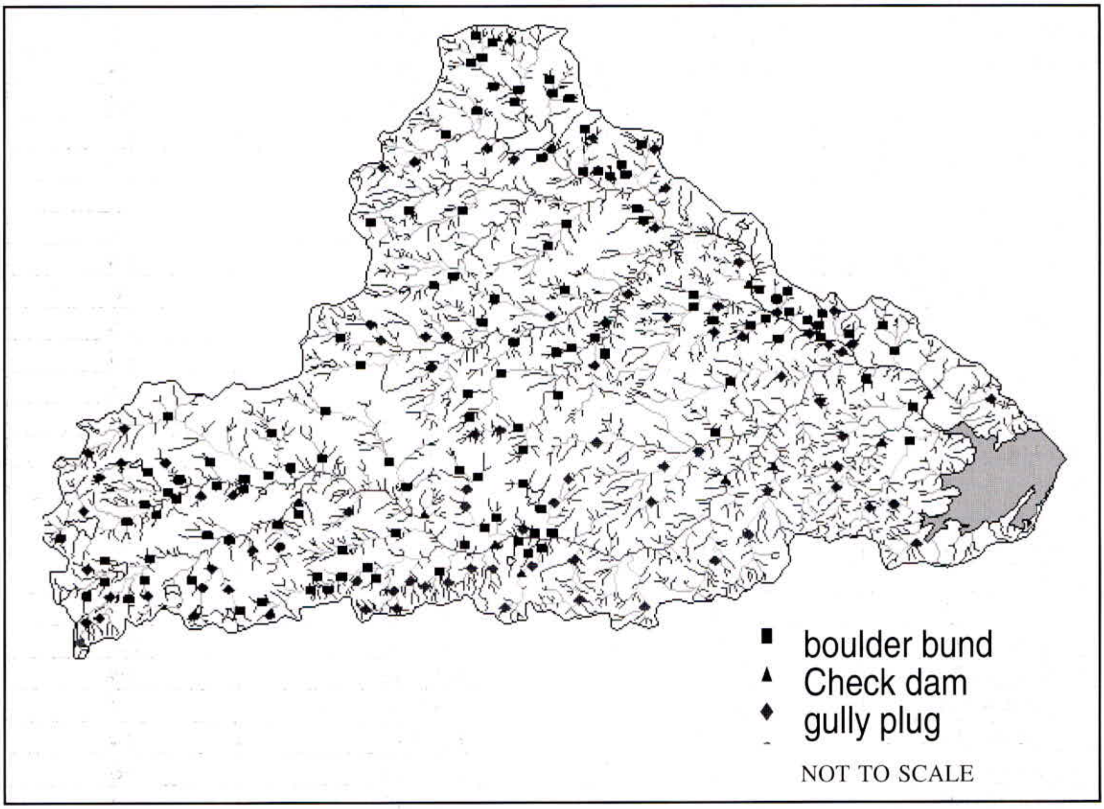

Fig. 3. CAT Plan map of Rangawan Reservoir Catchment Area

Table 4. Soil and water conservation structures and measures suggested for Rangawan reservoir catchment area

S no.	Structures / measures	Numbers
1	Boulder bund	121
2	Gully plug	88
3	Check dam	9
4	Percolation tank	1
	Total	219

CONCLUSIONS

The catchment area which is the source of endowment for the water resources projects are generally overlooked and resulting more and more soil loss lead to excessive sedimentation and reduction in useful storages of reservoirs. The prioritization of sub-watersheds is first and foremost work for development of scientifically designed catchment area treatment plan. The soil loss may serve the basis for prioritization work and USLE model which can be used for computation of soil loss spatially can be used continently. In the present study, a prioritization of sub-watersheds in Rangawan reservoir catchment has been done for development of CAT plan. The Rangawan reservoir catchment has been divided in to 39 sub-watersheds. Various thematic maps for USLE model have been generated and soil loss from each of the sub-watersheds has been computed. WS-13 has been found the most environmentally stressed sub-watershed where average annual soil loss is 21.94 t/ha/yr and WS-35 can be taken at the last for soil conservation works where soil loss is 1.59 t/ha/yr. The CAT plan developed for Rangawan reservoir catchment includes boulder bunds (121), check dams (9), gully plug (88), percolation tanks (1) and other agronomic and biological measures helpful in reducing the erosion and movement of soil from the catchment.

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