# RUSLE MODEL BASED SOIL LOSS ESTIMATION FROM A CATCHMENT IN BUNDELKHAND REGION

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## ABSTRACT

Sedimentation of the reservoir is a function of soil erosion rate of the river catchment area which reduces the water storage capacity of reservoir and availability of water for its designated use. Erosion of topsoil from the catchment also reduces fertility and the vegetation growth as well. Negative effects of sedimentation tend to become more and more relevant on a global scale due to population growth, reduction of dense forests, severe climatic conditions etc. which facilitate more and more soil erosion. The RUSLE model is the most commonly used model for estimation of spatial distribution of soil losses, soil erosion risk and planning development and conservation plan under different land cover conditions including croplands, rangelands, open and dense forests etc.

In the present study, an attempt has been made to estimate soil loss from the catchment of Benisagar dam catchment using RUSLE model. The Benisagar dam is a medium project in drought prone Rajnagar block Chhatarpur district of Bundelkhand region of M.P The dam has been constructed for irrigation and supply water to historical Khajurah city. The ILWIS 3.6, a GIS software has been used for preperation of thematic maps for the model. The detailed soil testing including soil texture, nutrient analysis, infiltration rate and hydraulic conductivity have been carried out to determine the K-factor map. The flow lengths for computation of SL-factor has been determined using DEM hydro processing module of ILWIS. The Normal Deviation Vegetation Index (NDVI) has been used to estimate C-factor map and land use map obtained from digital image analysis of LISS III data of IRS P6 has been used for extraction of P-factor map. The results of analysis indicated that the average annual soil loss from the Benisagar dam catchmewnt under present condition may be 8.23 t/ha/yr. The spatial distribution of soil loss obtained from RUSLE model has been divided in to different classes of soil loss and it has been observed that more than 50% of the study area falls in the range of 0.0 t/ha/yr to 5.0 t/ha/yr. The spatial distribution obtained from the analysis may be useful for prioritization of sub watersheds and planning of soil conservation measures and it may be concluded that 5.01 sq. km area having soil loss more than 10 t/ha/yr should be treated on priority basis.

## 1.0 INTRODUCTION

The soil erosion may be defined as detachment and transportation of soil. It is a well-established fact that reservoirs formed by dams, weirs or barrages on rivers are subjected to sedimentation. The process of sedimentation embodies the sequential processes of erosion, entrainment, transportation, deposition and compaction of sediment. The study of erosion and sediment yield from catchments is of utmost importance as the deposition of sediment in reservoir reduces its capacity, and thus affecting the water availability for the designated use. The eroded sediment from catchment when deposited on streambeds and banks causes breaching of river reach. The removal of top fertile soil from catchment adversely affects the agricultural production. According to a survey conducted by the Indian Council of Agricultural Research (ICAR) 174 million ha of India's total 329 million ha are affected by land degradation. A rough estimate of soil erosion and sedimentation for India reveals that about 5300 million tonnes of top soil are eroded annually and 24% of this quantity is carried by rivers as sediments and deposited in the sea, and nearly 10% is deposited in reservoirs reducing their storage capacity by 2%. The fertility status and the productivity of soil as a medium for biomass production depends largely on the top soil which, besides being a producer of biomass, is important for many other well-known important functions.

Scientist have been involved in soil erosion research for a long time and many models for soil loss estimation have been developed by Nearing et al. (1989); Adinarayana et al. (1999);D'Ambrisio et al. (2000); Veihe et al. (2001) Shen et al. (2003). Empirical soil erosion models in combination with soil, climate, vegetation and topography information have been implemented using remote sensing (Dwivedi et al., 1997; Hill and Scutt, 2002; Babun and Yusuf, 2001; Fu et al., 2005).The planners and mangers sometimes more interested to know the spatial distribution of soil erosion rather than absolute values and in such cases, the use of remote sensing and geographic information system (GIS) makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Millward and Mersey, 2001 and Wang et al, 2003). Coupling GIS and USLE/RUSLE has been shown in many cases to be an effective approach for estimating the magnitude of soil loss and identifying spatial locations vulnerable to soil erosion (Fu et al., 2006; Lim et al., 2005). The GIS tool for classification of Landsat-TM imagery has been used to estimate the crop management factor for USLE is in the research done by Miillword and Mersy (1999); Zhang (1999). De Jong (1994) has shown that satellite data can be used for producing vegetation related factors in soil erosion modeling that again compiled by Leprieur et al. (2000). The normalized difference vegetation index (NDVI) was found the most useful for computation of K factor by Symeonakis and Drake (2004) and Tateishi et al. (2004).

The generic of USLE and RUSLE was originally developed in USA, has proven valuable for estimation in other region of world including India. In India, Nema et al (1978) worked out some parameters of Universal Soil Loss Equation from runoff plot study conducted at Soil Conservation Demonstration and Training Centre (ICAR), Vasad. Values for 'K' factor and 'R' factor for soil and climatic conditions at Vasad and 'C' factor for Moong, Groundnut and Cowpea were worked out. Narain et al. (1993) have mapped erosion quantitatively in East Bengal. USLE is applied at 800 points over the state.

Forest cover data are in three categories namely more than 33%, between 19 and 33% and less than 19% tree crown cover density. Dense forest and Gangetic deltaic plain have erosion estimate between zero and five t/ha/year. Ram Babu et al (1978) computed and presented the monthly, seasonal and annual erosion index values for 44 stations situated in northern, central, western, eastern and southern rainfall zones of India.

## 2.0 METHODOLOGY FOR RUSLE MODEL

The USLE was originally developed for soil erosion estimation in croplands on gently sloping topography but with the development of RUSLE, it has broadened its application to different situations, including forests, rangeland and distributed areas (Renard et al, 1997). The RUSLE model can be defined as: For estimation of soil losses from Benisagar dam and Beniganj weir catchment, Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE) models have been used. The USLE model groups the numerous physical and management parameters that influence erosion under six factors, which can be expressed numerically. The RUSLE model can be expressed by the following equation:

$$A = R * K * L * S * C * P \qquad \text{....1.0}$$

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

### 2.1 Rainfall Erosivity Factor (*R*)

The *R* factor is determined by both rainfall and the energy imparted to the land surface by the rain drop impact. 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. It is a function of intensity and duration of rainfall and mass, diameter, and velocity of the rain drop. Erosivity is expressed as the long term mean annual rainfall erosion index based on the kinetic energy of the rain. Keeping the soil and slope parameter constant, studies indicated that the most valuable combination of indicators of erosion loss from allow soil is the rainfall energy. It is 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. The rainfall erosivity factor can be defined as the mean annual sum of individual storm erosion index values ($EI_{30}$). Where, $E$ is the total storm kinetic energy and $I_{30}$ is the maximum rainfall intensity in 30 minutes. 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, $R_a = 79 + 0.363 * P$ ….2.0

Seasonal R factor, $R_s = 50 + 0.389 * P$ ….3.0

where P is the rainfall in mm and $R_a$ and $R_s$ are annual seasonal R factor in *MJ mm ha$^{-1}$hr$^{-1}$*.

**2.2 Soil Erodibility Factor (*K*)**

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). Under the conditions of equal slope, rainfall, vegetative cover, and soil management practices, some soils will erode more easily than others due to inherent soil characteristics. Erodibility varies with soil texture, organic matter content. The RUSLE estimates the *K* value using textural property, organic contents, textural property and permeability. The Nomagraph for determination of K is given in Fig 2.

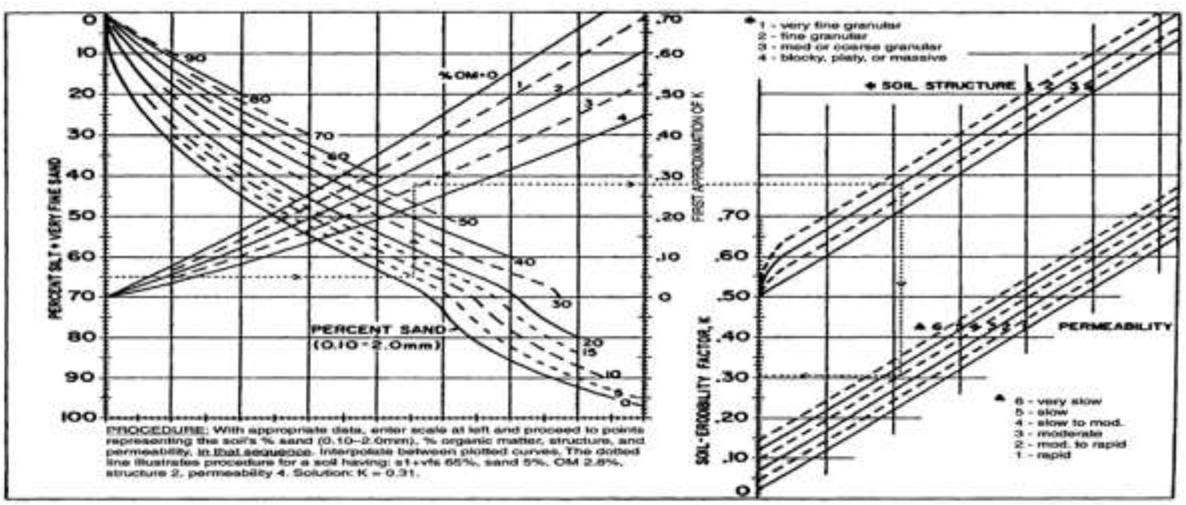



Figure No. 2: Nomograph for determining the soil erodibility factor (USDA, 1978)

For application of RUSLE, the equation given by Wischmeier et al. (1971) has been used and given below:

$$100K = 2.1M^{1.14}(10^{-4})(12 - a) + 3.25(b - 2) + 2.5(c - 3)$$ ….4.0

Where, *m* is the percent of silt, very fine sand and clay [(% of very fine sand+% of silt)*(100-% of clay)], *a* is the organic matter, *b* is the structure of the soil (very fine granular=1, fine granular=2, coarse granular=3, lattic or massive=4) and *c* is the permeability of the soil (fast=1, fast to moderately fast=2, moderately fast =3, moderately fast to slow=4, slow=5, very slow=6). For determination of organic matter from organic carbon, a factor 1.724 has been used (BUB, 2007; Wayne et al, 2003). In the present study, the soil map of study prepared by NBSS&LUP, India has been used and textural analysis, infiltration, hydraulic conductivity tests and nutrient analysis have been conducted on two to three sites in each soil class. Equation 5.0 has been used to determine K-factor for these soils.

**2.3 SL- Factor**

In RUSLE, the slope length factor (L) and slope steepness factor (S) are computed combined as LS factor using the following equation

$$LS = \sqrt{\frac{l}{22}}\left[0.065 + 0.045 * s + 0.0065 * s^2\right] \qquad ....5.0$$

where, l is the slope length in m and s is the slope in percent. In RUSLE, the slope length has been worked out using DEM hydro processing facility of ILWIS 3.6. Before deriving the slope length, the sinks from DEM were identified and filled. The filled DEM was used to generate flow direction map. The flow accumulation map was derived from flow direction map. The flow direction map is then used for drainage network extraction and in turn drainage network ordering map. Lastly, the network ordering maps is used for determination of slope length map for the area. The slope map was generated using a script in ILWIS software. Equation 5.0 has been used to determine SL-factor for the study area.

**2.4 Cover and Management Factor (C)**

The main role of vegetation cover in the interception of the rain drops is that their kinetic energy is dissipated by them. The crop management factor is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean, tilled fallow or identical soil and slope and under the same rainfall. A large amount of research and development energy has gone into the many existing C factor cropland. Factor C has been extended to include pasture, range, and idle land. However, available soil loss data from undisturbed land were not sufficient to derive C values by direct comparison of measured soil loss rates, as was done for the development of C values for cropland. For determination of factor C in RUSLE, the NDVI image has been used for determination of C factor. The following equation suggested by Van der et al. 1999, 2000 has been used for estimation of C factor.

$$C = \exp^{\left[-\alpha \frac{NDVI}{\beta - NDVI}\right]} \qquad ....6.0$$

The α-value of 2 and β-value of 1 gave good results (Ioannis et al, 2009) have been used in the study. In has been observed that some values of C-factor go greater than the limiting value of 1.0 and hence a scaling factor Z was used to keep the C-factor within the range of 0 to 1 (Mokua, F.O., 2009). The equation 7.0 can be written as:

$$C = Z * \exp^{\left[-\alpha \frac{NDVI}{\beta - NDVI}\right]} \qquad ....7.0$$

For computation of value of Z, a scalar graph has been plotted between NDVI and C and factor has been determined after three iterations to scale the values of C-factor between 0.0 to 0.9987.

### 2.5 Support Practice Factor (P)

Conservation practice conditions consist mainly in the methods of land use and tillage, and the agro technology. The P factor in RUSLE is expressed as a ratio, which compares the soil loss from the investigated plot cultivated up and down the slope gradient. The amount of soil loss from a given land is influenced by the land management practice adopted. The value of P ranges from 1.0 for up and down cultivation to o.25 for contour strip cropping of gentle slope.

### 2.6 Soil Loss computation

All the thematic maps have been generated in ILWIS GIS for RUSLE model separately. After multiplication of thematic maps R, K, LS, C and P, the annual and seasonal soil loss has been computed and histogram operation has been used to determine the rate of erosion from the catchment.

## 3.0 STUDY AREA

The Benisagar dam is situated in Rajnagar block of Chhatarpur district of Madhya Pradesh. The chhatarpur district lies in Bundelkhand part of M.P. suffered from frequent drought. Agro climatically, Chhatarpur district falls in the Bundelkhand plateau (Madhya Pradesh) sub-zones of Central Plateau Hills Region (CPHR) climatic zone. This region is interspersed with plateau and hilly areas with vast barren and uncultivatable land with excessive run-off. Nearly 15% of the land in this region is not available for cultivation.The Benisagar dam is an earthen dam constructed on confluence of river Khurar with river Rantiya which are tributaries of river Ken. The catchment area of dam is 76.85 $km^2$ and length of river Khurar upto dam site is 15 k.m. The gross storage capacity and dead storage capacity of the Benisagar reservoir is 27.59 MCM and 1.37 MCM respectively. The gross command area of the project is 6802.46 hectare while the cultivated area is 6267 hectare. The proposed irrigable area in the command through dam was 4170 hectare with proposed cropping pattern consists of Maxican wheat in 3000 hectare, ordinary wheat in 300 hectare and soybeen in 870 hectare. The catchment area of the dam is partly hilly and plain with shallow loamy soil subjected to high erosion. The location and drainage map of the study area has been given in Fig. 1.0.

## 4.0 ANALYSIS AND RESULTS

For application of RUSLE model for Benisagar dam catchment, a GIS data base of dam catchment including drainage, contour, basin boundary, soil type etc has been prepared. The Thiessen polygon map for the dam Benisagar dam catchment indicated that only Rajnagar R.G. station has impact on the catchment. The annual and seasonal R-factors have been estimated as 907.47 and 880.72 MJ mm $h^{-1}$ $ha^{-1}$ $yr^{-1}$ are respectively. For estimation of K-factor, the soil map of NBSS&LUP has been used to determine the type of soils in the study area. The textural analysis, infiltration, hydraulic conductivity and nutrient analysis have been carried out at two or three sites on each soil classes and average values have been used for determination of K-factor for each soil in the study area (Table 1.0). The contour map has been used for determination of flow length using DEM hydro module of ILWIS and slope length map has been generated. The slope length and slope map have been used for generation of SL-factor map. For determination of C-factor map, the NDVI image has been used and C-factor map was generated using land use map considering no conservation measures presently undertaken.

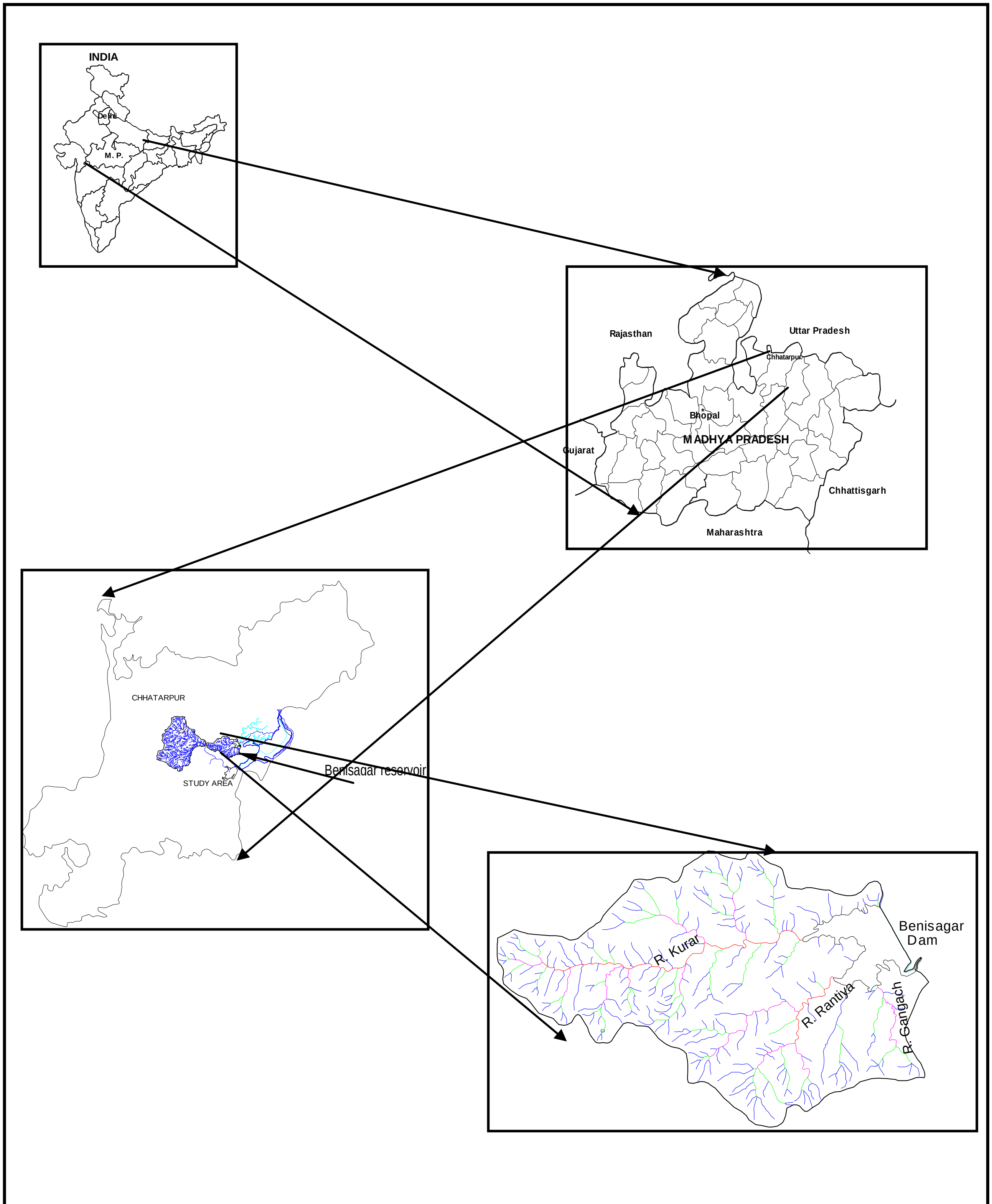


Fig. 1.0: Location and drainage map of Benisagar dam catchments in Chhatarpur district (M.P.)

Table 1.0: Soil analysis results and K-factor estimation.

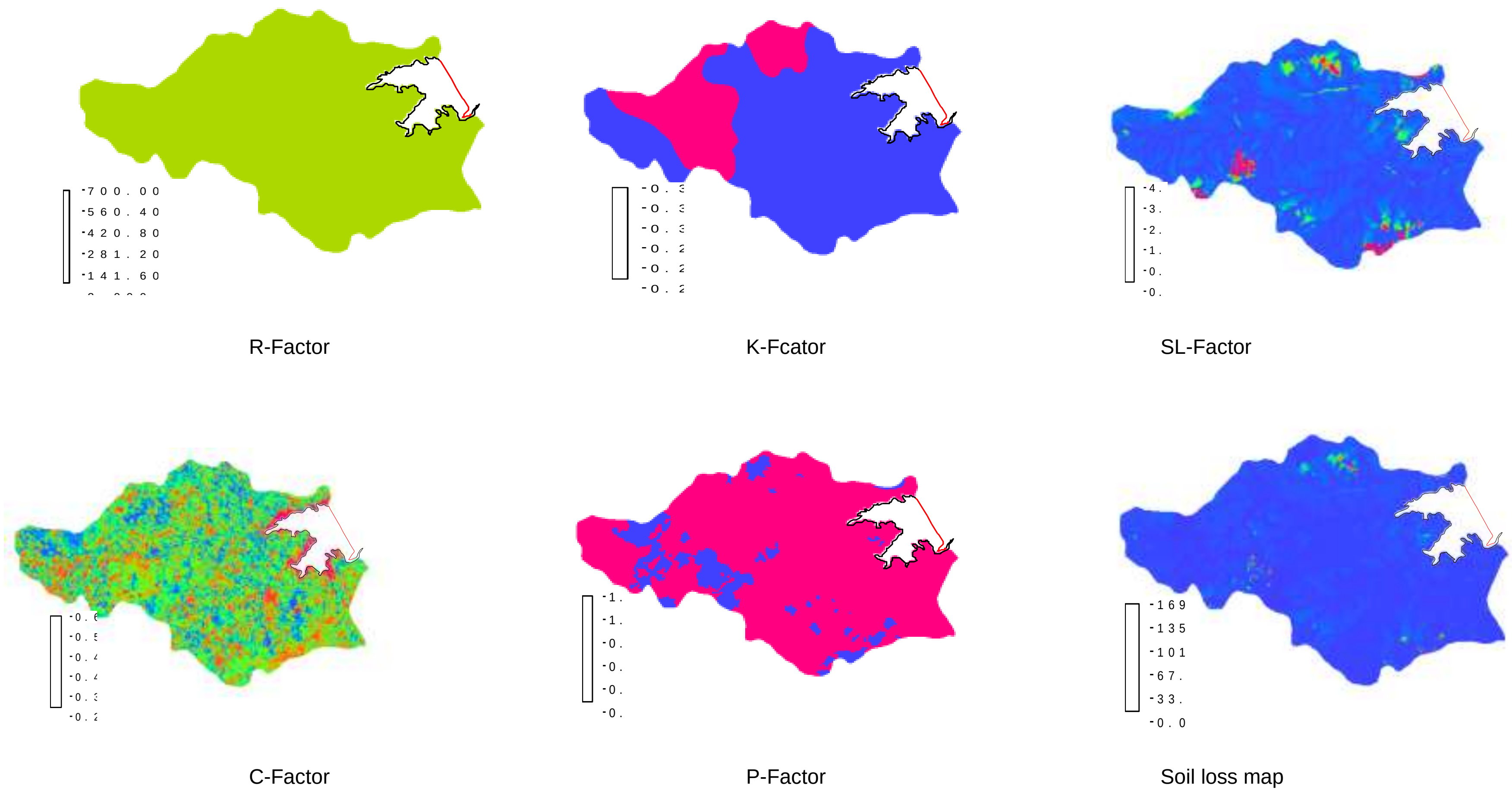
| Nomenclature | Soil type | % fine Sand | % Silt | % Clay | M | a | b | c | K Factor |
|---|---|---|---|---|---|---|---|---|---|
| 496 | Loamy, Kaolonatic, Hyperthermic, Typic Ustorthents | 7.30 | 63.73 | 5.97 | 6678.72 | 0.65 | 2 | 2 | 0.426 |
| 499 | Fine loamy, Kaolonatic, Hyperthermic, Typic Haplustalfs | 9.16 | 49.16 | 3.96 | 5548.88 | 0.52 | 2 | 1 | 0.435 |
| 507 | Loamy, Kaolonatic, Hyperthermic, Typic Ustorthents | 8.50 | 60.42 | 4.95 | 6551.08 | 0.26 | 2 | 2 | 0.435 |
| 512 | Fine loamy, Kaolonatic, Hyperthermic, Typic Haplustalfs | 10.74 | 56.35 | 4.18 | 6427.07 | 1.23 | 2 | 2 | 0.409 |

All the maps were integrated to determine the soil loss map of the study area and the average rate of soil loss has been determined using histogram operation. The R, K, SL, C, P-factors and soil loss map of Bensiagar dam catchment have been presented in Fig. 2.0. From the analysis, it has been observed that the average annual and seasonal soil loss from Benisagar dam catchment from RUSLE model have been computes as 8.23 t/ha/yr and 7.99 t/ha/yr respectively. As slope has been considered the main driving force for soil erosion, distribution of soil loss on different slope classes have been obtained and presented in Table 2.0. From the analysis, it has been observed that more than 50 % area of Benisagar dam catchment having slope up to 3% having annual soil loss in the range of 0.0 to 5.0 t/ha/yr and only 1.90 sq. km area has annual soil loss more than 20 t/ha/yr.

Table 2.0: Soil loss distribution on different slope range in Benisagar dam catchment.

| Soil loss Slope | 0.0-1.0 t/ha/yr | 1.0-5.0 t/ha/yr | 5.0-10.0 t/ha/yr | 10.0-20.0 t/ha/yr | 20.0-40.0 t/ha/yr | More than 40.0 t/ha/yr | Total |
|---|---|---|---|---|---|---|---|
| Lesse than 1% | 23.24 | 5.89 | 9.37 | 0.09 | 0.00 | 0.00 | 38.58 |
| 1% to 3% | 7.73 | 7.04 | 11.31 | 1.20 | 0.01 | 0.00 | 27.28 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3% to 5% | 0.43 | 0.55 | 1.24 | 1.42 | 0.23 | 0.00 | 3.88 |
| 5% to 10% | 0.15 | 0.04 | 0.14 | 0.39 | 0.46 | 0.08 | 1.25 |
| More than 10% | 0.12 | 0.00 | 0.00 | 0.02 | 0.09 | 1.03 | 1.26 |
| Total | 31.67 | 13.51 | 22.06 | 3.11 | 0.79 | 1.11 | 72.25 |




*Not to scale

Fig. 3: R, K, SL, C, P-factor and soil loss map for Benisagar dam catchment using RUSLE model

## 5.0 CONCLUSIONS

The soil loss estimation has been considered the basis of any scientific designed soil conservation program and RUSLE is one of the most used and widely accepted methods for estimation of soil loss from watersheds having varying slope, land uses and conservation practices. From the application of RUSLE model, prioritization of watersheds and areas for soil conservation can be identified. The GIS can be used conveniently and efficiently for determination of spatial distribution of soil loss using RUSLE model. The synoptic capability of remote sensing data may be useful for determination of impact assessment on soil erosion due to changes in land uses. The average annual soil loss from the Benisagar dam catchment has been estimated as 8.23 t/ha/yr which needs to be reduced using soil conservation measures.

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