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DEVELOPMENT OF EROSION HOTSPOTS FOR KAAS PLATEAU (ESZ) OF WESTERN GHAT, MAHARASHTRA USING RUSLE AND ARC GIS

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Abstract

Soil erosion is a silent killer converting fertile lands into barren patches thus accelerating the runoff velocities to further aggravate the erosion cycle. This study attempts to locate the most erodible locations known as erosion hotspots, for the site Kaas Plateau which is an ecologically sensitive zone (ESZ) of Western Ghat, Maharashtra, India. A combined tool of Revised Universal Soil Loss Equation (RUSLE) and Geographical Information System (GIS) is employed for this study. According to UNESCO (United Nations Educational Scientific and Cultural Organization), the Study area (Kaas Plateau) is a globally important treasure of biological diversity as it represents many endemic species of flowering plants, amphibians, reptiles, birds, mammals and invertebrates.

To achieve the goals of this study, the RUSLE factors were calculated using the data collected from past literature of the study area, National Beaureu of Soil Survey, Land use and Planning Department, Nagpur, Environmental Information System Department, Government of Maharashtra, Digital Elevation Model and satellite image. The rainfall-runoff erosivity factor (R) was derived from mean annual rainfall data. The soil data from past study was used to develop the soil erodibility factor (K). A Digital Elevation Model of the study area was used to develop the topographic factor (LS). Cover management factor (C) and Support practice factor (P) were determined from satellite image and contour cultivation classes and DEM respectively. The loss of topsoil results in low crop yield, reduction of reservoir capacity, cost increase of water treatment and damaging effects on aquatic life and wildlife habitats. An initial step for taking conservation measures in any land is to identify critical locations where erosion protection measures are needed.

Key words: Soil Erosion, RUSLE, ArcGIS, Remote Sensing, Kaas Plateau, Western Ghat, ESZ.

Introduction

Soil erosion is a three phase process consisting of the detachment of individual soil particles from the soil mass and transportation of these particles due to erosive agents, like flowing water and wind. After losing energy of erosive agents to transport the particles the ‘deposition’ takes place in the third phase. The soil erosion potential varies from area to area depending upon the topography, shape, soil characteristics, local climatic conditions and the land use and management practices of that area [1]. The soil erosion mainly depends upon three main factors, rainfall and runoff and soil protection and plant cover [3]. The raindrop impact causes detachment of soil particles. This soil splash is uniform in all directions on a flat surface. However, on steeper slopes more soil is splashed downhill. Rill to inter rill erosion erodes soil much more quickly than does the sheet erosion and hence the slope increases the soil loss [5]. Soil losses during storms are directly proportional to the storm parameter, which is the product of the totals of rill energy and the maximum 30-minute intensity. The storm energy is dependent on the amount of rain and the length of the storm [29].

Wischmeier and Smith developed the Universal Soil Loss Equation (USLE) [29] based on the Musgrave equation as follows:

$$A= R\times K\times L\times S\times C\times P$$

Where, A is the soil loss per unit area, R is the rainfall and runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the crop-management factor and P is the support practice factor.

The texture, organic matter content, structure and permeability are the four basic soil characteristics that affect the soil erodibility [6]. The soil structure for the arrangement of soil particles is strongly related to erosion. The desired low erosive soil structure is a granular composition. Conducted experiments and demonstrations explained the importance of aggregate stability on the characteristics of soil erosivity. Distributed erosion simulation models are useful in evaluation of different strategies for land-use and soil management improvement in watersheds. The land use changes from urban to agricultural or forested and plays an important role in soil erosion. The utility of high resolution satellite data for accurate mapping of land use and land cover which forms an important component while computing the land cover factor for soil loss estimation using RUSLE model. The use of GIS, and remote sensing data enables the accurate determination of the spatial distribution of the RUSLE parameters [16].

Methodology

General

Determination of erosion hotspots is a very useful task for environmental management specialists to make a suitable decision on the soil conservation measures that should be adopted for a given area. The Universal Soil Loss Equation (USLE) (Wischmeier, 1978) [29] or the Revised Universal Soil Loss Equation (RUSLE) (Renard, 1997) [19] are commonly used equations to predict soil erosion in the study area/watershed with the help of GIS tool.

This study is based on the application of the Revised Universal Soil Loss Equation (RUSLE) and a geographic information system (GIS) to locate the most erodible locations, namely erosion hotspots for the study area. GIS and RUSLE are used for the estimation of rainfall-runoff erosivity factor, soil erodibility factor, combined slope length and slope steepness factor, cover management factor, and support practice factor. These factors are employed for the estimation of soil erosion potential in the study area as follows:

$$A = R \times K \times L \times S \times C \times P$$

Where, A = soil loss potential for the grid in (tons/ha/year); R = rainfall-runoff erosivity factor in hundreds of (MJ mm ha−1 y−1); K = soil erodibility factor in (tons MJ−1 mm−1); L = dimensionless slope length factor; S = dimensionless slope steepness factor; C = dimensionless crop/cover management factor; P = dimensionless support practice factor.

Site Description and Location

The study area, Kaas Plateau is an ESZ (Ecologically Sensitive Zone) of Western Ghat of Maharashtra State India and most importantly it has been declared as a World Heritage site by UNESCO in 2012 [4] for the endemic and endangered wild life flora and fauna especially for amphibians. This site is situated at Satara Tehsil of Satara District. The study area is extended from West (latitude-73.78, longitude-17.72) to East (latitude-73.86, longitude-17.72) and from North (latitude-73.78, longitude-17.76) to South (latitude-73.81, longitude-17.69), covering the area of about 32 sq. km. The study area is located at the central elevated region in between three dams namely Koyna dam, Urmodi dam and Kaner dam. Elevation of the study area varies between 840 m at some lowest points to 1260 m at some of its highest points. Average temperature of the study area is about 26° C.

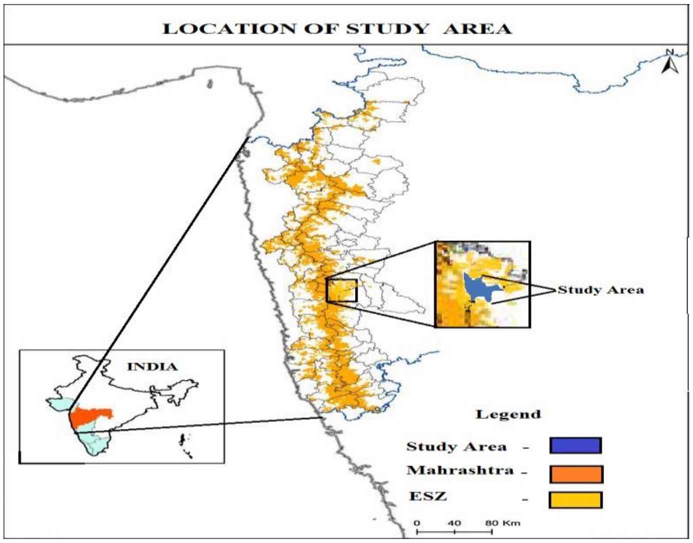

Figure 1.Location of Study Area

Data Sources

The digital elevation model (DEM)

The digital elevation model (DEM) is a digital file with terrain elevation specifications for ground points at regularly spaced intervals horizontally. It can also be shortly defined as, a digital representation of cartographic information. The digital elevation model (DEM) data files of study area are taken from the site of U.S. Geological Survey Department. This DEM data is then utilized in Arc GIS to create flow accumulation map, flow direction map, fill sinks map and slope map which are prerequisites to calculate RUSLE factors.

Soil Data

Various soil properties of the study area (Kaas Plateau) like organic matter content and the percentage of sand, silt and clay are obtained from literature by Watve A. et al. (2013) [28]. The percentage of organic matter content in the soil of the study area is 6.14 whereas the percentage of sand, silt and clay is 49.4, 29.46 and 20.89 respectively.

Precipitation Data

The rainfall data used in this study is obtained from Envis (Environmental Information System) department, Government of Maharashtra, Mumbai. There is no rain gauge station situated in or around this study area. Hence the average annual rainfall of study area is taken from the site of Envis as mentioned above.

Land use and Land cover

Land use and Land cover characteristics are very important in deciding and estimating the crop management (C) and support practices (P) factors of RUSLE model. The LISS III satellite data is obtained from Bhuvan (NRSC) web portal. This LISS III satellite data is processed using ERDAS software to prepare uniform stacked image of study area for obtaining land use land cover information and classes. This uniform stacked image is then used in ArcGIS to derive the crop management (C) factor.

Data Analysis

General

Data analysis is done using RUSLE model, Arc GIS, Microsoft office and different equations as proposed by many authors. The slope length and steepness (LS factor) or topographic factor is achieved with application of DEM in Arc GIS. Figure 2 displays the summary of methodology applied to achieve the objectives of this study.

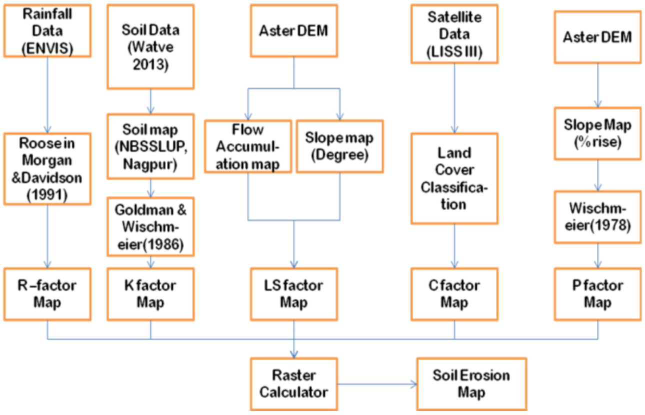

Figure 2.Methodology Flow Chart

Rainfall-runoff erosivity (R) factor

Literature shows that there are some equations which are derived to determine the value of Rainfall – runoff erosivity (R) factor with the help of only mean annual rainfall data P or MAR. Accordingly, the mean annual rainfall of selected study area (i.e. Kaas Plateau) from the report of Environmental Information System Department, Mumbai is identified as 2000-2500 mm. But in this case for the calculation of Rainfall runoff erosivity (R) factor, the average value of this range of mean annual rainfall is taken as 2250 mm.

According to different reference equations [27, 14, 9, 22], the mean annual rainfall data can be used for R factor calculation as follows:

Table 1.Relationship between R and P or MAR

No.	Equation	R and F Relationship
1.	Renald and Freimum – P.1994	$R=0.0483P^{1.61}$
2.	Roose in Morgan and Davidson (1991)	$R=0.5\times P$
3.	Kassam et al. 1992	$R=117.6\ (1.00105^{(MAR)})$ for $P< 2000$mm
4.	Singh et al. 1981	$R_{factor} =79 + 0.363$ MAR

Where,

R- Rainfall runoff erosivity ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$)

P/MAR- Mean Annual Rainfall (mm)

According to the Kassam table (1992) [9], the appropriate equation is Roose in Morgan and Davidson (1991) and corresponding suitable rainfall-runoff erosivity (R) factor value is 1125 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$

Soil Erodibility (K) factor

According to Goldman and Wischmeier (1986) [6] the mathematical equation of Soil erodibility factor 'K'has been represented as:

$$K = 1.292\ [2.1 \times 10^{-6} f_p - 1.14 \times (12 - P_{om}) + 0.0325\,(S_{str} - 2) + 0.025\,(f_{per} - 3)]$$

In which,

$$f_p = (\ P_{silt} \times 100 - P_{clay}\ )$$

Where,

K = Soil Erodibility factor in t.h /MJ.mm, f_p = Particle size parameter, P_{om} = Percent of organic matter, S_{str} = Soil structural code(very fine granular = 1, fine granular= 2, moderate or course granular = 3,blocky, platy or massive = 4), f_{per} = Profile permeability code(rapid = 1, moderate to rapid =2, moderate = 3, slow to moderate = 4, slow = 5, very slow = 6), P_{silt} = Percent of silt, P_{clay} = Percent of clay.

The percentages of silt (0.005 to 0.05mm), sand (0.05 to 2.0mm) and clay (sizes < 0.005mm), are obtained from literature (Watve et al.2013) as 29.46 %, 49.40 % and 20.89 % respectively. The soil textural class is estimated using the textural triangle as Loam. Since the soil is Loam and the organic matter of the study area is 6.14 %, the codes S_{str} =3 and f_{per} =4 are obtained from soil permeability and texture classifications given by USDA.

Putting all the values of parameters in Goldman and Wischmeier (1986) equation, the Soil Erodibility Factor (K) is estimated as 0.18 t.h /MJ.mm.

Slope length- steepness (LS) factor

With the integration of Digital Elevation Models (DEM) into a GIS, the slope gradient (S) and slope length (L) may be determined accurately. Accordingly, in the RUSLE both the factors which give L and S are united to give the combined topographic (LS) factor [8]. However, the accuracy with which it can be estimated depends on the resolution of the digital elevation model (DEM) [21]. The combined topographic (LS) factor is computed rather than the individual slope length and slope gradient, as the upstream contributing area is generally favored instead of individual slope lengths [21].

The LS factor in RUSLE can be computed using the raster calculator in Arc GIS to build an expression for estimating combined LS factor. It is based on flow accumulation and slope steepness [11] which is also used for this study using the following equation:

$$LS = ([\text{Flow Accumulation}] \times \text{Cell Size}/22.13)^{n}\ (\text{Sin}\ ([\text{Slope of DEM}] \times 0.01745)/0.0896)^{m} \times 1.4$$

Using the Aster Digital Elevation Model (DEM) (USGS web portal) prerequisites for flow accumulation map (which are flow direction map and fill sinks map) are generated. After this, using flow direction map and fill sinks map, the flow accumulation map is generated. Next the slope map in degrees is generated.

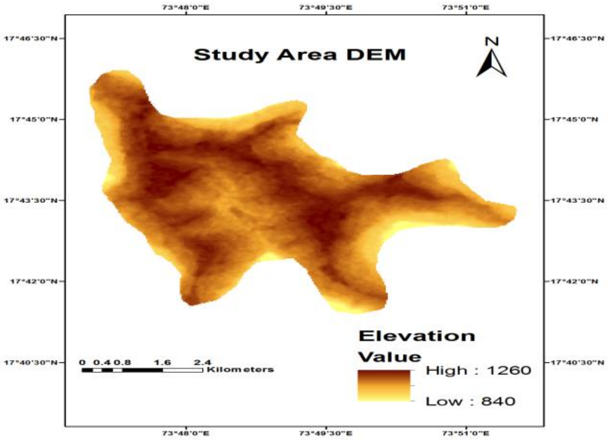

Fig 3. DEM of study area (Kaas Plateau)

Finally, flow accumulation map and slope map (degree) generated above are used in the LS factor equation along with the cell size of DEM as 30m, n = 0.6 and m = 1.3. Then this equation is generated in raster calculator tool in Arc GIS to get LS factor map.

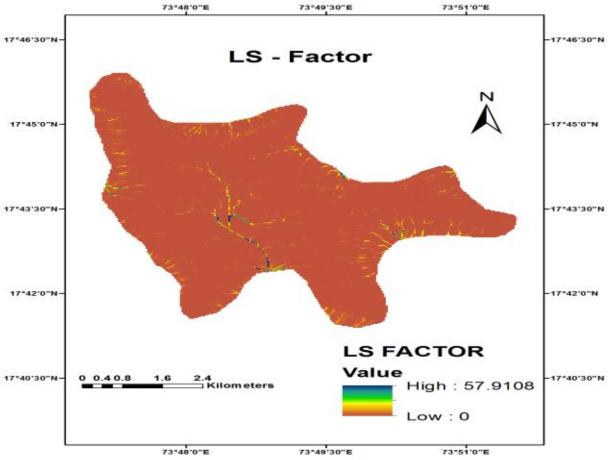

Fig 4.Slope length- steepness (LS) /Topographic factor map of study area (Kaas Plateau)

Cropping or Cover management factor (C)

The land cover and management (C) factor represents the effects of management, vegetative cover over the land and also, erosion control practices for controlling soil loss, the value of (C) factor generally ranges from 0 in water bodies to slightly greater than 1 in barren land, where there is no vegetation, root biomass, and other surface covers to resist various erosive forces. The distinctive values are about 1 for bare soils, and 0.001 for forests. For the present study the C-factor values are assigned for the land cover and management factors to each corresponding land use and land cover (LU/LC) classes. These values have been selected and assigned from available experimental values as tabulated in earlier literature. The C-factor values for each Land use and Land cover (LU/LC) class are shown in Table [source USDA (1972), Rao (1981)] as given below:

Table 2 Cover and management (C) factor

Land use/ Land cover class	C - factor
Settlement	1.0
Vacant land	1.0
Crop land	0.28
Plantations / Vegetation	0.28
Dense forest	0.004
Degraded forest	0.008
Land with scrub	0.18
Water bodies	0

LISS III satellite data is obtained from BHUVAN web portal and processed using ERDAS software to get uniform stacked data for selected study area as shown in the Fig.5.

After this, the satellite image is processed into the Arc GIS environment with the help of spatial analyst tool, editor tool and merging tool. Afterwards the polygons of this study area are reclassified according to their different land use/ land cover classes to obtain the C – factor map for the study area (Kaas Plateau) as shown in the Fig.6.

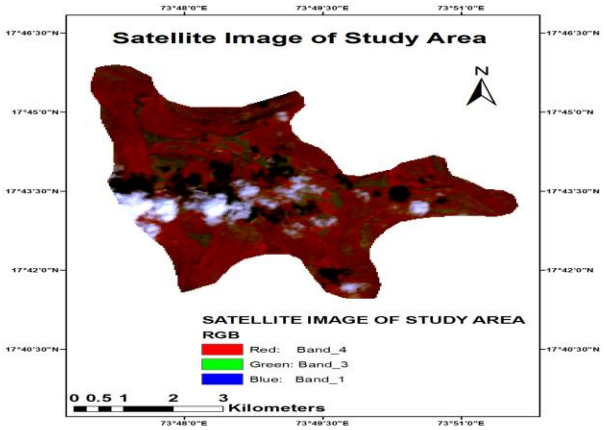

Fig 5 Satellite Image of study area (Kaas Plateau)

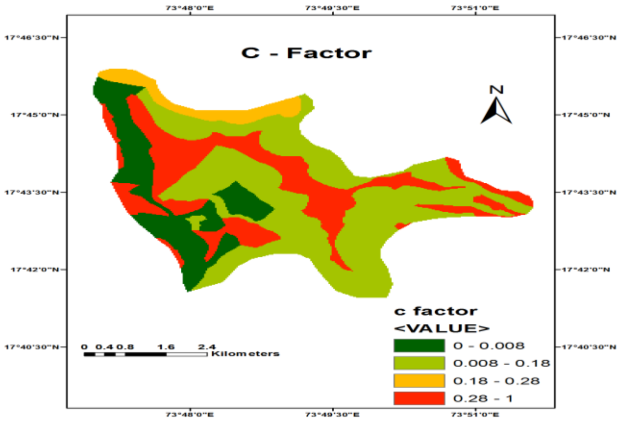

Fig 6 Cover and management (C) factor map of study area (Kaas Plateau)

Support Practices (P) factor

The support practices factor (P-factor) can be defined as the ratio of the soil loss with a specific support practice to the consequent loss with up slope and down slope cultivation. For the understanding of conservation practices required to be taken up in the study area the generation of P-factor map is very important. The influence of drainage patterns, runoff concentrations, runoff velocities, and hydraulic forces exerted by runoff on soil can be monitored effectively with the help of evaluation of support practices factor for specific study area. The supporting mechanical practices include the effects of contouring, strip cropping, or terracing. In the present study area, however, no major conservation practices are followed except bunded agricultural lands which are limited to paddy growing areas only.

Therefore, the classification given by Wischmeier (1978) for the support practices factor (P-factor) in paddy fields with consideration of only contouring of the study area is considered. Moreover, the study area (Kaas Plateau) is having the paddy growing fields along with the contouring land. Hence this classification is suitable and is given as follows:

Table 3.Support practices factor (P-factor) Wischmeier (1978) [29]

Slope (%)	Contouring	Strip Cropping	Terracing
1-2	0.60	0.30	0.12
3-8	0.50	0.25	0.10

9-12	0.60	0.30	0.12
13-16	0.70	0.35	0.14
17-20	0.80	0.40	0.16
21-25	0.90	0.45	0.18

Using the information from Table 3, the support practices factor (P-factor) map is generated in Arc GIS environment with the help of slope map (% rise) of the study area (Kaas Plateau). Slope map (% rise) is generated with the help of DEM. Next, to generate the P – factor map in ArcGIS, the tools like spatial analyst, reclassify, editor and merge are used.

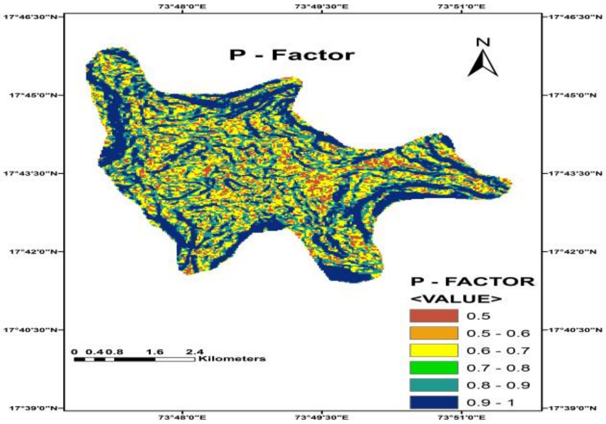

Fig 7.Support Practices (P) factor map of study area (Kaas Plateau)

Soil Erosion/Soil Loss (A) Map

Soil erosion map in raster form is generated in Arc GIS environment with the help of raster calculator tool and overlaying the generated maps of R, K, LS, C, and P as given below:

$$A = R \times K \times LS \times C \times P$$

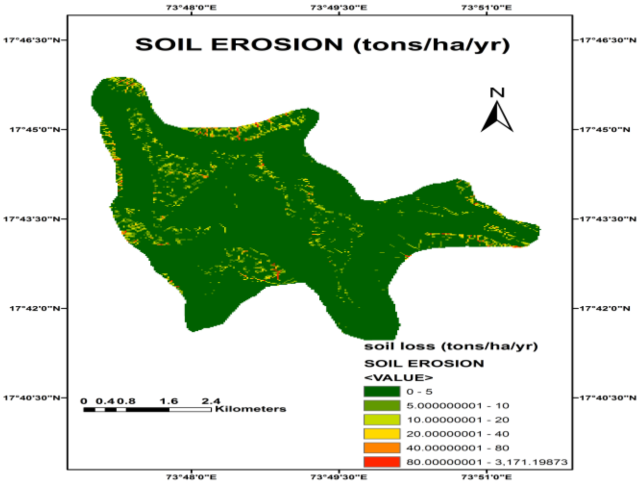

Fig 8.Soil Erosion (A) map of study area (Kaas Plateau) (tons/ha/yr)

Results and discussions

Rainfall-runoff erosivity (R) factor

As selected study area (Kaas Plateau) is very small in the sense of variation of rainfall, the Rainfall-runoff erosivity (R) factor calculated by Morgan and Davidson equation is uniform throughout the study entire study area (Kaas Plateau), from generated map of R – factor, which is found to be 1125 MJ.mm/ha.h.yr and verified with the help of table by interpolation.

Soil erodibility (K) factor

Generally, Soil erodibility (K) factor can be obtained from nomograph method. However, due to organic matter exceeding the required limit of nomograph method, this method could not be used. The Goldman and Wischmeier (1986) [11, 43] equation is used to find Soil erodibility (K) factor. The soil properties/ characteristics (% silt, % sand, % clay, % organic matter) required for this equation are obtained from Watve et al. (2013). As the selected study area (Kaas Plateau) is very small, the soil properties/ characteristics and also Soil erodibility (K) factor are uniform throughout the entire study area (Kaas Plateau). From K- factor map, soil erodibility is found to be 0.18 t.h/MJ.mm. The K- factor is very high in this case.

Slope length – steepness/Topographic (LS) factor

Instead of finding L and S factors separately which is very complicated method, use of the Aster Digital Elevation Model (DEM) is very suitable in Arc GIS environment to find combined Slope length – steepness/Topographic (LS) factor. Flow Accumulation Map, flow direction map, fill sinks map and slope map (degrees) are generated. From the map generated slope length – steepness/ topographic (LS) factor is found to be in range of 0 to 57.9108. LS- factor is close to zero for most of the area, but it is very high at some of the steeper regions.

Crop/cover management (C) factor

The multiband LISS III data is stacked into ERDAS to get uniform image of the study area (Kaas Plateau). This uniform satellite image is classified according to land use land cover classification [Table 2 USDA(1972), Rao(1981)] [26,18], to obtain the C-factor map. The map generated for C – factor showed that, the values of C –factor are close to 0 in dense forest, degraded forest and water body areas, close to 1 in vacant and settled lands; and the values are moderate in cropped, vegetated lands.

Support practice (P) factor

The study area (Kaas Plateau) has the cropping pattern which consists of paddy fields along the contours. The P - factor values are assigned for the study area (Kaas Plateau) according to the paddy fields with consideration of only contouring of the study area with the help of Arc GIS and slope map (% rise). This classification gives P factor map which provides values of P factor close to 0.55 in central part of study area and values close to 1 in the peripheral part of study area.

Soil Erosion/Soil Loss (A)

With the help of RUSLE equation and Arc GIS, the rainfall- runoff erosivity (R) factor map, soil erodibility (K) factor map, combined slope length and slope steepness (LS) factor map, cover management (C) factor map, and support practice (P) factor map are created. These thematic maps are then processed in raster calculator tool in Arc GIS for the generation of soil erosion (A) map of the study area. The generated map of soil erosion estimates the values in tons/ha/yr. The soil erosion map shows that the value of (A) ranges from 0 to 3171 tons/ha/yr. Maximum region of study area (Kaas Plateau) comes under 0 to 10 tons/ha/yr. However, some places in central region and also in peripheral region with steeper slopes have very high values greater than 40 and upto 3171 tons/ha/yr.

Conclusions

The soil erosion (A) map indicates that the average value of soil loss over the study area (Kaas Plateau) is 1.99 t/ha/yr (approximately 2 t/ha/yr) which is within the safe limit, but erosion hotspots (highly erodible locations) are present in the steep regions specifically in the vacant lands (lower east region) with soil loss upto 140.087 t/ha/yr, land without scrub (northern middle region) with soil loss upto 161.63 t/ha/yr and also some part from crop lands (upper east and lower central regions) with soil loss upto 120.47 t/ha/yr and 3171.1987 t/ha/yr, respectively. It is observed that a large portion of plain area which forms major part of study area (Kaas Plateau) (having a slope up to 5˚) also contributes to the soil loss of the watershed exhibiting annual soil erosion upto 10 tons/ha/yr whereas, some portion is having soil erosion in the range of 11-15 tons/ha/yr. The major portion which includes the endemic species of flower plants and also fauna, due to which the study area (Kaas Plateau) is included into world heritage sites by UNESCO has some soil erosion hotspots in the central northern region with soil loss upto 87.18 t/ha/yr and northeast region with soil loss upto 85.34 t/ha/yr. These areas need to be conserved and specific mechanical support practices and cover management strategies should be applied so as to avoid the upcoming threats to endemic flora and fauna of this plateau. In the present study, the RUSLE model adopted for estimating the annual soil loss in the study area (Kaas Plateau) provided satisfactory results and can be efficiently used for evaluating soil erosion in similar areas. Soil conservation, management and protection measures must be adopted to check soil erosion in the identified hotspots of the study area (Kaas Plateau). In the regions under crop cultivation, the soil conservation methods such as terracing, bunding, agro-forestry techniques, crop rotation and some biological and physical techniques of soil and water conservation methods must be applied. The use of ArcGIS and remote sensing data enabled the precise determination of the spatial distribution of the RUSLE parameters. The establishment of database through conventional methods is very time consuming and also costly. Hence, remote sensing and GIS can play an important role in creation of input parameters for remote areas where ground based observations are difficult for the soil erosion modeling. The methodology presented and results obtained in this study can help water resources managers and soil scientists.

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[C] Web portal of U. S. Department of Agriculture.

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