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Geo-spatial technology application for prioritization of land resources in Udham Singh Nagar District of Uttarakhand, India

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A loss of soil resources by prolific watersheds is a frequent problem confronting hydrologists and watershed managers. Soil erosion is a major factor in losses of soil. Different models are used for prediction of the amount of soil loss by erosion. In the present study, modelling using Revised Universal Soil Loss equation (RUSLE) is integrated with Remote Sensing (RS) and Geographical Information Systems (GIS) techniques and employed to estimate soil erosion and prioritization of watersheds of Udham Singh Nagar district of Uttarakhand, India. The results showed that Udham Singh Nagar district's major portion (38.66%) is covered with agriculture land and only 17.57% area is covered with forest. Water-bodies have occupied 2.18% area of US Nagar district. A large variation has been noticed in case of built-up land which has been recorded as 5.71%. US Nagar has more agricultural land. Udham Singh Nagar is having plane topography hence the range of soil erosion is from 0 to 40 ton/ha/year. However, most region of Udham Singh Nagar district falls under the category of 0-2 ton/ha/year soil erosion. The value of soil losses in most of cases is less than 1 t/ha/yr except in case of 11 watersheds, where it is slightly higher than 1 t/ha/yr. Moreover, it has been concluded that major portion of Udham Singh Nagar district were slight prone category of soil erosion, and therefore, no major plan/activity is required for reducing soil losses. Only checking large amount of runoff and enhancing organic matter build up in the soil will suffice the purpose.

Keywords: GIS, Prioritization, Remote sensing, RUSLE, Soil erosion
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Natural resources play vital role in the social, economic or political strength of a nation and it depends mostly on the availability and their proper utilization. The geospatial techniques are efficiently used for more specific mapping and management of land resources[10]. Among all the natural resources, Land and water are the two important natural resources but due to unscrupulous and indiscriminate utilization these resources are degrading rapidly additionally inappropriate distribution of natural resources making the condition more worrisome. Udham Singh Nagar is a district of Uttarakhand in northern India. Since the area is located in the foothills of the Himalayas, a very thick column of alluvium is deposited and the piedmont fan deposits known as Bhabar & the Tarai Alluvium are further classified into two distinct divisions. They have significantly different Hydro-geological attributes. In the study area the groundwater usually flows from north to south.

Watershed is a natural hydrological unit and the most effective method to sustainable integrated land and water management. Judicious management and conservation of soil and water resources on watershed basis is perquisite for sustaining the productivity[14]. It involves measurements related parameters like geological, hydro-geological, geo-morphological and hydrological, soil, land cover/land use etc. The characterization and priority assessment of the watershed are problem identification, management and periodic monitoring of the area[18]. With the advancement of computer technology, especially geographic information systems (GIS) provide valuable support for managing large data generated by conventional and remote sensing techniques. Further GIS also allows the integration of these datasets in map or tabular formats to derive meaningful information and outputs. The Geographical

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Information Systems (GIS) technology provides suitable alternatives for efficient management of large databases while drainage characteristics of basin and sub basins have been studied using conventional methods[4,8,15]. Integrated resource data analysis at different scales allows for the evaluation of natural resource capacity and limitations and for the creation of sustainable use plans for land and water resources. Remote sensing methods have an important role to play in achieving maximum water resources project preparation and operations. Remote sensing has shown great potential to provide a wealth of data and knowledge that was inadequate with the observations in situ. Remote sensing technology resolves the requirements of reliability and speed and is an ideal tool for producing spatial information that is considered a prerequisite for planned and controlled watershed development[11].

The RUSLE model application with GIS allows for analysing soil erosion in detail since the process has a spatially distributed character. The GIS and Remote Sensing (RS) provide the model with spatial input data whereas the RUSLE can be used to measure soil erosion from the watershed[17].

The objective of the study is to estimate soil erosion and prioritize based on erosion rate for efficient and adequate treatment of that region to enhance productivity by conserving soil and water.

Materials and Methods

Study Area

The study was conducted at Udham Singh Nagar District formed in October 1995 asshown in Fig. 1. Rudrapur is the district headquarters. Udham Singh Nagar is located at 28.98°N 79.40°E.The district has sub-humid climate. The maximum temperature in the plain areas ranges from 38ºC to 40ºC and the minimum between 6°C and 11°C. The intensity of rainfall varies from maximum in June & July while minimum in November & December. The soils of area are mainly Loamy, sandy loamy and clay loamy.

Data used

The rainfall data of 14 years (2001–2014) was collected from Meteorological Department, GBPUA&T, Pantnagar. The data of soil like silt, sand and clay in soil, percentage of organic matter, soil structure code and permeability code were

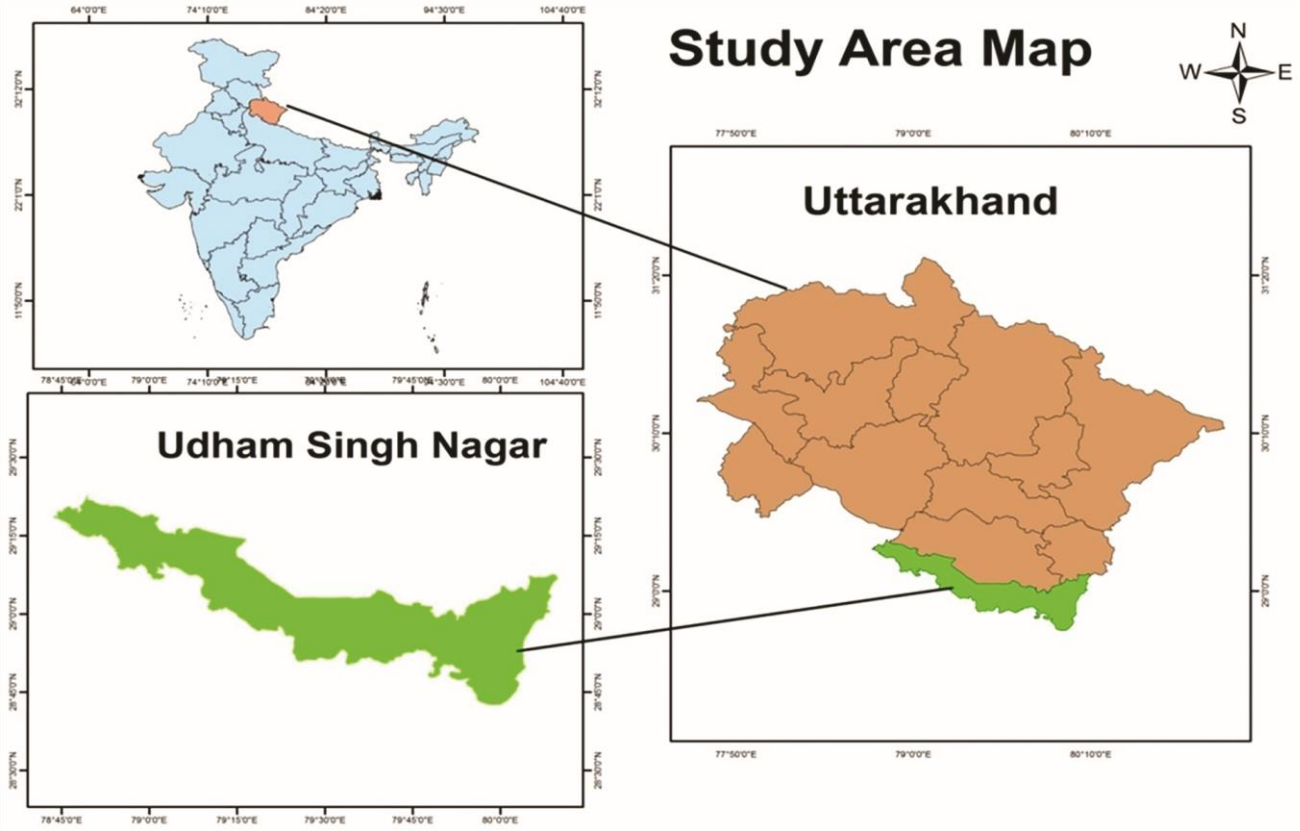

Fig. 1 — Location map of Study Area (Udham Singh Nagar district)

obtained from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) Nagpur. Satellite imagery of LANDSAT 8 was downloaded from https://landsat.usgs.gov/ site. ENVI and QGIS were used for generation of various thematic layers namely contour, drainage, LU/LC and other data sets of the study area.

Methodology

The RUSLE quantifies soil erosion using five factors as show in Fig. 2 and equation given below[2]:

A = R K L S C P

Where, A is the average annual soil loss per unit area

R is the rainfall and runoff factor, 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, P is the support practice factor

R-factor

For the estimation of soil erosion, the rainfall data of 14 years (2001–2014) was collected from Meteorological Department, GBPUA&T, Pantnagar from which the rainfall runoff erosivity factor (R-factor) was estimated. The soil map was procured from the National Bureau of Soil Survey & Land Use Planning, and it was digitized and converted to digital format on 1:50,000 scale.

K-factor

The soil erodibility factor (K-factor) map was digitized and prepared in QGIS using the soil map procured from NBSS&LUP and the values of K-factor were assigned to the different soil types in the region according to the U.S. customary units.

LS-factor

The ASTER data was used to prepare the slope map and the flow accumulation map of the study area, which were then used for preparing the LS factor map in QGIS. The DEM was utilized to deduce the flow direction to prepare the flow accumulation map. The LS factor map was then prepared using the slope and flow accumulation map in raster calculator in QGIS. The drainage of the study area was delineated from the Survey of India topographical map in 1:50,000 scale and was updated by using higher resolution Landsat 8 satellite image.

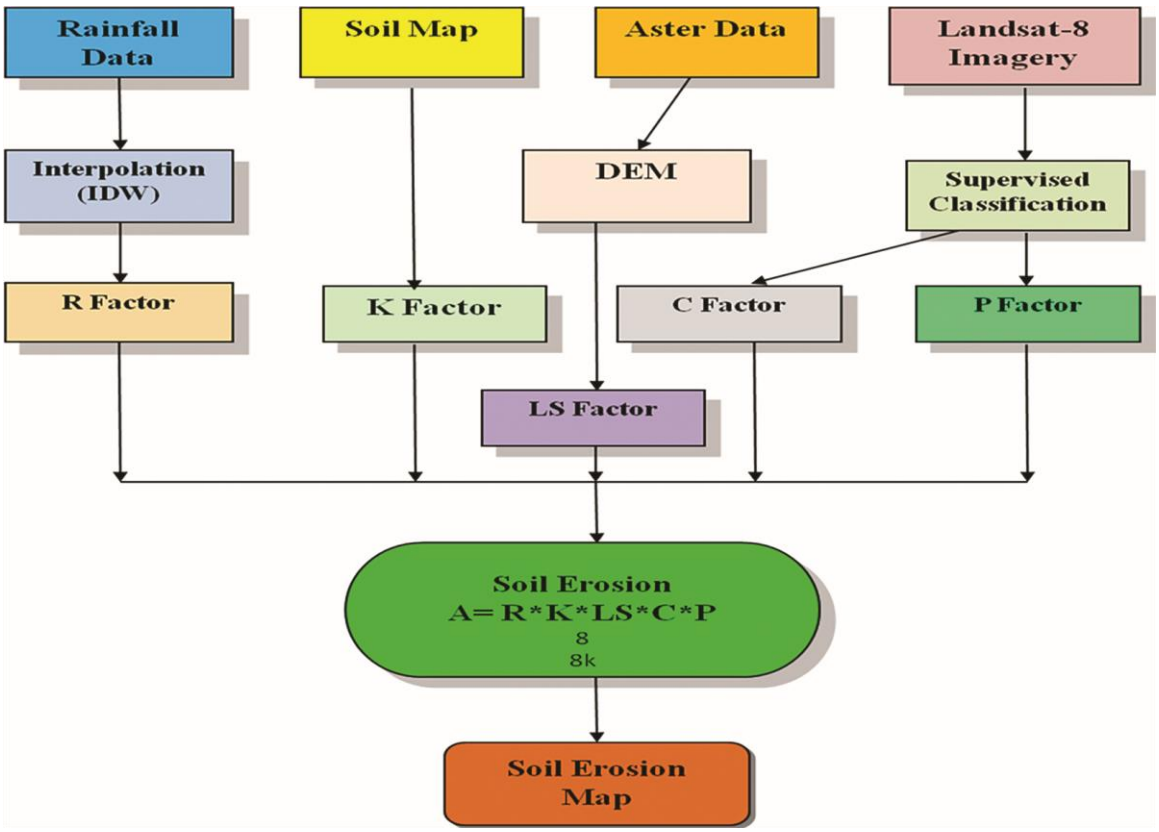

Fig. 2 — Different Factors of RUSLE

C-factor and P-factor

The Land use/ Land cover (LU/LC) map was prepared from the Landsat 8 satellite data which provided accurate mapping of different LU/LC categories due to its high spatial resolution. The LU/LC map was used for preparing the land cover and management factor (C-factor) map. The values of C-factor were assigned to the different land use land cover classes in the study area. The P-factor map was also prepared using the watershed's land use land cover chart and the P-factor values were applied to the different characteristics based on the soil management activities used in the study area with reference to previous studies.

All the five parameter maps (having the same coordinate system) were used to estimate soil erosion and spatial distribution of different soil erosion zones in the Udamsingh Nagar district. Raster Calculator was used to build the expression: (R×K× LS×C×P) which, when applied to all cells in a raster coverage of the watershed, produced a map of average annual soil erosion.

Prioritization of Resources

Prioritization of natural resources is limited and their wide utilization is imperative and essential. The resource-based approach is considered realistic for prioritizing the watershed, as it involves an integrated approach[9]. In this study, knowledge-based weightage system was adopted for sub-watershed prioritization based on its factors and after careful observation of the situation in the field as depicted in Table S1. The basis for assigning weightage to the various themes was based on the relative importance of each parameter in the study area. The weightage system implemented here depends entirely on the local terrain and can vary from place to place. The water-holding capacity or porosity and permeability of the formation in the area were also considered while assigning weightage.

Results and Discussion

The prioritization of the watersheds of the Udham Singh Nagar district was carried out using remote sensing and GIS technique by assessing potential soil losses arising due to the rainfall, slope and soil factors and reduced by land cover and management practices. This technique is quite robust in evaluating the influence of different land covers and soil management factors in quantitative estimations of soil loss. The remotely sensed data plays an important role in delineation of the land cover with greater precision of type and extent and to evaluate the appropriate annual cover factors. Implementation of Revised Universal Soil Loss equation using integration procedure of GIS enabled the prediction of soil loss at the sub-watershed level. The estimation of spatially varying soil losses requires the generation of the thematic layers such as land use and land cover, land slope, soil characteristics, land cover and management practices[20].

Land Use and Land Cover

The supervised classification technique was employed for generating Land use and Land cover (LU/LC) maps (Fig. 3) of Udham Singh Nagar district. Minimum distance algorithm was employed to achieve the task. The ground truth has been performed for the verification of the objects at different places. Land uses for Udham Singh Nagar includes fallow land, water bodies, rivers and built-up land spreading over it is 33.42%, 2.18%, 2.46% and 5.71% respectively as shown in Table 1. In Udham Singh Nagar district major portion (38.66%) of the district is covered with

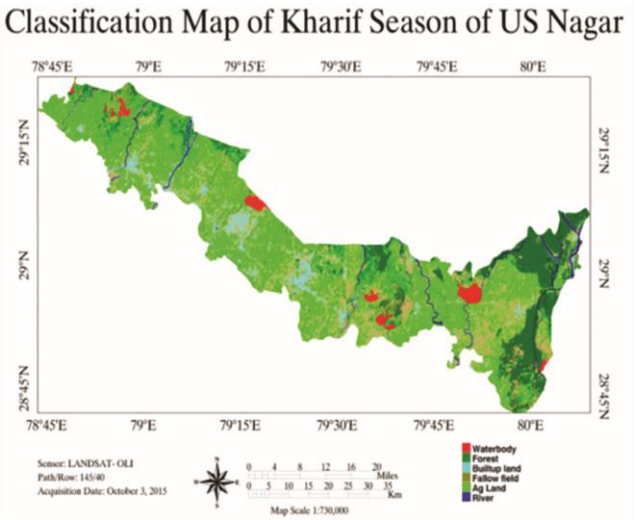

Fig. 3 — LU/LC Map of Study Area

Table 1 — Area of different Land Use and Land Cover features of Kharif Season

Sr. No.	Feature	Area in (ha) of US Nagar	Area in (%) of US Nagar
1	Water Body	6,165.63	2.18
2	Forest	49,634.19	17.57
3	Builtup Land	16,136.01	5.71
4	Fallow Land	94394.16	33.42
5	Agricultural Land	109,199.97	38.66
6	River	6,958.35	2.46
	Total	282,488.31	100

agriculture land and only 17.57% area is covered with forest. Water-bodies have occupied area 2.18% US Nagar district. A large variation has been noticed in case of built-up land which has been recorded as 5.71%. Udham Singh Nagar has more agricultural land. The land of Udham Singh Nagar district comes under plain category. There is abundance of water in this district as it comes under Tarai region. The soils are highly fertile and have good potential to hold water. The water which enters into soil of Bhabar region comes on the surface in Tarai region. Therefore, many small water streams/riverlets have their origin in this region. The water table is also high and good amount of rainfall occurs round the year which is sufficient for growth of vegetation. All these conditions are favourable for agriculture therefore at a major portion of land rice-wheat, sugarcane-sugarcane cropping system have been adopted. Forest has also been preserved at a considerable region; however this forest is mostly planted forest. A considerable region also comes under water-bodies. A number of water bodies have been developed (2.18%) to control the flow of different rivers and also to use rainwater for irrigation purpose. Udham Singh Nagar district has maximum density of water-bodies per unit area of geographical land in India.

NDVI map of study region

The NDVI image of Udham Singh Nagar district has been given in Fig. S1. The NDVI value is maximum in the region containing forest cover; however, its value is less over agricultural fields. Eastern, western and northern regions of Udham Singh Nagar district are exhibiting higher vegetative values corresponding to higher vegetative cover.

Land slope layer

The land slope of Udham Singh Nagar district is less than 10 degree as shown in Fig. S2. The spatial variation of slope suggests that most of the district comes under 0-2 degree slope. However, there are certain scattered regions in North-western part of the districts, which shows slope approximately 10 degrees. These regions falls just close to the Himalaya, therefore the slope is relatively higher. The district of Udham Singh Nagar is having many water bodies, which have been shown with land slope of 0 degree.

Average annual rainfall

The average annual rainfall in Udham Singh Nagar is very high, almost 1500 mm in most of the parts of district and around 2000 mm in some region of the central part of the district (Fig. S3). The higher rainfall in the North-central region of the Udham Singh Nagar district is due to the steep slope in this region[12]. The steep slope causes orographic effect which causes higher rainfall activities[6].

Soil layers

Organic matter

The organic matter layer of Udham Singh Nagar district has been shown in the Fig. S4, which is also exhibiting fairly higher value of organic matter in the entire district. There are few pockets especially in the central and eastern region of Udham Singh Nagar district which contains low amount of organic matter. The higher amount of organic matter in Udham Singh Nagar district is due to the fact that all the rivers flow down from Udhan Singh Nagar to Udham Singh Nagar district, and also brings lots of organic matter with them from hilly regions. The role of Organic matter is crucial in maintaining aggregation bounding among soil particles. The higher aggregation bounding reduces the loss of soil[7].

Soil structure class

The soil structure codes have been extracted from the soil database of NBSSLUP, Nagpur. The legend of the map shows information of soil texture. Therefore, soil textural classes were derived with the help of Soil Texture Triangle and the structure codes have been assigned. The value of soil textural codes is least in case of sandy soil, while it is maximum in case of fine silty and fine loamy soils. The sandy soil exhibits less adhesive properties and is more prone to soil erosion, while silty and loam soils exhibit higher value of soil structural classes, therefore are good to reduce the soil erosion[13]. The soil structure code (Fig. S5) of Udham Singh Nagar district is 3 over most part, which shows that the soils of Udham Singh Nagar district are not prone to soil losses.

Particle size parameter

Particle size parameter is the function of texture of the soil mostly depending on silt, fine sand and sand. Higher value of particle size parameter leads to the higher amount of soil losses. The spatial distribution of particle size parameter over Udham Singh Nagar districts have been show in Fig. S6. There are mainly two classes of particle size parameter i.e. low value

approximately 2000 in most part of the district and relative higher value of the parameter approximately 8000 mostly in eastern part of the district and over some scattered pockets.

Hydrological modelling

Flow accumulation

The water through precipitation falls over pieces of land masses and flow from top region to the lower region in gradual manner. While flowing from one region to other it gets accumulated. The water when start flowing from its original region has low velocity, which gradually increases when it passes through the lower regions. Not only velocity but also volume of water gradually increases. Therefore, the lower regions of the topographical space are more prone to soil losses than relatively higher regions. The flow accumulation over districts of Udham Singh Nagar has been shown in the Fig. S7. The flow accumulation over district of Udham Singh Nagar is exhibiting fairly well distribution. Though, north-south expansion of the district is quite small, still the value of flow accumulation is relatively high due to the fact that water is getting accumulated from parts of Udhan Singh Nagar district.

Delineation of watershed boundaries and identification of water channel

The boundaries of watershed in the district of Udham Singh Nagar have been delineated using digital elevation map (DEM) prepared with ASTER data. ASTER-DEM is available at 30 m resolution and has been widely acclaimed for its three dimensional accuracy. Grass module embedded in Quantum GIS has been used to delineate boundaries of watershed. Grass computes flow direction of water from each cell and there after accumulated water flow is summarized. Based on accumulated water flow major water streams are also identified as shown in Fig. S8. Grass produces result in raster data model, which was transformed into vector data model using raster to vector conversion module available in grass.

Estimation of soil loss using RUSLE model

Soil loss assessment was carried out using Revised Soil Loss Equation (RUSLE) for Udham Singh Nagar district. The various factors as being discussed below are required to compute soil losses through RUSLE equation.

Rainfall-runoff Erosivity Factor (R)

The quantative expression of the rainfall-runoff parameter causing soil erosion is the R factor. It is greatly influenced by the intensity and duration of precipitation events and by the amount of resulting runoff[5]. The R value incorporates total precipitation intensity and duration pattern of rainfall[16]. The value of R factor varies from 2 to 8 MJ mm/ha/h/year. The Fig. S9 show the R factor map of Udham Singh Nagar.

Soil Erodibility Factor (K)

The factors such as texture, composition, organic matter and permeability are very important in determining soil erodibility. Soil erodibility is managed by a complex set of physical and chemical properties, and is generally empirically determined[13]. Soil analysis data was available for all soil types found in Udham Singh Nagar district. K values are assigned in the soil chart to the respective soil types. Using K factor values, K factor map was prepared in QGIS and shown in Fig. S10. The value of the factor K in Udham Singh Nagar District was found to range from 0.002 to 0.010.

Slope Length Steepness Factor (LS)

DEM generated slope length is based on the assumption that each slope plane consists of a homogeneous type of slope and vegetation cover which, in reality, may not be the case The value of K factor in Udham Singh Nagar District was found to range from 0.002 to 0.010. GIS techniques aim to estimate very long slope lengths on flat to very gentle slopes while deriving topographic parameters, which can lead to over estimation of soil loss. As a result, the LS factor does not fully account for the hydrological processes that affect runoff and erosion, its importance as a measure of the landscape's sediment transport capacity[6]. ASTER DEM was used in percent and degree to derive slope map. As shown in Fig. S11, LS factor map was prepared using QGIS. The value of LS factor for study area for Udham Singh Nagar district ranged from 0 to 12.

Cover Management Factor (C)

Information on land use allows for a better understanding of land use aspects of crop patterns, fallow land, forests and wastelands and surface water bodies, which are essential for development planning/erosion studies.C factor is generally derived from a LU/LC classification from the satellite data[1].

Remote sensing and GIS technique have a potential to generate a thematic layer of LU/LC of a region. The study area has been classified into seven land use classes. Using LU/LC map and C factor values, C factor map was prepared in QGIS and is shown in Fig. S12. In the district, crop management factor was found to range from 0.2 to 1.00. Conservation practice factor of the district for micro watersheds was assigned based on percentage slope. P factor map was prepared in QGIS and is shown in Fig. S13.

Erosion Control Practices Factor (P)

The P factor values on different slope gradients are calculated. Its value ranges from 0.3 to 1.2 and it is clear that more is the value of slope more will be the value of P factor. It found to be more than 1 when slope is above 30%. The value of P factor is very low of the order of 0.4 in most of the Udham Singh Nagar district because the value of slope is very low as shown in Fig. S13. Hence contribution of P factor is less in erodibility.

Soil losses

The annual soil loss for micro-watersheds was estimated using annual average R factors (based on daily rainfall data of), K, LS, C and P. All the various layers viz. R, K, LS, C and P were generated in GIS and laid over to obtain the product which gives Udham Singh Nagar an annual soil erosion map. In a given watershed the soil erosion rate (t/ ha/yr) was calculated as total soil loss. Prioritization of micro watersheds inside the basin is based on risk of soil erosion. The Fig. 4 shows the Soil erosion potential map of Udham Singh Nagar district.

Watershed level soil losses

The watershed erosion maps show the ranges of erosion in different watersheds and thus showing nature of watersheds according to the severity of soil erosion in them. According to soil erosion prone ranking, negligible watersheds fall in severely prone range in Udham Singh Nagar, most of watersheds exhibit small amount of soil erosion. Watershed boundaries were overlaid on raster-based soil loss erosion for computation of average soil loss from each watershed has been depicted in Fig. 5. Udham Singh Nagar is having plane topography hence the range of soil erosion is much lesser. The erosion ranges from 0 to 40 ton/ha/year. However, most region of Udham Singh Nagar district falls under the category of 0-2 ton/ha/year soil erosion. A small region especially close to rivers and having relatively higher slope is exhibiting slightly high soil erosion ranging from 20-40 ton/ha/year. Land use and land cover map of Udham Singh Nagar district is shows that the farmers of district do intense agriculture. The cropping intensity of district is close to 200. That means farmers take usually two crops in a year. Therefore, agricultural fields remain occupied throughout the year and reduce to possibility of erosion. Thick forest cover, human settlement and water-bodies are further contributing to reduced soil erosion.

Prioritization of watersheds for sustainable development

The watersheds identified in the Fig. 6 were prioritized based on potential of soil losses. The soil has been assumed as the most important natural resources due to its importance in providing support to vegetation, providing nutrients to plants, providing

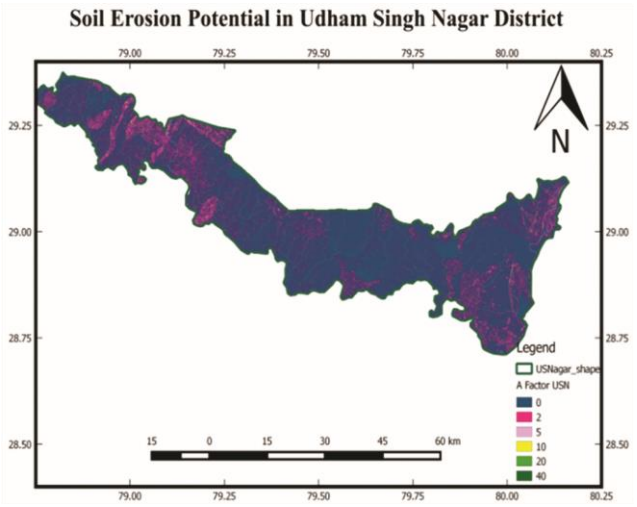

Fig. 4 — Soil erosion potential map of study area

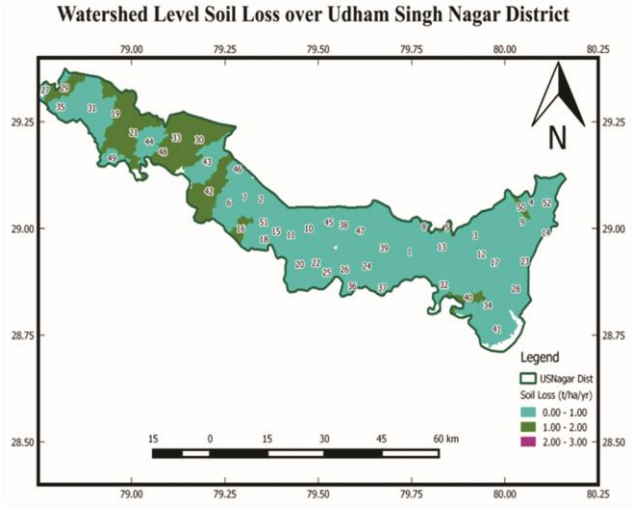

Fig. 5 — Watershed level Soil loss map of Study area

water retention capacity and many other services. Water is other important natural resources, which should be conserved/ judiciously used for sustainable development. However, water in the study region is sufficiently available in terms of precipitation therefore prioritization based on soil losses assumed prime importance[3]. The geospatial database has been created as mentioned above in the different sections. The soil erosion risk was calculated using the Revised Universal Soil Loss Equation (RUSLE). The pixel level soil erosion was averaged at watershed boundary so that watershed could be prioritized. The critical level of the sub-watershed was then determined using the criteria suggested by[19]. Each sub-watershed was given a rank according to the soil erosion risk. The Udham Singh Nagar was divided into 52 watersheds for prioritization. Six different categories with potential soil losses of less than 5 t/ha/yr (slight), 5-10 (moderate), 10-20 (high), 20-40 (very high) and 40-80 (severe) and more than 80 (very severe) were considered for prioritization and were given ranks of sixth, fifth, fourth, third, second and first, respectively.

The prioritized classes of watersheds of Udham Singh Nagar districts have been shown in Table 2. Udham Singh Nagar district being in located in flat topography exhibits low soil loss potential. Therefore all watersheds are falling in the category of sixth prioritization. The value of soil losses in most of cases is less than 1 t/ha/yr except in case of 11 watersheds, where it is slightly higher than 1 t/ha/yr. Therefore, no big plan/activity is required for reducing soil losses. Only checking large amount of runoff and enhancing organic matter build up in the soil will suffice the purpose[13,19].

Conclusions

Prioritization of land resources based on potential of soil losses was done with integration of Remote Sensing and GIS techniques for effective management. The land has been assumed as the most important natural resources due to its importance in providing support to vegetation, providing nutrients to plants, providing water retention capacity and many other services. The creation of geo-database on land use and land cover, slope, soil properties, climatic variable and hydrological characterization was found to be very effective and used for estimating soil losses. Landsat 8 (OLI) optical data of 145/40 path and row was used to create land use and land cover map of Udham Singh Nagar district. Because near about 60 % area covered with agricultural practices, forest and builtup area which reduces soil loss. On the basis of results it may be concluded that a major portion of Udham Singh Nagar is under safe limit of soil erosion. Agricultural land can be protected by means of these majors which increase the productivity of the crops and directly benefit the producer economically. The economic benefits to the producer fulfill Pradhan Mantri Krishi Sinchayee Yojana's (PMKSY) goal, which focuses mainly on increasing productivity by using different techniques to manage the watershed.

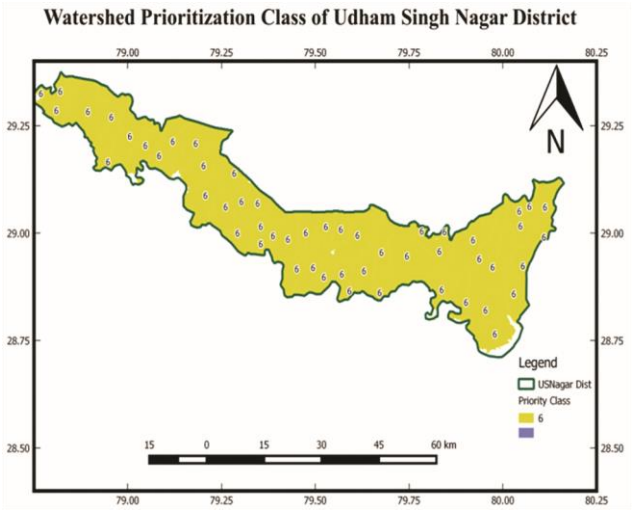

Fig. 6 — Watershed Prioritization map of study area

Table 2 — Showing priority classes and the criteria adopted for watershed prioritization with total number of watershed falling in each category

Sr. No	Priority Class	Soil Loss (t/ha/yr)	Class	No. of Watersheds USN
1	6	< 5	Slight	52
2	5	5-10	Moderate	-
3	4	10-20	High	-
4	3	20-40	Very High	-
5	2	40-80	Severe	-
6	1	>80	Very Severe	-

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Conflict of Interests

The authors declare no conflict of interest.

Author Contributions

Devendra Kumar and Arvind performed this research, Ajeet Singh Nain directed overall, Amandeep Singh, Aman Mor and Sushant Bhardwaj assisted in writing this article.

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