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Assessment of soil erosion using GIS and remote sensing techniques in Dzumah watershed of upper Dhansiri, Nagaland

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Abstract
In the present study, an attempt was made to estimate the average annual soil loss in a small watershed in Nagaland, India, using GIS-based Universal Soil Loss Equation (USLE) technique. Remote sensing data, Digital Elevation Model (DEM), soil and rainfall data were used for determining the USLE parameters. The results showed that R-factor varied from 734.02 and 4157.30 MJ mm ha^{-1} h^{-1} $year^{-1}$. The K-factor ranged from 0.03 to 0.074 t ha h ha^{-1} MJ^{-1} mm^{-1}. The LS-factor of the watershed ranged from 0.03 to 54.44. C-factor and P-factor values ranged from 0.07 to 0.53 and 0.28 to 1.0, respectively. The average annual soil loss in Dzumah watershed was found to be 5.38 t ha^{-1} $year^{-1}$, which is less than the permissible soil loss limit recommended for Himalayan regions. It was also observed that almost 90% of the watershed area was under light and moderate erosion classes with each class occupying 1777.34 and 4089.67 ha, respectively. Based on the findings, it was inferred that the watershed is stable with no major risks of erosion. The stability of the watershed despite its rugged terrain could be due to the excellent forest cover in the steep sloped higher reaches of the watershed. Furthermore, given the fragile mountainous environment of the watershed, it is significantly important to conserve the existing forest cover and adopting appropriate soil conservation measures to any changes in the land use for sustaining the stability of the watershed.

Keywords: Soil loss, watershed, GIS, remote sensing, USLE

Introduction

Soil is a fragile layer on the earth's surface and it is vital for sustaining all terrestrial life forms on earth. It may appear to be a robust and infinite natural resource, but it is the frail product of soil formation processes that could span thousands of years. Development of a thin 5 cm depth of soil could take hundreds to thousands of years whereas the same can be eroded off in a single rainstorm event (Nivesh and Kumar, 2018) [7]. Soil is therefore, an indispensable natural resource in any given ecosystem. Soil erosion is a widespread problem with far reaching on-site and off-site consequences. It is responsible for a multitude of global crisis such as desertification of arable land, threatening food security, siltation of dams and reservoirs effectively minimizing water storage capacity, pollution of water bodies and a myriad of other environmental complications. In recent times, climate change has induced changes in the spatial and temporal variation in rainfall patterns across the world. The severe onslaught of high intensity rainstorm during rainy season, transitioning into prolonged periods of dry spell coupled with faulty land use systems has further intensified the problems caused by erosion. Therefore, efforts to control erosion and mitigate its effects have become vitally important. Assessment of soil loss and determination of the spatial variability of erosion are essential pre-requisites for formulation of suitable soil conservation strategies.

Nagaland, a North-Eastern state in India, is characterized by steep slopes, intricately dissected and rolling topography. The state has a total geographical area of 16,579 km^2 of which only 8.48% can be considered as plain, implying that the state is vulnerable to erosion. The annual rainfall of the state varies from 1700 to 2600 mm, of which 90% of the rainfall occurs during the month of June to November (Verma, 2007) [14]. The high annual rainfall, the steep topographical and terrain settings and the existing primitive method of *jhum*/shifting cultivation practiced in the state are highly conducive for soil erosion to take place. In this view, the present investigation was carried out to assess soil loss in the Dzumah watershed of Upper Dhansiri River in Nagaland using GIS-based Universal Soil Loss Equation (USLE) technique.

Materials and Methods

Study area and data collection

The Dzumah watershed in Chumukedima (erstwhile Dimapur) district of Nagaland, is located between 93° 51' 33" to 94° 00' 16" E longitude and 25° 40' 45" to 25° 47' 01" N latitude at a height of 328 to 2345 m above mean sea level. The watershed has an area of 6555 ha. A total of 19 sampling locations as represented in Fig. 1, were randomly selected from the watershed area for collection of soil samples. Cloud-free, high resolution multispectral data of Sentinel-2A captured on 15th November, 2019 with a spatial resolution of 10 m was downloaded from the USGS website (earthexplorer.usgs.gov) to be used for land use/land cover classification and generation of Normalized Difference Vegetation Index (NDVI) map of the watershed. Shuttle Radar Topographic Mission-Digital Elevation Model (SRTM-DEM) of 30 m spatial resolution was also downloaded from the USGS website (earthexplorer.usgs.gov). ArcGIS 10.8 and QGIS 3.10 softwares were used in the present study for processing of spatial data and preparation of thematic maps.

Computation of USLE parameters

The Universal Soil Loss Equation (USLE) is an empirical method of estimating average annual soil loss developed by Wischmeier and Smith (1978) [17]. The equation is a product of five input factors and is expressed as follows:

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where, A is the average annual soil loss (t ha^{-1} year^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), LS is the slope length and steepness factor, C is the cover management factor and P is conservation practice factor.

In this study, the Universal Soil Loss Equation (USLE) was combined with GIS technologies to estimate the potential soil loss from the watershed. A cell size of 30 x 30 m was considered as basic operational unit for erosion analysis. Average annual soil losses were grouped into different classes as suggested by Prasanakumar *et al*. (2011) [10].

Rainfall erosivity factor (R)

Monthly rainfall data of 23 years (1998–2020) was used for calculating the R-factor. As there was no record of rainfall intensity, monthly rainfall data was used for calculating annual R-factor using the following relationship developed by Wischmeier and Smith (1978) [17]:

$$R = \sum_{i=1}^{12} 1.735 \, X \, 10^{[1.5 \, log_{10} \, (P_i^2/P) - 0.08188]} \quad (2)$$

Where, R is Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), P_i = Monthly rainfall (mm) and P is annual rainfall (mm).

Soil erodibility factor (K)

The collected soil samples were first analyzed for soil textural class and organic matter content using International pipette method (Piper, 1996) [9] and Walkley and Black method (1934) [15], respectively. The K-factor was calculated using the following equation as given by Wischmeier and Mannering (1969) [16]:

$$K = \frac{2.1 \times 10^{-4} \, (12 - OM) M^{1.14} + 3.25(s-2) + 2.5(p-3)}{759.4} \quad (3)$$

Where,
K is soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}),
OM is

Percentage of organic matter, S is soil structure code, P is permeability code and M is a function of the fraction of the primary particle size. Estimation of the function of the primary particle size fraction (M) was done using the following equation:

$$M = (\% \text{ silt} + \% \text{ sand}) \times (100 - \% \text{ clay}) \quad (4)$$

Slope length and steepness factor (LS)

To calculate LS factor, flow accumulation map and slope map (degrees) were derived from DEM using Spatial Analyst module in ArcGIS. LS factor was computed using Moore and Burch (1986a,b)[5,6] equation as given below:

$$LS = \left(Flow\ accumulation \times \frac{Grid\ size}{22.13}\right)^{0.4} \times \left(\frac{Sin\ Slope}{0.0896}\right)^{1.3} \quad (5)$$

Where, flow accumulation represent the upslope contributing area for a given grid cell, grid size (30 m for this study), 22.13 is the USLE unit plot length (m) and sin slope is value of slope degree in sin.

Cover management factor (C)

The C-factor represents the effects of vegetation and soil cover on soil erosion. In the present study, the Semi-Automatic Classification Plugin (SCP) of the QGIS software was used for performing a supervised classification of land use/land cover of the study area. The Maximum Likelihood algorithm was selected for the image classification. Currently, due to wide variations in the spatial and temporal patterns of land cover, remote sensing satellite datasets are used for the evaluation of C factor (Karydas *et al.*, 2009; Tian *et al*., 2009) [4,13]. The Normalized Difference Vegetation Index (NDVI) is an indicator of the vegetation health and is expressed as follows:

$$NDVI = \frac{NIR - R}{NIR + R} \quad (6)$$

Where
NDVI = Normalized Difference Vegetation Index
NIR = Near Infrared Band
R = Red Band

The C-factor of the study area was calculated based on the works of Durigon *et al*. (2014) [2] and is given as follows:

$$C = \frac{(-NDVI + 1)}{2} \quad (7)$$

Conservation practice factor (P)

The P-factor reflects the effects of conservation practices to decrease the runoff and erosion (Renard *et al.,* 1997; Yue-Qing *et al.*, 2008) [12, 18]. The P-factor values range from 0.25 to 1. Higher P-factor values correspond to areas with no conservation practices (forest/natural vegetation) whereas lower values correspond to crop land with strip and contour cropping. The P-factor values for different management practices in the study area were adopted as suggested by Rao (1981) [11].

Results and Discussion

USLE parameters

In the present study, rainfall data of 23 years (1998 - 2020) was used for calculation of R factor. The lowest and the highest annual R-factor was observed in the year 1998 and 2017 with values 734.0 and 4157.3 MJ mm ha^{-1} h^{-1} $year^{-1}$, respectively (Table 1). The R factor was considered to be homogenous in the study area.

Soil physical properties and organic matter content influences soil erodibility. The dominant soil type in the study area was found to be clay loam in nature. The organic matter content varied from 0.53 to 2.57% (Table 2). The soil erodibility factor (K) of the Dzumah watershed ranged from 0.03 to 0.074 with an average of 0.045 (Table 2). K-factor map of the study area is depicted in Fig. 2.

The slope classes of the study area were classified based on the USDA classification as adopted by Pamela *et al.* (2018) [8]. The DEM derived slope map revealed that majority of the watershed area was under hilly, moderately steep and steep slope classes (Table 3). The topographic factor (LS) of the Dzumah watershed ranged from 0.03 to 54.44. Slope map and LS factor map are depicted in Fig. 3 and 4, respectively.

The C-factor is a measure of the relative efficiency of different land use and crop management systems in controlling erosion. Five broadly distinct land use classes were observed in the Dzumah watershed *i.e.*, dense forest, open forest, cultivated area, buildup area and water body, occupying 3998.55, 1553.54, 322.5, 392.65 and 287.76 ha, respectively. The land use/land cover and corresponding areal statistics are presented in Table 4. It was observed that forest land use was dominant in the study area, with dense and open forest land collectively occupying 5552.09 ha, which accounted for almost 85% of the total watershed area (Fig. 5). In the present study, the C-factor of the watershed was derived using NDVI. The use of vegetation indices such as the NDVI gave better results in estimating C-factor (Almagro *et al*., 2019) [1]. The NDVI values of the Dzumah watershed ranged from -0.08 to 0.87 (Fig. 6). The C-factor ranged from 0.07 to 0.52 (Fig. 7).

Soil erosion processes and erosion rates are minimized by implementing different methods of conservation practices. No significant conservation measures were observed in the study area. Therefore, based on the existing land use system, P-factor values of 0.28 and 1.0 were assigned to cultivated areas and other land uses, respectively (Fig. 8).

Average annual soil loss

The soil loss for each of the year *i.e.*, from 1998 to 2020, was computed by multiplying the thematic layers of all the USLE parameters individually for each year using raster calculator in ArcGIS. The average annual soil erosion map was then generated by overlaying the erosion map of all the years and computing cell statistics using the Spatial Analyst Toolbox in ArcGIS. The findings showed that the average annual soil loss of the Dzumah watershed was 5.38 t ha^{-1} $year^{-1}$ (Table 5). It was also observed that almost 90% of the watershed area was under light and moderate erosion classes with each class occupying 1777.34 and 4089.67 ha, respectively (Table 6, Fig. 9). Severe erosion was observed only in those areas with steep gradients and denuded and exposed construction sites. The Himalayan region has a permissible soil loss of 15 t ha^{-1} $year^{-1}$ (Jasrotia *et al.*, 2006) [3]. Based on this information, it can be inferred that the Dzumah watershed is stable with no major risks of erosion. The stability of the watershed could be attributed to the excellent vegetation cover despite the hilly and undulating terrain. It was also noticed that most of the forested areas were found in the steep sloped higher reaches of the watershed and the cultivated and rural buildup areas were observed in low lying areas having comparatively gentler slopes. It is also worth noting that *jhum*/shifting cultivation, which is considered to be destructive and unsustainable, was not observed in the study area, nor was it reported from the locals during field survey. The inaccessibility and constraints to cultivation practices in such steep slopes and other socioeconomic factors could have hindered the changes in the land use system, thus effectively preserving the native forests in the watershed.

The Dzumah watershed was found to be stable despite its intricately dissected and rough terrain settings. However, considering the fragile hilly and mountainous environment of the watershed, it is significantly important to preserve the current status of forest cover and adopting appropriate soil conservation measures to any changes in the land use for sustaining the stability of the watershed. The USLE model also estimates only the soil losses that occur due to sheet and rill erosion. Therefore, soil losses from other sources such as gully and stream bank erosion also needs to be investigated. These findings can serve as a source of primary information for planners and decision makers in devising environmentally sustainable options in future developmental activities.

Table 1: Year-wise rainfall erosivity factor (R) of Dzumah watershed

Sl. No.	Year	Annual R
1	1998	734.0
2	1999	2517.2
3	2000	3595.3
4	2001	2051.9
5	2002	2421.8
6	2003	1546.7
7	2004	3717.0
8	2005	2337.4
9	2006	2359.6
10	2007	3499.4
11	2008	1950.6
12	2009	1263.4
13	2010	3070.7
14	2011	3509.4
15	2012	2374.7
16	2013	3526.0
17	2014	2070.2
18	2015	1863.0
19	2016	2559.9
20	2017	4157.3
21	2018	2473.8
22	2019	1729.5
23	2020	1388.2
Average		2465.9

Table 2: Soil properties and K factor of Dzumah watershed

Sample number	Coordinates (Decimal degrees)		Sand (%)	Silt (%)	Clay (%)	Textural Class	OM (%)	Permeability	Soil Structure Code	M	K
	Longitude	Longitude									
1	93.8720862	93.8720862	35.80	42.50	20.10	Loam	0.53	3	2	6256.17	0.068
2	93.8811345	93.8811345	19.70	46.20	32.50	Silty Clay Loam	1.31	3	2	4448.25	0.043
3	93.8945354	93.8945354	27.70	38.80	32.50	Clay Loam	1.74	4	2	4488.75	0.045
4	93.8936231	93.8936231	33.80	52.20	11.70	Silt Loam	2.03	3	2	7593.8	0.074
5	93.900196	93.900196	18.80	46.70	33.30	Silty Clay Loam	1.64	3	2	4368.85	0.041
6	93.9104677	93.9104677	19.00	51.40	28.30	Silty Clay Loam	1.48	3	2	5047.68	0.049
7	93.9310979	93.9310979	34.70	29.80	34.10	Clay Loam	2.57	4	2	4250.55	0.039
8	93.9197039	93.9197039	35.50	33.40	28.60	Clay Loam	1.72	4	2	4919.46	0.050
9	93.9390183	93.9390183	30.00	34.50	32.80	Clay Loam	2.38	4	2	4334.4	0.041
10	93.9431405	93.9431405	32.40	34.20	29.40	Clay Loam	1.35	4	2	4701.96	0.049
11	93.9435515	93.9435515	20.00	44.30	33.80	Silty Clay Loam	1.58	3	2	4256.66	0.040
12	93.9192593	93.9192593	21.00	52.30	24.20	Silt Loam	2.44	3	2	5556.14	0.050
13	93.9155765	93.9155765	35.00	28.00	35.20	Clay Loam	1.66	4	2	4082.4	0.041
14	93.926405	93.926405	35.80	28.40	33.50	Clay Loam	1.79	4	2	4269.3	0.043
15	93.9703183	93.9703183	19.40	36.50	42.60	Silty Clay Loam	1.27	3	2	3208.66	0.030
16	93.9369824	93.9369824	27.30	33.10	38.20	Clay Loam	2.15	4	2	3732.72	0.036
17	93.9895084	93.9895084	19.30	47.70	31.80	Silty Clay Loam	1.87	3	2	4569.4	0.042
18	93.9856627	93.9856627	24.60	38.50	35.50	Clay Loam	2.4	4	2	4069.95	0.038
19	93.9074576	93.9074576	27.10	33.50	37.80	Clay Loam	2.36	4	2	3769.32	0.036
	Average										0.045

Table 3: Slope classes of Dzumah watershed based on USDA classification

Description	Slope		Area (ha)	Percent Area
	Percent	Degree		
Flat	0-3	<2	208.4	3.18
Undulating	3-8	2-5	616.68	9.4
Moderately Sloping	8-15	5-8	495.14	7.55
Hilly	15-30	8-17	1606.78	24.51
Moderately Steep	30-45	17-24	1802.54	27.5
Steep	45-65	24-33	1292.3	19.72
Very Steep	>65	>33	533.57	8.14

Table 4: Land use/land cover classes of Dzumah watershed

Sl. No.	Land use class	Area (ha)	% of total geographical area
1	Cultivated area	322.50	4.92
2	Dense forest	3998.55	61
3	Open forest	1553.54	23.7
4	Buildup area	392.65	5.99
5	Water body	287.76	4.39
Total		6555.00	100.00

Table 5: Year-wise annual soil loss of Dzumah watershed

Sl. No.	Year	Average annual soil loss (t $ha^{-1} yr^{-1}$)
1	1998	1.60
2	1999	5.49
3	2000	7.84
4	2001	4.48
5	2002	5.29
6	2003	3.38
7	2004	8.11
8	2005	5.10
9	2006	5.15
10	2007	7.64
11	2008	4.26
12	2009	2.78
13	2010	6.70
14	2011	7.66
15	2012	5.18
16	2013	7.70
17	2014	4.52
18	2015	4.07
19	2016	5.59

20	2017	9.07
21	2018	5.40
22	2019	3.78
23	2020	3.04
	Average	5.38

Table 6: Area under different classes of erosion in Dzumah watershed

Soil loss (t ha^{-1} yr^{-1})	Area (ha)	% Area	Soil erosion class
0-3	1777.34	27.11	Light
3-10	4089.67	62.39	Moderate
10-25	588.82	8.98	High
25-50	98.33	1.50	Severe
>50	0.84	0.01	Extreme

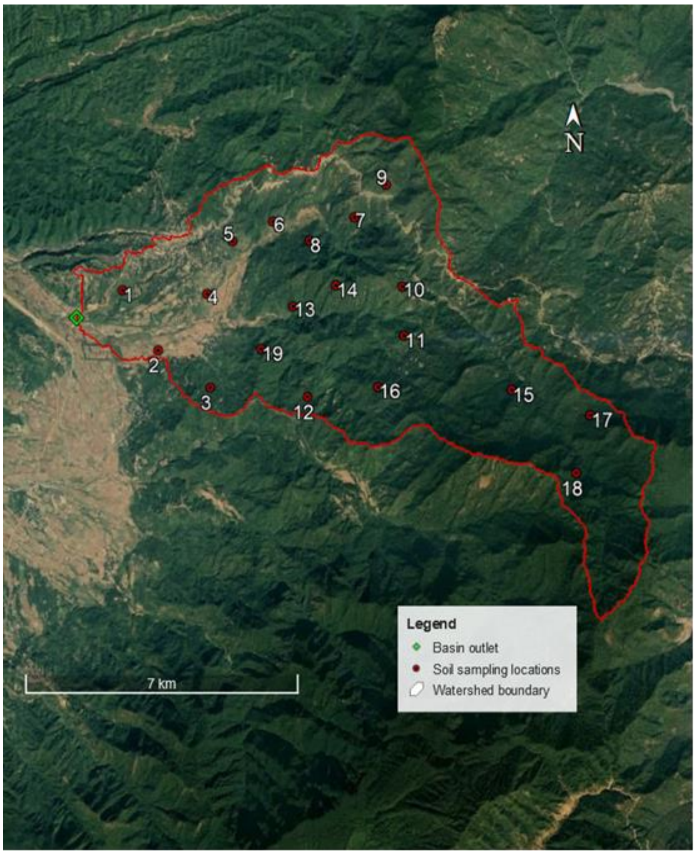


Fig 1: Spatial extent of Dzumah watershed

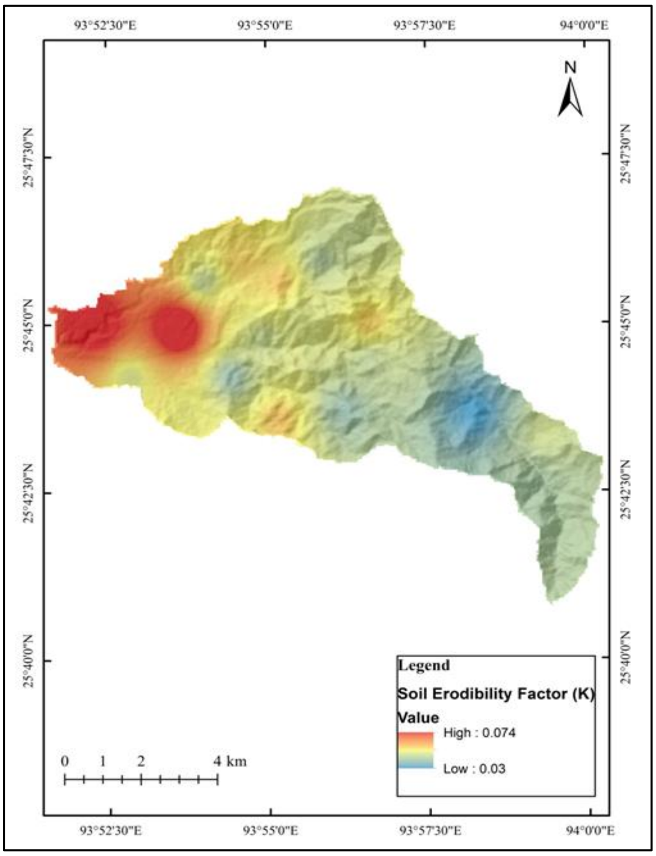


Fig 2: Soil erodibility factor (K) map of Dzumah watershed

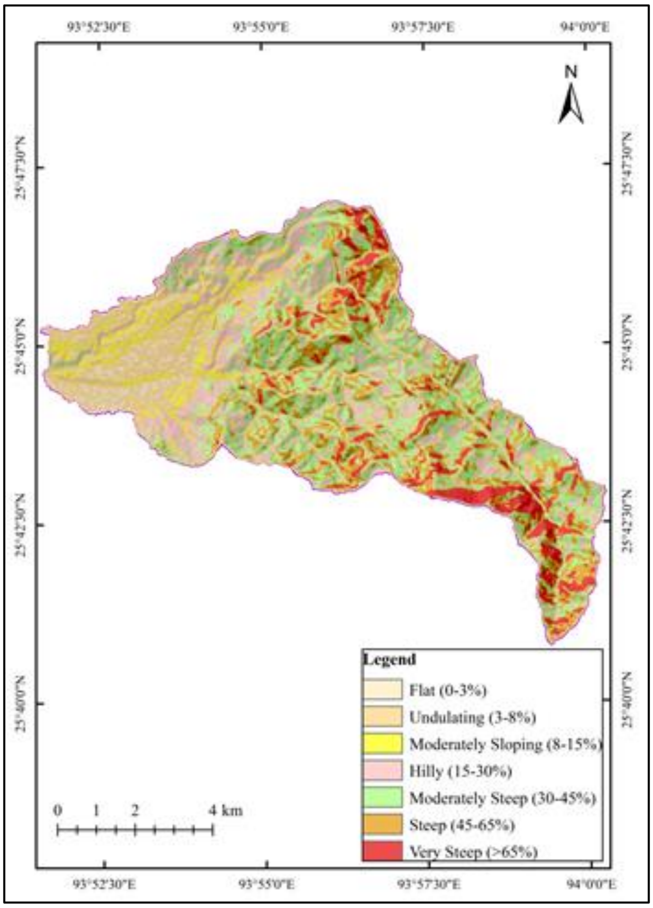


Fig 3: Slope map of Dzumah watershed

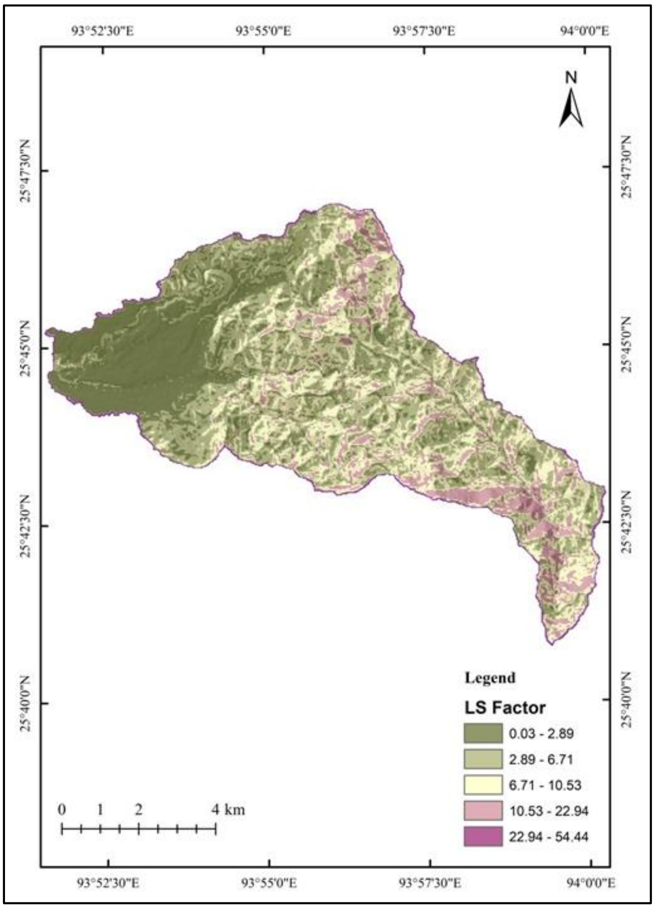


Fig 4: Slope length and steepness factor (LS) map of Dzumah watershed

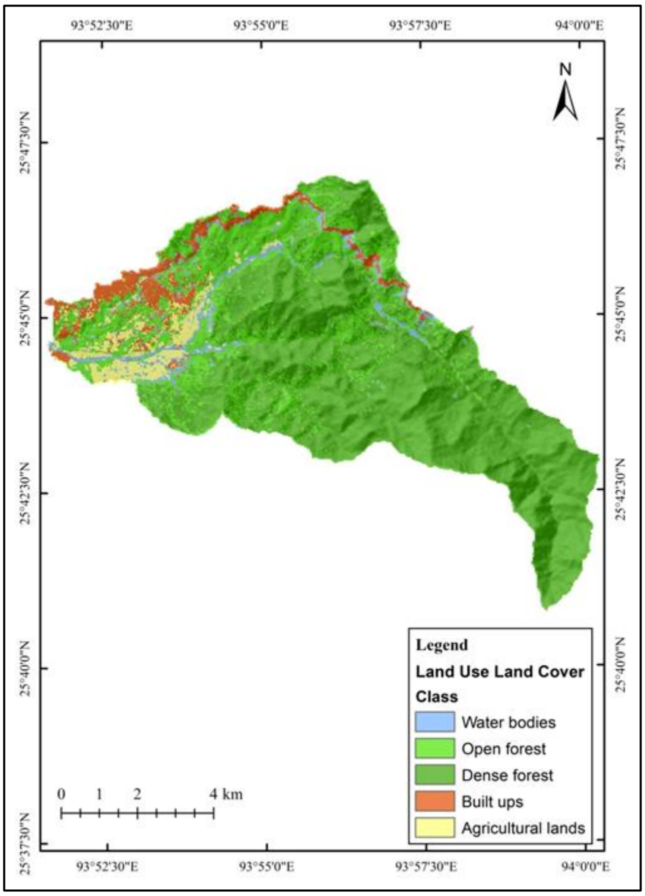


Fig 5: Land use/land cover map of the Dzumah watershed

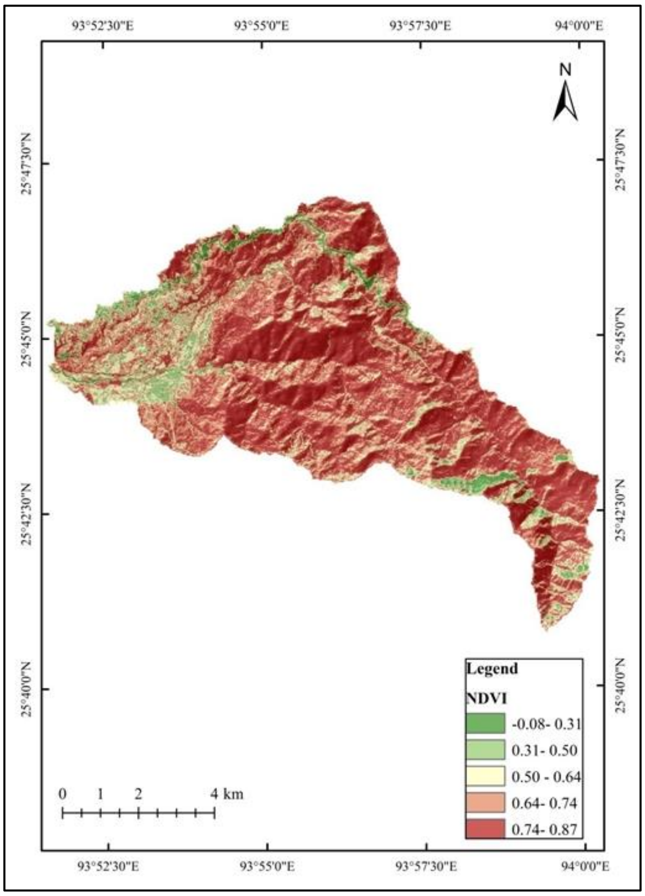
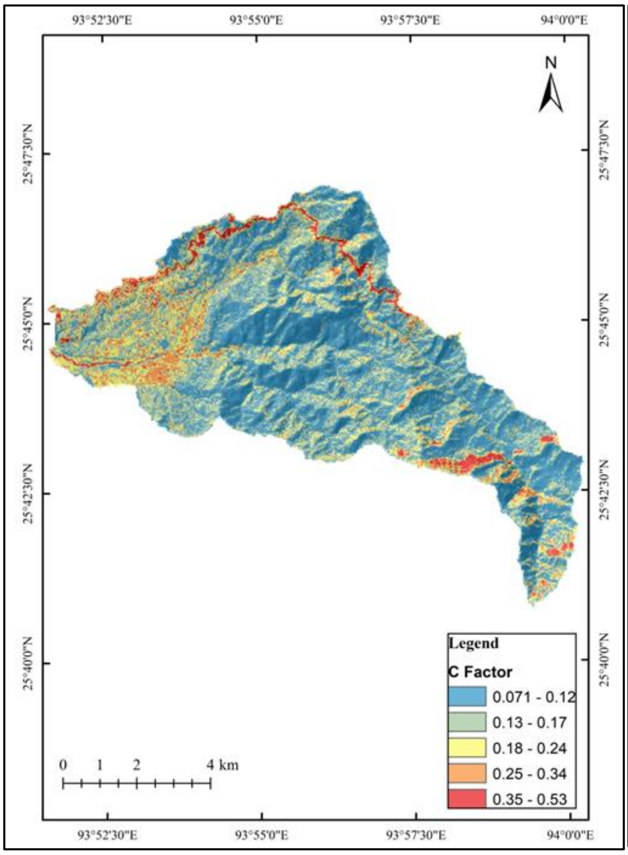


Fig 6: NDVI map of Dzumah watershed



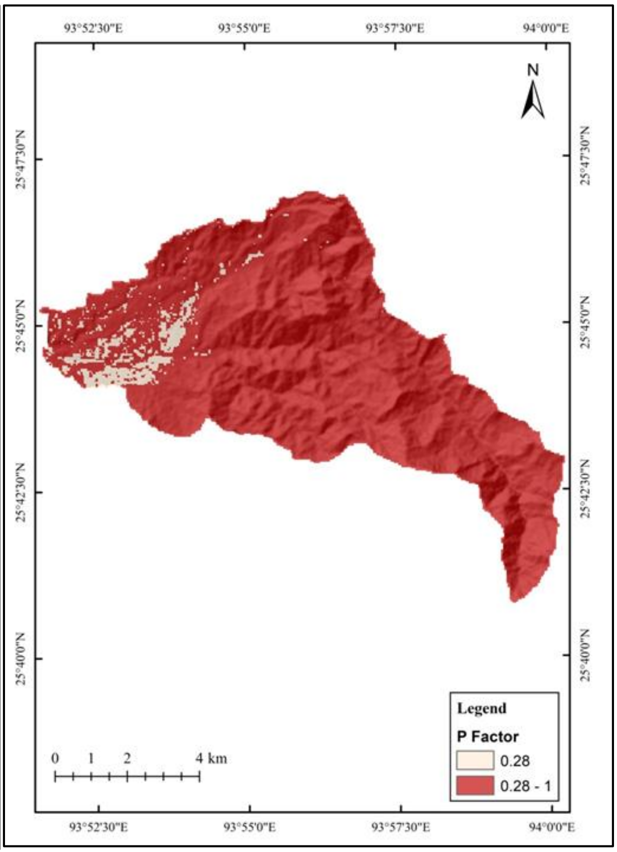


Fig 7: Crop management factor (C) map of Dzumah watershed **Fig 8**: Conservation practice factor (P) map of Dzumah watershed

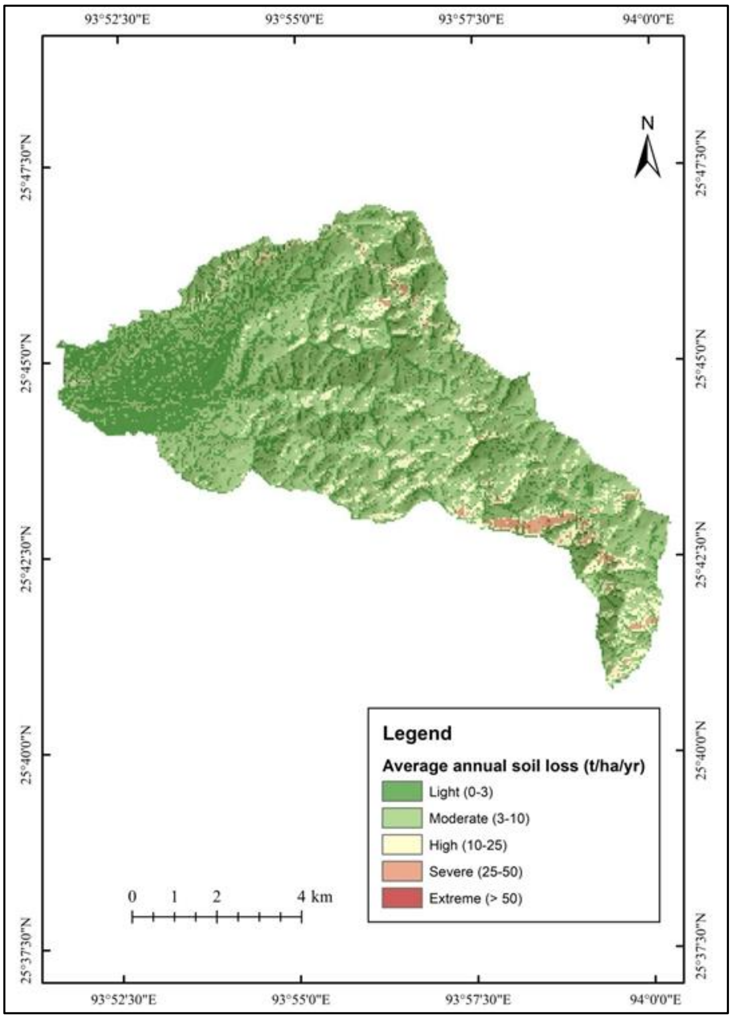


Fig 9: Average annual soil erosion map of Dzumah watershed

References

1. Almagro A, Thomé TC, Colman CB, Pereira RB, Marcato J, Rodrigues DBB. Improving cover and management factor (C-factor) estimation using remote sensing approaches for tropical regions. International Soil and Water Conservation Research. 2019;7(4):325-334.
2. Durigon VL, Carvalho DF, Antunes MAH, Oliveira PTS Fernandes MM. NDVI time series for monitoring RUSLE cover management factor in a tropical watershed. International Journal of Remote Sensing. 2014;35(2):441–453.
3. Jasrotia AS, Singh R. Modeling runoff and soil erosion in a catchment area, using the GIS in the Himalayan region, India. Environmental Geology. 2006;51:29-37.
4. Karydas CG, Sekuloska T, Silleos GN. Quantification and site specification of the support practice factor when mapping soil erosion risk associated with olive plantations in the Mediterranean Island of Crete. Environmental Monitoring and Assessment. 2009;149:19–28.
5. Moore ID, Burch GJ. Physical basis of the length slope factor in the Universal Soil Loss Equation. Soil Science Society of America. 1986a;50(5):1294-1298.
6. Moore ID, Burch GJ. Modeling erosion and deposition: Topographic effects. Transactions of American Society of Agriculture Engineering. 1986b;29(6):1624-1630.
7. Nivesh S, Kumar P. Estimation of sediment load using ANN, ANFIS, MLR and SRC Models in Vamsadhara River Basin, India. Annals of Plant and Soil Research. 2018;20(1):37–45.
8. Pamela P, Sadisun IA, Arifianti Y. Weights of evidence method for landslide susceptibility mapping in Takengon, Central Aceh, Indonesia. In: Proceedings of the IOP conference series: Earth Environmental Science, Bandung, Indonesia. 2018. https://doi.org/10.1088/1755-1315/118/1/012037
9. Piper CC. Soil and Plant analysis. Hans Publishers, Mumbai. 1996.
10. Prasannakumar V, Vijith H, Geetha N, Shiny R. Regional scale erosion assessment of a Sub-tropical Highland segment in the Western Ghats of Kerala, South India. Water Resource Management. 2011;25:3715–3727.
11. Rao YP. Evaluation of cropping management factor in Universal Soil Loss Equation under natural rainfall condition of Kharagpur, India. In: Proceedings of the Southeast Asian Regional Symposium on Problems of Soil Erosion and Sedimentation. Asian Institute of Technology, Bangkok. 1981, p. 241–254.
12. Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agricultural Handbook. 1997;703:126-131.
13. Tian YC, Zhou YM, Wu BF, Zhou WF. Risk assessment of water soil erosion in upper basin of Miyun Reservoir, Beijing, China. Environmental Geology. 2009;57:937–942.
14. Verma AK. Rainwater harvesting techniques for increasing crop production in Nagaland. In: Composite Farming Practices and Economic Development (eds. A. Sharma, R. K. Singh). 2007, p. 1-10.
15. Walkey A, Black IA. Determination of organic matter in soil. Soil Science. 1934;37:549-556.
16. Wischmeier WH, Mannering JV. Relation of soil properties to its erodibility. In: Proceedings of the Soil Science Society of America. 1968;33:131-137.
17. Wischmeier WH, Smith DD. Predicting rainfall erosion losses. USDA Agricultural Research Services Handbook 537. USDA, Washington, DC. 1978 p. 57.
18. Yue-Qing X, Xiao-Mei S, Xiang-Bin K, Jian P, Yun-Long C. Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. Environmental Monitoring and Assessment. 2008; 141:275–286.