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Watershed Prioritization based on LULC Characteristics using GIS and TOPSIS: A case of Chathe watershed

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ABSTRACT

Watershed prioritization based on land use and land cover demonstrated the role of different features on possibilities of soil erosion. Sub-watershed prioritization is more crucial to restrict the soil erosion as well as loss of nutrients from the top soil. The study assigned the weight to various LULC features based on their role in soil erosion. Finally with the help of Technique for Order of Preference by Similarity to Ideal Solution **(***TOPSIS), LULC-based prioritization index has been constructed and prioritized the seven sub-watersheds.Highest acreage of agricultural fallow land and barren scrubland with less amount of forest coverage in WS5 turns into more susceptible category compared to others, whereas lower acreage of barren scrubland, agricultural fallow land and cropland with higher coverage of forest in WS6 turns into lower susceptible category.*

Keywords: LULC, TOPSIS, watershed and prioritizat

INTRODUCTION

Watershed prioritizing based on land use and land cover is a relevant study in present days that is important for long-term soil erosion and sediment yield monitoring, as well as water resource management. The land use and land cover (LULC) controlled the soil erosion and sediment yields in any watershed, and the changing phenomena of LULC abruptly changes the erosion potentiality (Wu and Chen, 2012). Watershed prioritising aids in the identification of a watershed's most vulnerable locations in terms of soil erosion. Soil erosion reduces agricultural output by removing numerous macro and micro nutrients from topsoil. In this context, prioritisation and watershed management are used to determine the optimummanagement strategy for long-term growth(Choudhari *et al.*, 2018).Application of geographic information system (GIS) and image analysis helps reduce field work and traversing and establish relationship between landform and soil in the watershed and its sub-divisions (Pushpanjali *et al.*, 2022). In the lower Himalayan region, land use and land cover has been altered due to the shifting cultivation as well as developmental work which further increased the potentiality of soil erosion(Mishra *et al.*, 2017). Rainfall intensity controlled the peak runoff flow which was further controlled by the land use and land cover as well as soil characteristics. Furthermore, soil erosion and sediment yield further depends on the conservation support practices and cover of land surface with other characteristics of terrain(Eniyew *et al.*, 2021). Mostly,vegetation cover plays an important role in the reduction of soil erosion as well as degradation, moreover, it enhances the amount of organic matter which further increased the stability of soil particles and reduced the soil erosion (Ruiz-Colmenero *et al.*, 2013). In the recent days, remote sensing and GIS technique minimized the time of LULC related data acquisition. Along with this processed LULC data is easily downloadable from various sources which are more accurate and ready for application (Gharai *et al.*, 2018). Earlier researchers have applied ranking methods with average rank for prioritization of sub-watersheds (Chauhan *et al.*, 2016; Das *et al.*, 2021).(Javed *et al.*, 2009) integrating LULC with morphometric characteristics for watershed prioritization. For watershed prioritizing, a few researchers used RS-GIS with MCDM approaches (Chowdary *et al.*, 2013; Jaiswal *et al.*, 2014; Jaiswal *et al.*, 2015). The current study used integrated GIS-MCDM to prioritize sub-watersheds based on LULC for Chathe watershed in Medziphema, Nagaland, India. The Bhuvan LULC map was used in this investigation (NRSC, India). TOPSIS and knowledge-based relative weightage are used to create the prioritizing index. The TOPSIS technique establishes the priority index

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based on the ideal best and worst circumstances. Features that are more prone to soil erosion are given a higher rank, and vice versa. The constructed index correctly identifies the key sub-watershed based on all of the LULC properties. Rarely researcher attempt such a study in Nagaland; therefore, this study was undertaken to prioritize the Chathe watershed based on LULC characteristics.

MATERIALS AND METHODS

The present study was conducted in the Department of Soil and Water Conservation, Nagaland University, Medziphema, Nagaland during 2019-20 based on LULC data of 2015. Chathe watershed is located at Medziphema block in Dimapur district, Nagaland (Fig. 1).

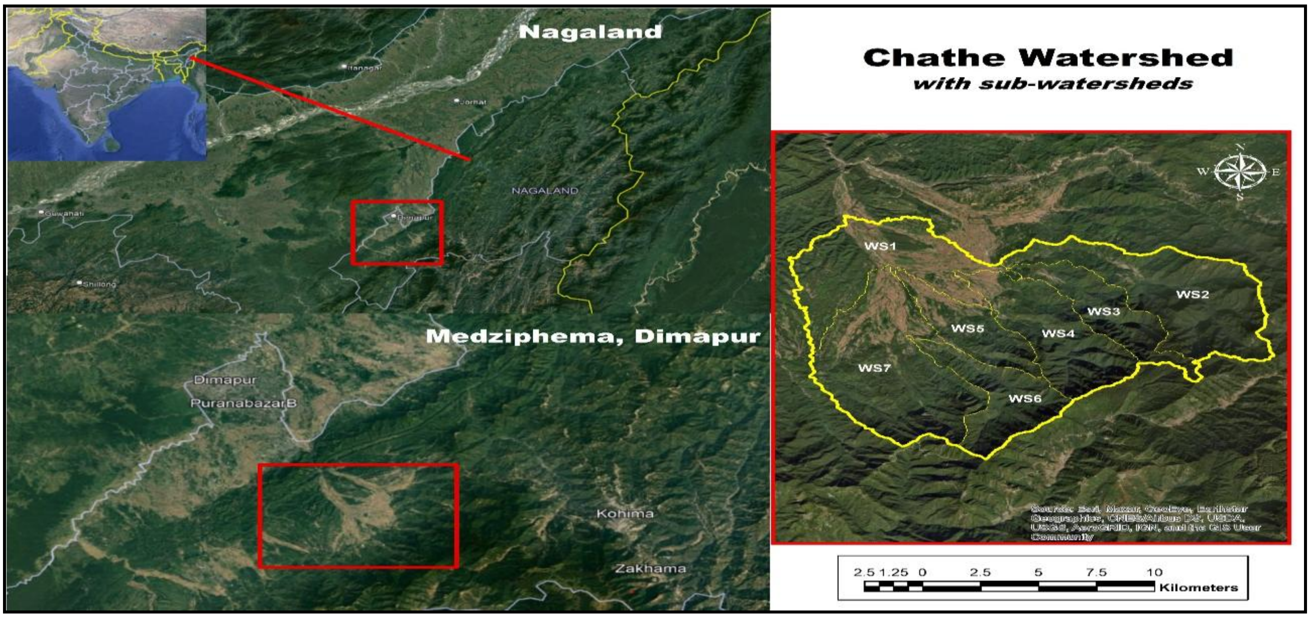

Fig.1: Location of the study area

The total area of the watershed is 209.60 sq. km and the main stream is Chathe and earlier known as Depupani which is the tributaries of Upper Dhansiri river. The Bhuvan's prepared LULC data of 2015 was primarily employed in this work to identify key watershed. Finally, extracted the area of the nine LULC classes using ArcGIS 10.8.1 by raster to polygon conversion. For prioritization of sub-watershed, rankingall the classes according to their role in runoff as well as soil erosion and sediment yield, like highest rank assigned to barren scrubland (where shifting cultivation took place) and all types of vegetation coverage given the lowest rank (Table 1). Finally, relative weights were calculated by following equation;

$$RW_i = \sum_{i=1}^{n=9} {w_i}/{SR}$$

Where, RW_i is the relative weight of individual class, i is the class of LULC (cropland, forestetc.), n is the total no. of LULC class, w_i is the corresponding rank of the i^{th} class and SR is the summation of rank. This corresponding relative weight considered as weight of individual class of the LULC for calculating prioritization index with the help of TOPSIS.

Table 1: Weights of LULC classes

LULC	Rank	Relative weight
Agricultural fallow	3	0.13
Agricultural plantation	1	0.04
Barren rocky	4	0.17
Barren scrubland	6	0.25
Built-up(rural)	5	0.21
Cropland	2	0.08
Forest	1	0.04
Plantation	1	0.04
Scrub forest	1	0.04
	24	

Final prioritization has been done based on the TOPSIS method. The following are the steps in the calculation:

Calculation of weighted normalized matrix:Area of the different class of LULC considered as input and units of the area in sq. km. that's why avoid the normalization step. Relative weight of different class is considered here according to domain knowledge.

$$W_{ij} = I_{ij} \times w_j$$

where, j indicates the weight of jth criteria (LULC class).

In the next step, the ideal positive and ideal negative values were calculated. Lower percentage of forest, plantation, scrub forest, agricultural plantation and croplandwas considered as ideal positive and higher percentage of agricultural fallow, barren scrubland, barren rocky and built-up areawas considered as ideal negative solution. The Euclidean distance from the ideal solution and ideal negative solution were calculated as follows:

$$S_i^+ = \left[\sum_{j=1}^{m} (W_{ij} - W_j^+)^2\right]^{0.5}$$

$$S_i^- = \left[\sum_{j=1}^{m} (W_{ij} - W_j^-)^2\right]^{0.5}$$

Final Priority Index (PI) was calculated by the following equation:

$$PI = \frac{S_i^-}{(S_i^+ + S_i^-)}$$

Moreover, ranks were assigned according to the magnitude of final priority index i.e., 1st rank to highest value and lowest rank to lowest value.

RESULTS AND DISCUSSION

Area of land use and land cover

The particular class coverage is covered as below (Fig 2):

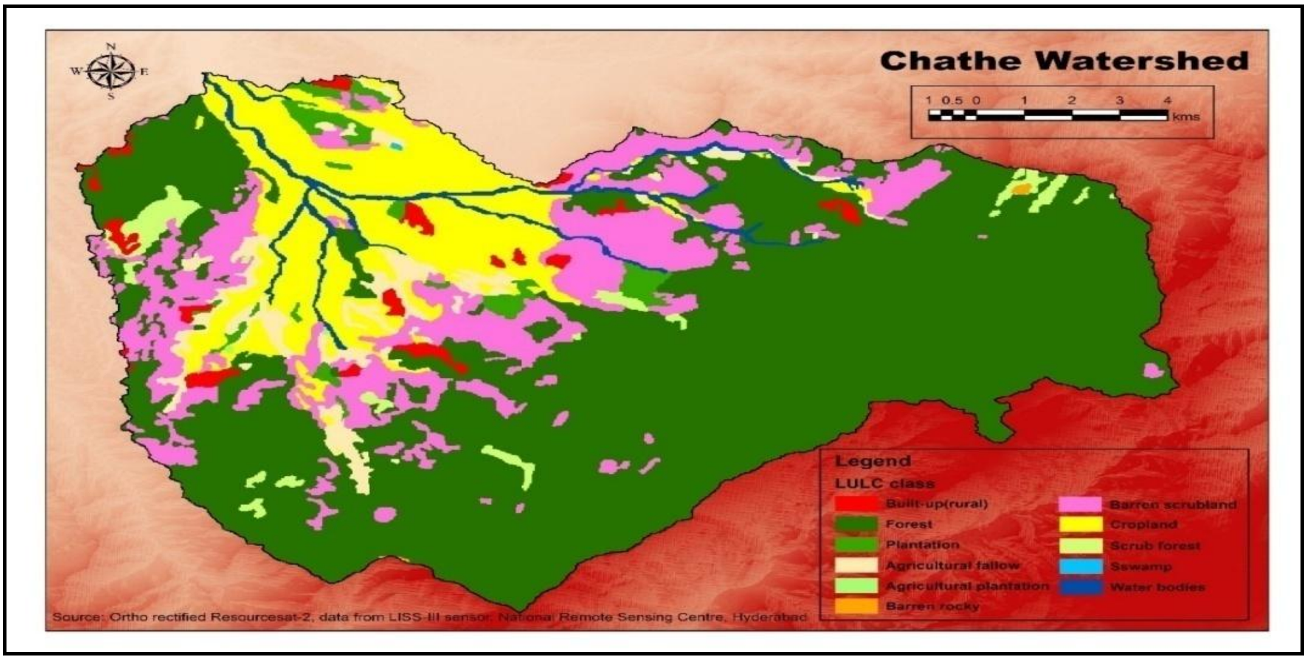

Fig. 2: LULC map of the study area

Agricultural fallow

The entire agricultural fallow land in the Chathe watershed is 7.24 square kilometers. Among the sub-watersheds, WS7 (4.10 sq. km) has the most coverage, while WS4 has the least. Only two watersheds, WS5 and WS7, have more than 1 sq. km of land as agricultural fallow, and the others have less than 1 sq km (Table 2). At the same slope, the maximum amount of agricultural fallow land enhanced the potential for soil erosion and sediment yield (Zhang *et al.*, 2015).

Table 2: LULC coverage (sq. km)

LULC	WS1	WS2	WS3	WS4	WS5	WS6	WS7
Cropland	14.27	0.36	0.21	2.33	2.59	0.22	8.39
Agricultural fallow	0.74	0.50	0.07	0.00	1.69	0.14	4.10
Forest	10.74	35.37	15.65	18.85	6.24	17.79	26.70
Built-up(rural)	1.96	0.32	0.08	0.19	0.45	0.04	0.85
Waterbodies	1.26	0.63	0.68	0.46	0.27	0.00	0.79
Barren scrubland	4.94	4.77	2.23	5.54	3.90	1.71	7.84
Agricultural plantation	0.004	0.00	0.00	0.00	0.00	0.00	0.06
Plantation	1.81	0.06	0.00	0.86	0.69	0.00	0.55
Barren rocky	0.00	0.10	0.00	0.00	0.00	0.00	0.03
Swamp	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Scrub forest	1.46	0.78	0.00	0.41	0.03	0.09	0.85

Agricultural plantation:

The term agricultural plantation refers to land that is covered in a variety of fruit crops, with pineapple being the most prevalent in the studied region. The entire area covered by pineapple in this watershed is 0.06 sq km, which is a relatively small area. The most was found in WS7, the least in WS1, and the rest had no cover. The soil particles are held in place by the roots of the agricultural plantation, which reduces the risk of erosion.

Barren rocky:

The barren rocky surface is referred to as bare surface with rock. The total area is 0.13 sq. km, which is quite little. The most was detected in WS2 (0.10 sq. km) and the least in WS7 (0.03 sq. km), with the rest having no coverage. Because the barren rocky surface had no vegetation and was naked, drainage was at its highest and there was a greater risk of soil erosion.

Barren scrubland:

Bare surface with least vegetation coverage, normally covered by short grass.The shifting cultivation had the largest impact in this area. The shifting cultivation sorted out the vegetation, and the land became degraded, increasing the possibility for soil erosion. This feature covers a total area of 30.93 sq. km. WS7 (7.84 sq km) has the most coverage, while WS6 has the least (1.71 sq. km). WS4 (5.54 sq. km) came in second, followed by WS1 (4.94 sq. km), WS2 (4.77 sq. km), WS5 (3.90 sq. km), and WS3 (2.23 sq. km) (Table 2).

Built-up (rural):

The term rural built-up area refers to an area with the least amount of impervious surface and few rural settlements. Soil erosion becomes more likely in rural areas with less impermeable surfaces. This feature has a total size of 3.89 sq. km. WS1 (1.96 sq km) has the highest coverage, while, WS6 has the lowest (0.04 sq. km). Except for WS1, the remaining sub-watersheds have coverage of less than one sq. km. Increased coverage increased the risk of soil erosion.

Cropland:

Cropland refers to arable land having a crop cover. Higher cropland coverage reduces soil erosion because the roots of the crops hold the soil in place and prevent it from being transported. Cropland without conservation measures on a steep slope, on the other hand, has a larger risk of soil loss. The overall cropland area in this watershed is 28.36 sq. km. WS1 (14.27 sq km) has the largest coverage, while WS3 (0.21 sq. km) has the lowest. WS7 has the second highest coverage (8.39 sq. km). As a result, in terms of cropland coverage, WS3 has a higher risk of soil erosion than others.

Forest:

Forests are defined as dense forest covers with a high canopy density. Increased forest cover reduced the runoff and soil erosion. Soil erosion on steep slopes was sometimes exacerbated by steam flow from the forest. This area has a total forest covering of 131.34 sq. km, which covers the majority of the land in the Chathe watershed. WS2 (35.37 sq. km) has the most coverage, followed by WS7 (26.70 sq. km), WS4 (18.85 sq. km), WS6 (17.79 sq. km), WS3 (15.65 sq. km), WS1 (10.74 sq. km), and WS5 (6.24 sq. km). Soil loss increased when the amount of forest under any sub-watershed was lowered. WS5 has more vulnerable in this aspect.

Plantation:

Plantation are those that stand alone and have a low canopy density. However, in comparison to bare earth, the plant's root retains the soil in place fairly well. In any region, the more areal covering reduced the possibilities of soil erosion. This feature covers a total area of 3.97 sq. km. WS1 (1.81 sq km) has the most coverage, followed by WS4 (0.86 sq km), WS5 (0.69 sq km), WS7 (0.55 sq km), and WS2 (0.06 sq. km). In WS3 and WS6, there WAS no coverage. Soil erosion is more likely when this feature's coverage is lower (Table 2).

Scrub forest:

The term scrub forest refers to low-growing trees and plants. They covered the land surface, and the forest roots held the soil particles in place, reducing runoff and soil erosion even more. In any region, the greater the area covered, the lower the risk of soil erosion. This feature has a total size of 3.62 sq. km. WS1 (1.46 sq. km) had the most cover, followed by WS7 (0.85 sq. km), WS2 (0.78 sq. km), WS4 (0.41 sq. km), WS6 (0.09 sq. km), and WS5 (0.03 sq. km). Such a feature was not covered in WS3.

Table 3: Percentage coverage of different LULC

LULC	WS1	WS2	WS3	WS4	WS5	WS6	WS7
Cropland	38.49	0.85	1.21	8.32	16.53	1.13	17.02
Agricultural fallow	2.14	1.34	0.41	0.00	10.90	0.70	8.31
Forest	28.26	81.58	82.53	65.46	39.37	88.91	52.40
Built-up	3.87	0.77	0.46	0.67	2.54	0.20	1.71
Waterbodies	3.66	1.50	3.73	1.64	1.70	0.00	1.61
Barren scrubland	14.30	11.76	11.65	19.68	24.35	8.61	15.91
Agricultural plantation	0.01	0.00	0.00	0.00	0.00	0.00	0.12
Plantation	4.94	0.14	0.00	2.83	4.38	0.00	1.13
Barren rocky	0.00	0.23	0.00	0.00	0.03	0.00	0.06
Swamp	0.09	0.00	0.00	0.00	0.00	0.00	0.00
Scrub forest	4.24	1.84	0.00	1.43	0.19	0.46	1.72
Total	100	100	100.00	100	100	100	100

Sub-watershed prioritization

In this study area, the areal coverage of different features considered as measures unit for prioritization. Maximum cover percentage of the barren scrubland, barren rocky, rural built-up, agricultural fallow land within the individual sub-watershed was considered as higher potentiality of soil loss (Table 3). On the other hand, cropland, agricultural plantation, forest, plantation and scrub forest considered as lower contributor (Bhattacharya *et al.*, 2019; Kidane *et al.*, 2019; Parihar, 2021). For instance, higher percentage of agricultural fallow land in respect to total sub-watershed area considered ideal best solution for prioritization. Furthermore, with the help of relative weight as per contribution rank and TOPSIS method (Table 1), final LULC based priority index has been constructed. The Table 4 showed the priority index score and their level of priority (Fig. 3). The highest score was found in WS5 (0.78) followed by WS4 (0.62), WS7 (0.53), WS2 (0.42), WS3 (0.43), WS1 (0.42) and WS6 (0.38). Therefore, WS5 has higher possibilities to soil erosion compared to others and WS1 has lower in respect to LULC areal cover. Highest amount of agricultural fallow land and barren scrubland with less amount of forest coverage in WS5turns into more susceptible category compared to others whereas lower amount of barren scrubland, agricultural fallow land and cropland with higher coverage of forest in WS6 turns into lower susceptible. Therefore higher forest coverage with lower bare surface have less possibilities of soil erosion(Kidane *et al.*, 2019).

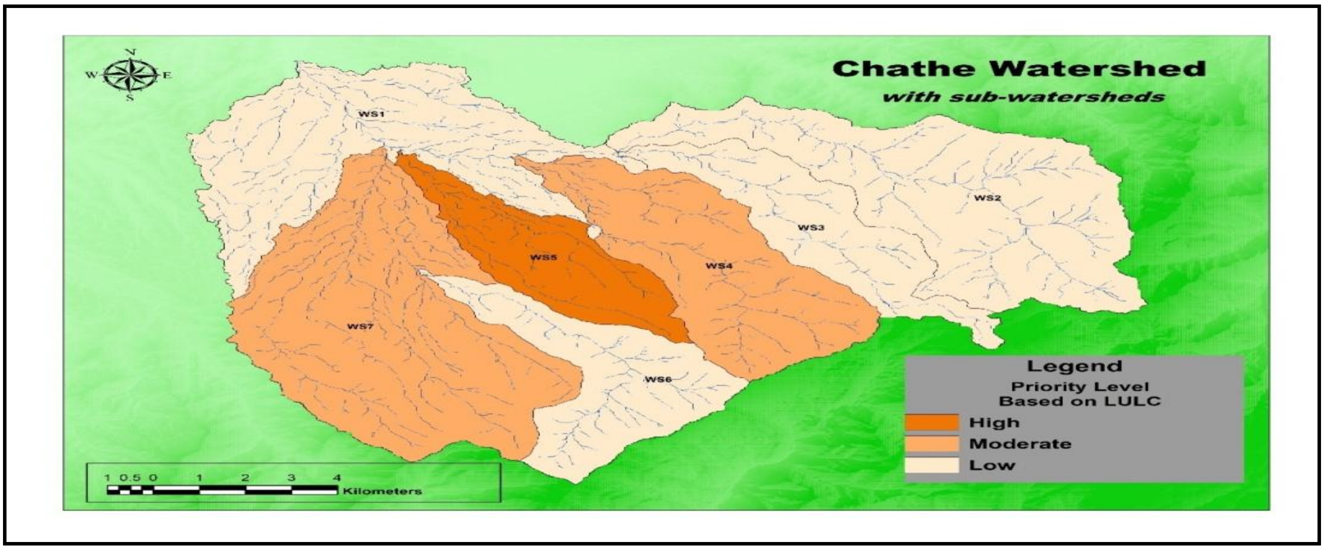

Fig. 3: LULC based Priority level

Table 4: Priority index based on LULC

Sub-watershed	Priority index	Rank
WS1	0.42	6
WS2	0.44	4
WS3	0.43	5
WS4	0.60	2
WS5	0.78	1
WS6	0.38	7
WS7	0.53	3

The study concluded that less amount of vegetation coverage turned any watershed into more susceptible category in terms of soil erosion. Moreover, the study also concluded that presences of lower amount of barren scrubland, agricultural fallow land and cropland somehow restricted the erosion susceptibility. Therefore, the LULC-based prioritization index had significant role in sub-watershed prioritization.

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