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Watershed prioritization based on morphometric characteristics using integrated RS-GIS and MCDM technique: A case of Chathe watershed

Sewak Ram, RC Nayak and Manoj Dutta

Abstract

Chathe watershed is divided into seven sub-watersheds that are prioritized for soil and water conservation based on linear, areal, and relief features. Individual aspects as well as an integrated index created by the AHP and TOPSIS were used to priorities sub-watersheds from the ALOS-PALSAR DEM. The final result revealed that WS2 was the most prioritized sub-watershed with a high priority rating, with WS4 and WS7 following closely behind. WS3 and WS6 are on the moderate level, while WS1 and WS5 are in the low level. Higher linear and relief characteristics, as well as higher drainage density and stream frequency in an elongated basin with lower infiltration, were found to be more vulnerable. This work will assist the research community in taking necessary soil and water conservation measures in that area in future.

Keywords: Prioritization, Morphometric, AHP, TOPSIS

Introduction

Watershed prioritizing based on morphometric parameters 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 (Gajbhiye *et al.*, 2014) [8]. Morphometric approaches disclose the dimensions of many features of a watershed in terms of shape, size, and relief (Choudhari *et al.*, 2018) [5]. The morphometry of a watershed affects soil erosion and sediment output (Jain & Goel, 2002) [11]. Such events are tightly controlled by rainfall and runoff, further altering the hydro-meteorological status of the watershed. Watershed prioritization assists in identifying the most vulnerable areas of a watershed in terms of soil erosion. Soil erosion primarily removes various macro and micro nutrients from topsoil, lowering agricultural yields. In this regard watershed management with prioritization sort out the best management plan for sustainable development (Choudhari *et al.*, 2018) [5].

Water resource management relies heavily on quantitative analysis of geographical characteristics of watersheds (Horton, 1932) [10]. Gregory, 1966 [9]; Schumm, 1956 [20]; Strahler, 1957 [21] computed the morphometric characteristics of other watersheds after that. However, they primarily used empirical formulas, which is a more time-consuming and difficult task. Many researchers have used remote sensing and GIS techniques to do this (Avinash *et al.*, 2011; Choudhari *et al.*, 2018; Moharir & Pande, 2014) [2, 5, 18]. Even without considering soil parameters, morphometric approaches prioritised the sub-watershed based on Earth's surface layout and landforms (Biswas *et al.*, 1999; Clarke, 1996) [3, 7].

Because remote sensing and GIS techniques reduced data collecting and processing time, some researchers are currently attempting morphometric analysis based on them, such as (Javed *et al.*, 2011; Rekha *et al.*, 2011) [15, 19] and others. They analyzed the elevation, drainage line, sub-watershed, drainage density, drainage frequency, and stream order (number and length) using the DEM dataset. Finally, a ranking of individual factors and a compound rank average score were used to prioritizes. For watershed prioritizing, a few researchers used RS-GIS with MCDM approaches (Chowdary *et al.*, 2013; Jaiswal *et al.*, 2014; Jaiswal, Ghosh, Galkate, *et al.*, 2015; Jaiswal, Ghosh, Lohani, *et al.*, 2015) [6, 14, 13, 12].

The current study used integrated RS-GIS-MCDM to prioritize sub-watersheds based on morphometric parameters for Chathe watershed in Medziphema, Nagaland, India. This study also used an ALOS-PALSAR DEM because of its higher spatial resolution (12.5 metre). Linear, areal, and relief morphometric features are extracted from this digital dataset, and a prioritizing index is constructed using ranking and compound average rank algorithms for particular aspects, as well as the AHP and TOPSIS. The AHP methods are highly beneficial for weight assignment, and the TOPSIS technique determines the priority index based on the ideal best and worst cases. Based on all of the morphometric characteristics combined, this integrated method successfully identifies the critical sub-watershed. Very rare researcher attempts such kind of study in Nagaland, that's why this study intrinsic for such kind of study in this region in future. This type of study also supports the research community in prioritizing the sub-watershed by allowing them to analyze all of the parameters under each aspect at a glance which further aids to taking necessary soil and water conservation strategies for sustainable watershed development.

Materials and Methods

Chathe watershed considered as study unit which is located at Medziphema block in Dimapur district, Nagaland. 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. Fig.1 shown the study area. The ALOS-PALSAR DEM (spatial resolution 12.5 metre) data were primarily employed in this work to identify watershed, sub-watershed and drainage features, as well as their varied properties and elevation. Finally, using ArcGIS 10.8.1 and Microsoft Excel software, all parameters and morphometrics characteristics were estimated based on the extract dataset and empirical formula. Figure 2 depicts a detailed operating flow chart.

For prioritization of sub-watershed, ranking all the parameters under linear aspects according to their magnitude, such as 1st rank assigned to highest value and lowest rank assigned to lowest value. In case of areal aspect, reverse ranking method applied, such as 1st rank assigned to lowest value and lowest rank to highest value. In relief, ranking method as same as linear aspect. Compound score of individual aspect calculated based on following equation and priority ranking assigned according to reverse magnitude i.e., lowest value considered as 1st priority rank.

$$\boldsymbol{CS} = {\sum \boldsymbol{r_{ij}}}\Big/{\boldsymbol{N_j}}$$

Where, CS is compound score, r_{ij} is rank of i^{th} parameter of j^{th} aspect and N_j is the total no. of parameters under j^{th} aspect.

Based on above equation, individual priority index of linear, areal and relief has constructed and assigned priority rank. After that weight of individual aspect-based priority index has obtained by AHP (Analytical Hierarchy Process) and final priority index constructed by TOPSIS. Moreover, rank assigned according to the magnitude of final priority index i.e., 1st rank to highest value and lowest rank to lowest value (Table 1).

Results and Discussion

Sub-watershed prioritization

Based on the different morphometric characteristics under three aspects, seven sub-watersheds have prioritized according to their performance in every parameter. Generally, assigned rank to all parameters according to the susceptibility to soil erosion and abovementioned integrated methods. In this study, watershed prioritized individually based on linear, areal and relief characteristics.

Prioritization based on linear aspect

Under the linear aspect, all parameters have a direct relationship to runoff and soil erosion. As a result, higher values are assigned to the first rank. The lowest compound score (average rank) denotes a high priority level. (Chauhan *et al*., 2016) [4] used the same strategy to priorities watersheds. Table 1 shows the relative importance of several characteristics among sub-watersheds. According to the compound score, WS1 (2.57) got top place followed by WS7, WS2, WS6, WS5, WS4 and WS3. Similar findings were reported by Chauhan *et al*., (2016) [4]; Choudhari *et al*., (2018) [5]; Javed *et al*., (2011) [15] and others. WS1, WS2, and WS7 are included in the high level, only WS3 is in the low level, and the rest are in the moderate level, as shown in table 1. The higher potentiality of soil erosion in WS1 was driven by the highest mean stream length, mean stream length ratio, and order stream length ratio with the third largest basin length and total stream number, as well as the second highest mean stream length. Lower values for all parameters in WS3 indicate lower soil erosion susceptibility.

Prioritization based on areal aspect

All parameters under areal aspect have not direct relation to runoff and soil erosion, however, drainage density, stream frequency, infiltration number, length of overland flow, constant of channel maintenance, fineness ratio and texture ratio has direct relation (Ameri *et al*., 2018) [1]. Seven sub-watersheds have been given priority based on their lower average rank score (compound score) (Table 1). In terms of erosion susceptibility, WS7 is the first preceding sub-watershed, while WS5 is the last, according to the score. Table 1 shown the level of priority based on the areal aspect. Out of seven, three sub-watersheds (WS2, WS4, and WS7) are classified as high, three as moderate (WS1, WS3, and WS6), and one as low (WS5). Soil erosion is more likely in elongated basins with high drainage density and fineness (Ameri *et al*., 2018) [1]. As a result, WS7 has the lowest elongation ratio and form factor, as well as the highest texture ratio, second highest fineness ratio, and drainage density, indicating that it is a zone with a higher risk of soil loss. In compared to WS7, the above-mentioned parameters are in the opposite order of other sub-watersheds, making them less susceptible.

Prioritization based on relief aspect

All characteristics have a direct relationship to runoff and soil erosion under the relief aspect. As a result, the first rank is given a higher value. A high priority level is indicated by the lowest compound score (average rank). The same technique was utilized by Chauhan *et al*., (2016) [4] to priorities watersheds. Table 1 depicts the relative importance of several sub-watershed parameters. WS3 (1.67) took first place in the compound score, followed by WS6, WS4, WS2, WS7, WS5, and WS1. Five sub-watersheds (WS2, WS4, WS5, WS6, and WS7) are included in the moderate level, WS1 is in the low level, and WS3 is in the high level, as shown in table 1. In WS3, the highest basin relief, relief ratio, and relative relief, combined with the second highest ruggedness number and gradient ratio, has triggered the risk of soil erosion. Lower conditions of all parameters, on the other hand, lowered the potential for soil erosion in terms of relief characteristics in WS1.

Integrated Prioritization Index

Finally, prioritized all the seven sub-watersheds based on the integrity prioritization index which calculated based on the linear, areal and relief prioritized index with the help of AHP and TOPSIS. AHP applied for calculation of weightage of three prioritization index according to the inter-influence among three indices. Table 2 shown the pairwise comparison matrix and weight of individual priority index. Besides, TOPSIS method identifying the sub-watersheds according to the ideal best and ideal worst condition, here minimum value of the linear, areal and relief priority index considered as ideal best condition and maximum value considered as ideal worst condition. Final integrated score of the seven sub-watersheds have been ranked as per their magnitude of the score like 1st rank assigned to the highest value and lowest values to lowest rank. Table 8 shown the rank of the individual sub-watershed according to their priority. WS2 got top place followed by WS4, WS7, WS6, WS3, WS1 and WS5. Fig.3 shows the level of priority of sub-watersheds. Therefore, WS2 has more potentiality to soil erosion compared to others and less susceptibility found in WS5. Higher basin length, mean bifurcation ratio, stream numbers with highest availability of stream per sq. km area in elongated basin, higher length of overland flow and constant of channel maintenance with lower resistance (higher texture ratio) as well as steep slope (higher basin relief) triggered the potentiality of soil erosion in WS2. Generally, steep slope increased the soil erosion (Tucker & Bras, 1998) [22] and morphometric parameters have positive relation to the soil erosion (Ameri *et al*., 2018) [1]. Therefore, the lower value of the integrated morphometric score of the sub-watershed have lower chance to soil erosion and higher has high chance. These results are coincide with the results of (Gajbhiye *et al*., 2014; Kadam *et al*., 2019; Meshram & Sharma, 2017) [8, 16, 17]. The result shows the value of the integrated score is very near of WS2, WS7 and WS4. Therefore, indicates these three are more prone to soil erosion and has higher sediment yield capacity. Furthermore, the integrated result also reported that basin length, total stream length, stream number, drainage density, stream frequency, infiltration number, basin shape, fineness ratio, texture ratio and basin relief have crucial role in sub-watershed prioritization in respect to soil erosion and sediment yield.

Table 1: Prioritization of sub-watershed

Parameter/Rank	**Linear Aspects**						
	Sub-watersheds						
	WS1	**WS2**	**WS3**	**WS4**	**WS5**	**WS6**	**WS7**
Basin length	10.03	11	6.83	8.74	6.24	7.19	12.02
Rank	3	2	6	4	7	5	1
Mean stream length	0.83	0.48	0.46	0.51	0.78	0.57	0.66
Rank	1	6	7	5	2	4	3
Stream length ratio	13.66	0.75	0.68	0.74	0.75	0.85	0.56
Rank	1	4	6	5	3	2	7
Mean bifurcation ratio	2.84	5.33	4.44	4.62	6.5	4.11	3.68
Rank	7	2	4	3	1	5	6
Total stream length	109.91	87.94	36.12	62.47	38.08	41.99	130.7
Rank	2	3	7	4	6	5	1
Order length ratio	34.79	1.72	1.62	1.71	1.77	1.84	1.8
Rank	1	5	7	6	4	2	3
Stream number	132	185	79	122	49	74	199
Rank	3	2	5	4	7	6	1
Compound score	2.57	3.43	6	4.43	4.29	4.14	3.14
Prioritization (Rank)	1	3	7	6	5	4	2
Priority Level	H	H	L	M	M	M	H
	Areal Aspects						
Drainage density	3.06	2.08	1.98	2.22	2.44	2.1	2.65
Rank	1	6	7	4	3	5	2
Stream frequency	3.67	4.38	4.33	4.33	3.14	3.7	4.03
Rank	6	1	3	2	7	5	4
Drainage texture	2.38	4.15	2.51	4.19	2.13	2.58	4.78
Rank	2	5	3	6	1	4	7
Drainage intensity	1.2	2.1	2.19	1.95	1.29	1.76	1.52
Rank	1	6	7	5	2	4	3
Elongation ratio	0.674	0.667	0.706	0.685	0.713	0.701	0.66
Rank	3	2	6	4	7	5	1
Infiltration number	11.24	9.11	8.57	9.6	7.68	7.78	10.68
Rank	1	4	5	3	7	6	2
Circularity ratio	0.15	0.27	0.23	0.42	0.37	0.31	0.36
Rank	1	3	2	7	6	4	5
Form factor	0.36	0.35	0.39	0.37	0.4	0.39	0.34
Rank	3	2	6	4	7	5	1
Length of overland flow	0.16	0.24	0.25	0.23	0.2	0.24	0.19
Rank	7	2	1	4	5	3	6
Constant of channel maintenance	0.33	0.48	0.51	0.45	0.41	0.48	0.38
Rank	7	2	1	4	5	3	6

Compactness coefficient	2.61	1.93	2.08	1.55	1.65	1.81	1.67
Rank	7	5	6	1	2	4	3
Shape factor	2.8	2.86	2.56	2.71	2.5	2.59	2.93
Rank	5	6	2	4	1	3	7
Fineness ratio	0.18	0.25	0.22	0.3	0.27	0.25	0.29
Rank	7	5	6	1	3	4	2
Texture ratio	1.82	3.3	2.04	3.33	1.82	2.09	3.63
Rank	7	3	5	2	6	4	1
Compound score	4.14	3.71	4.29	3.64	4.43	4.21	3.57
Prioritization (Rank)	4	3	6	2	7	5	1
Priority Level	M	H	M	H	L	M	H
	Relief Aspects						
Basin Relief	352	2139	2284	1957	1513	2041	1873
Rank	7	2	1	4	6	3	5
Relief Ratio	0.04	0.19	0.33	0.22	0.24	0.28	0.16
Rank	7	5	1	4	3	2	6
Ruggedness Number	1.08	4.45	4.52	4.34	3.7	4.29	4.96
Rank	7	3	2	4	6	5	1
Relative relief	6.35	47.99	72.65	67.2	65.67	71.11	44.99
Rank	7	5	1	3	4	2	6
Dissection index	0.62	0.85	0.86	0.86	0.85	0.84	0.87
Rank	7	4	3	2	5	6	1
Gradient Ratio	0.04	0.17	0.21	0.19	0.16	0.23	0.15
Rank	7	4	2	3	5	1	6
Compound score	7	3.83	1.67	3.33	4.83	3.17	4.17
Prioritization (Rank)	7	4	1	3	6	2	5
Priority Level	L	M	H	M	M	M	M
Integrated Prioritization index	0.39	0.66	0.57	0.65	0.38	0.60	0.64
Rank	6	1	5	2	7	4	3
Level	L	H	M	H	L	M	H

Source: Calculated by authors, Note: H-high, M-moderate and L-low

Table 2: Pairwise comparison matrix, CI, CR and weight

	Linear	Areal	Relief	λmax	CI	CR	Weight
Linear	1.00	0.33	1.00	3	0.00	0.00	0.2
Areal	3.00	1.00	3.00				0.6
Relief	1.00	0.33	1.00				0.2

Source: Calculated by authors

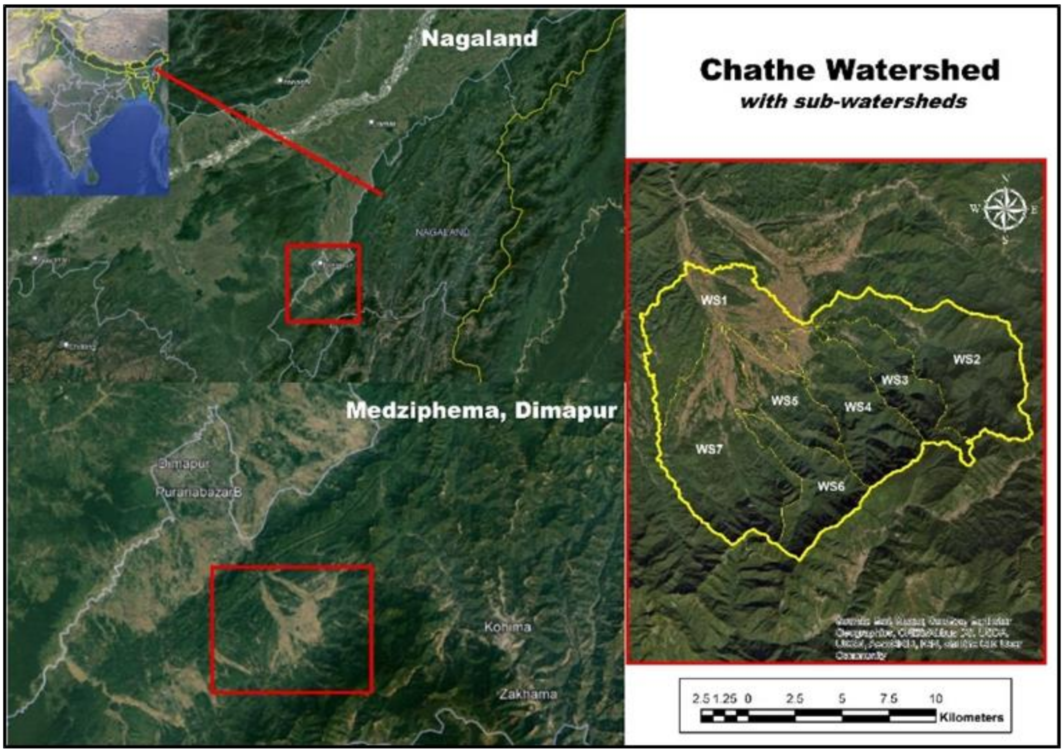

Fig 1: Location of the study area

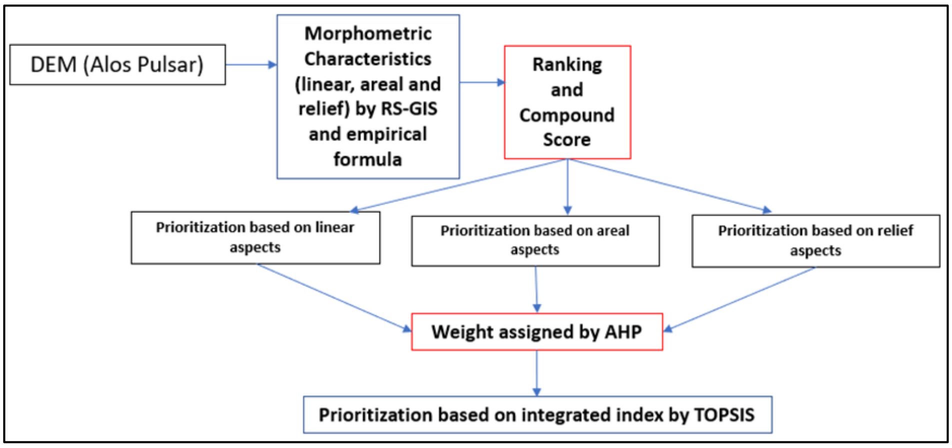

Fig 2: Flow of methodology

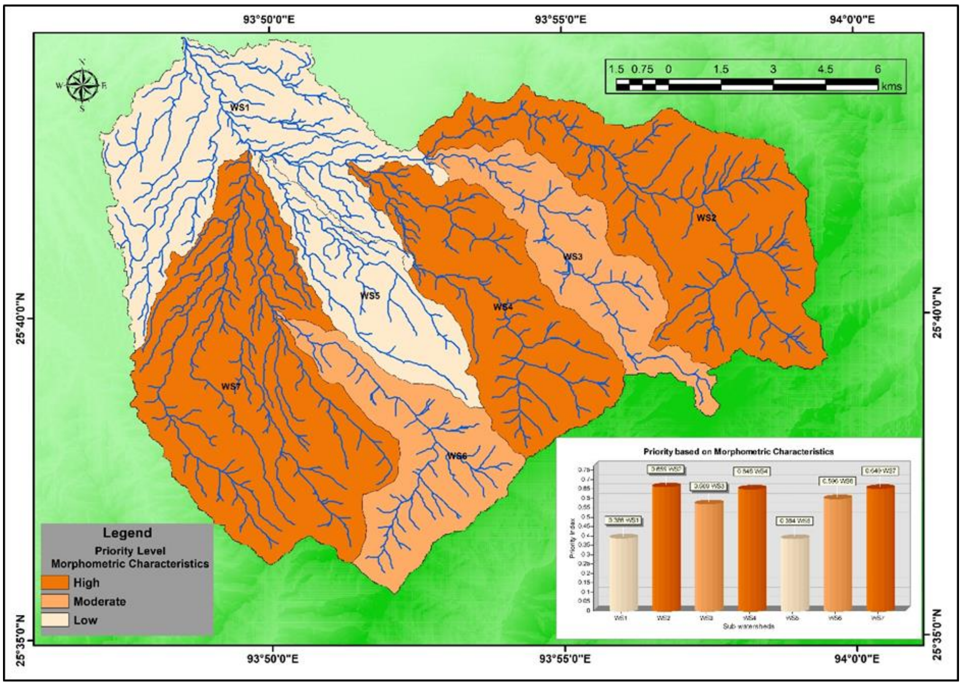

Fig 3: Prioritization of sub-watershed by integrated index

Conclusion

The study found that combining the ALOS-PALSAR dataset with GIS is a good way to extract morphometric traits and priorities sub-watersheds. In addition, the study demonstrated the level of priority based on the linear, areal, and relief aspects, as well as the integration of the three aspects using AHP and TOPSIS. The outcome is consistent from the individual parameter level to the holistic level. As a result, the study assists the researcher in implementing such a system for sub-watershed prioritization. The level of priority of distinct sub-watersheds in terms of soil erosion and sediment yield potentiality, which aids in the adoption of conservation technologies in the appropriate and essential areas within the Chathe watershed to accomplish long-term soil and water conservation.

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