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WATERSHEDS PRIORITIZATION AND MANAGEMENT PLANNING USING GIS: A STUDY OF THE CATCHMENT AREA OF MAHANANDA RIVER, WEST BENGAL, INDIA

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Abstract: *As watershed management and Soil conservation are two sides of a coin, both are needed to pay attention simultaneously in the context of socio-economic development as well as environmental sustainability also. This present research work is going to emphasise on the watershed management of the seven sub-watersheds (SWs) of the source catchment area of Mahananda River considering the different parameters of three main geomorphic aspects namely, linear aspects, relief aspect and areal aspects as well as different Land use/ Land Cover pattern also with using Digital Elevation Model and satellite images in GIS environment. The results of such prioritization reveal that SW4, SW5 and SW6 have needed highest priority as their average priority index ranges in between 2.65 to 3.79; the moderate priority should be given to SW1and SW7 and the lowest priority for SW2 and SW3, basis of which, watershed management planning should be done.*

Keywords: Areal Aspects, Average Priority Index, Digital Elevation Model, Linear Aspects, Relief Aspects.

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Introduction

Socio-economic development through the use of environmental resources should be always in a sustainable manner but uncontrolled access of resource leads environmental degradation. The agricultural practices and deforestation with growing population is increasing day by day in the source catchment of Mahananda River (Kiran, 2013). This condition is responsible for huge amount of soil erosion and hence, well watershed management planning is required. As several research works (Puno and Puno, 2019; Iqbal and Sajjd, 2014; Balasubramanian et al., 2017)has represented watershed management planning through sub-watersheds prioritization, this present research work is also going to represent a watershed management planning considering relevant geomorphic and land use/ land cover parameters in GIS environment. After dividing the whole catchment area into a number of sub-watersheds, the various geomorphic parameters underline a respects, relief aspects and areal aspects combined with LULC parameters like forest cover, built-up area, agricultural land etc. should be considered for their ranking and on the basis of compound factor, watersheds are prioritized (Puno and Puno, 2019).The research work of Iqbal and Sajjad (2014) represented that the land use and land cover under built-up, water bodies, agricultural land and barren land categories are directly proportionate with soil erosion while land under forest cover, tea plantation etc. are inversely proportionate. In the areal aspects, Drainage Density, Stream frequency and Drainage Textures are directly proportionate with high run off and high prioritization, in the relief aspects, average slope and relative relief are also directly proportionate (Balasubramanian et al., 2017). Not only Drainage and Relief features, shape of the sub-watersheds is also important as the peak of runoff varies due to geometry of watersheds (Iqbal and Sajjd, 2014).

Objectives

i. To prioritize the sub-watersheds on the basis of geomorphic and LULC parameters.
ii. To analyse the compound factor of all sub-watersheds and their chances of soil erosion for watershed management planning.

MATERIALS AND METHODS

Study Area

The source catchment area of Mahananda River is situated at Darjeeling district, West Bengal, of which longitudinal and latitudinal extensions are ranges in between 88°17’ E to 88° 27’ E and 26°55’ N to 26°41’ N respectively (Figure-1). This river is the only one in north Bengal which flows towards south west direction due to tectonic controls from springs in Dow Hill Forest (as river Mahanadi) and meet with Balason River up to which the study area is selected(Kumar, Kumar and Shrivastava, 2020). The catchment area of this river is 245.48 sq. km and the mean estimated discharge in Monsoon season is more than the other seasons (Rudra, 2016).

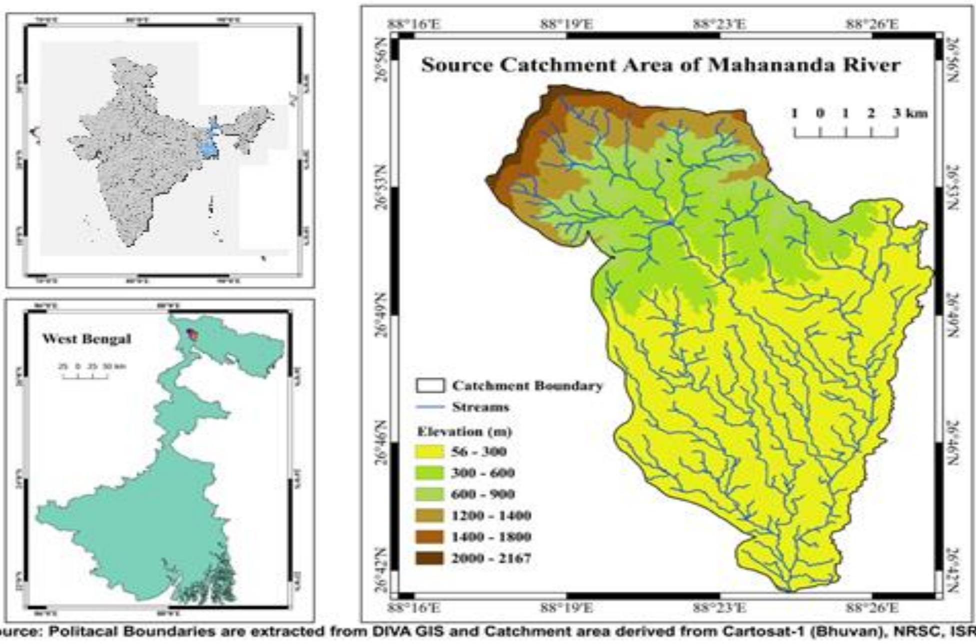
Materials

This research work is totally dependent on secondary data. Elevation data (Cartosat-1, PAN, 2.5m spatial resolution) and satellite image (Resourcesat-2, LISS-III, 24m spatial resolution dated 12nd November, 2017) of the study area has been collected from Bhuvan (National Remote Sensing Centre, ISRO).

Methods

“Channel Network and Drainage Basin” algorithm was used for watershed delineation and stream ordering in QGIS software. After that important geomorphic parameter of each watershed have calculated and analysed by using following formulas (Table-1).

Figure-1: Location Map of the Study Area



Source: Politacal Boundaries are extracted from DIVA GIS and Catchment area derived from Cartosat-1 (Bhuvan), NRSC, ISRO.

Table 01: Geomorphic Parameters and Formulas

Geomorphic Parameters	Formulas	Sources
Stream Ordering	Hierarchical methods	Strahler (1964)
Bifurcation Ratio (R_b)	$R_b = N_u / N_{(u+1)}$	Schumm (1956)
Stream Length Ratio (R_l)	$R_l = L_u / L_{(u-1)}$	Horton (1945)
Relative Relief (R_r)	$R_r = H_{max} - h_{min}$	Smith (1935)
Dissection Index (D_i)	$D_i = R_r$/ Absolute Height	Nir (1957)
Average Slope (S_a)	$S_a = {}^{tan-1}(N X i)/ 636.6$	Wentworth (1930)
Drainage Density (D_d)	$D_d = L_K / A_K$	Horton (1945)
Stream Frequency (Fs)	Fs=Number of streams / areas	-------
Drainage Texture (T)	$T = D_d X F_s$	Horton (1945)
Form Factor (R_f)	$R_f = A / L^2$	Horton (1932, 1945)
Elongation Ratio (R_e)	$R_e = \pi R_2 / 4$	Schumm (1956)

N_u is number of streams in a given order; $N_{(u+1)}$ is number of streams of the next higher order; L_u is total length of the all streams in a given order; $L_{(u-1)}$ is total length of the all streams of next lower order; H_{max} = maximum height; h_{min} = minimum height; N is number of contour crossing; i is contour interval; L_K is the total length of all streams in given area; A_K is area; A is basin area; L is basin length and R is the result of Basin area is divided by basin length.

All the watersheds are ranked on the basis of above-mentioned parameters and summed up for compound factor which is further divided by the number of parameters for geomorphic priority index calculation. Thereafter, Land use/ Land Cover map of the Mahananda catchment area is prepared by supervised classification methods of satellite image. After classification, areas under different LULC categories of each watershed are calculated and LULC prioritization has been done on the basis of their ranking. After all, overall priority of each watersheds has been calculated by average value of both geomorphic and LULC priority index. Depending on overall priority index, watershed management planning will be done.

RESULTS AND DISCUSSIONS

Linear Aspects

Bifurcation Ratio (R_b) and Stream Length Ratio (R_l) of each sub-watershed has been calculated on the basis of number of streams of each order and their length (Table-2 & 3). According to Strahler (1964), all the stream segments which have no tributaries are considered as first order stream and when two first order streams meet with each other into a single stream then this will be categorised as second order streams (Figure-2). Two second order streams will be merged into third order and so on (Strahler, 1956).

Table 02: Order-Wise Stream Length of All Sub-Watersheds

SW	Number of Streams				
	1st Order	2nd Order	3rd Order	4th Order	5th Order
1	17	10	4		
2	14	9	3		
3	10	6	2		
4	59	16	15	17	23
5	54	24	10	18	
6	41	23	17		
7	28	16	11		
Total	224	104	66	32	19

Table 03: Order-wise Stream Numbers of all Sub-watersheds

SW	Stream Length (km.)				
	1st Order	2nd Order	3rd Order	4th Order	5th Order
1	17.59	6.19	4.02	0.00	0.00
2	8.66	6.44	0.81	0.00	0.00
3	12.68	4.76	0.68	0.00	0.00
4	44.94	14.49	18.58	18.20	10.96
5	44.07	20.57	11.77	13.01	0.00
6	31.32	28.95	16.33	0.00	0.00
7	27.01	13.57	6.52	0.00	0.00
Total	186.27	95.00	58.71	31.21	10.96

Bifurcation Ratio (R_b)

In this case, SW1, SW2 and SW3 have recorded with higher bifurcation ratio and remaining sub-watersheds have recorded comparatively low (Table-4). This scenario focus on the more geological disturbance of upper catchment areas while the middle and lower part comparatively lower disturbed areas.

Stream Length Ratio (R_l)

Here, SW2, SW3 and SW7 represent with comparatively lower Stream length ratio which means the difference in slope gradient amongst the areas with different stream orders is low and SW1, SW4, SW5 and SW6 have greater difference in slope gradient (Table-4).

Relief Aspects

Relative Relief (R_r)

SW1 has highest relative relief as 1835 metres and some others high undulated watersheds (SW3, SW2 and SW4) have recorded also high relative relief. Lowest relative relief has been recorded in SW7. Lower relative relief reveals comparatively less chances for river erosional activities while higher values draw special attention to check the soil erosion (Table-4).

Table 04: Quantified Geomorphic Parameters of All Sub-watersheds

SW	Linear Aspects		Relief Aspects			Area Aspects				
	R_b	R_l	R_r	D_i	S_a	D_d	F_S	T	R_f	R_e
1	2.100	1.112	1835	0.848	20◦1'16''	1.217	1.358	1.652	0.474	0.777
2	2.278	0.768	1245	0.753	21◦15'4''	1.251	2.045	2.559	0.864	1.049
3	2.333	0.528	1576	0.788	18◦37'59''	1.400	1.390	1.946	0.459	0.765
4	1.594	0.980	1068	0.950	11◦23'1''	1.655	2.007	3.321	0.122	0.393
5	1.735	1.012	738	0.914	7◦35'39''	1.496	1.773	2.653	0.298	0.615
6	1.568	1.206	687	0.916	7◦21'21''	1.702	1.799	3.061	0.176	0.474
7	1.602	0.789	158	0.712	1◦52'39''	1.718	2.006	3.447	0.170	0.466

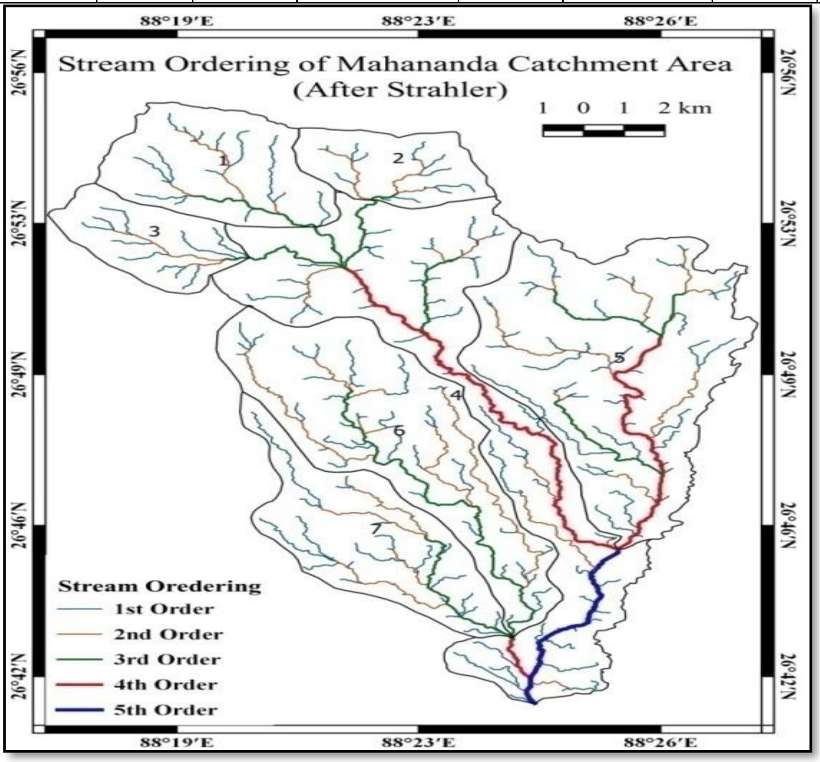


Figure 02: Stream Ordering

Dissection Index (D_i)

SW1, SW4, SW5 and SW6 have higher value and need more attention for soil conservation while remaining watersheds deserve lower priority in this sense (Table-4).

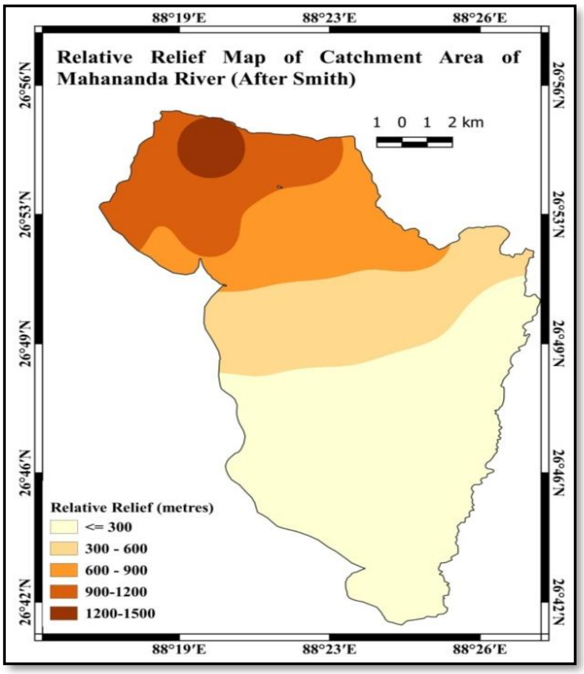
Average Slope (S_a)

SW1, SW2, SW3 and SW4 have comparatively higher average slope combining with higher relative relief, enhance the probability of more soil erosion with increasing the potential energy of streams' water and remaining watersheds with lower average slope (ranges in between 1 to 7 degrees) are represented as less chances for erosional works (Table-4).

Areal Aspects

Drainage Density (D_d)

SW7, SW6 and SW4 are recorded as higher drainage density. Due to lower undulating surface coupled with less permeability of the ground layers and less vegetation cover while in the northern and north-eastern parts has recorded with low density as their have low chances to widely distribute due to more undulating surface and high vegetation cover (Table-4).



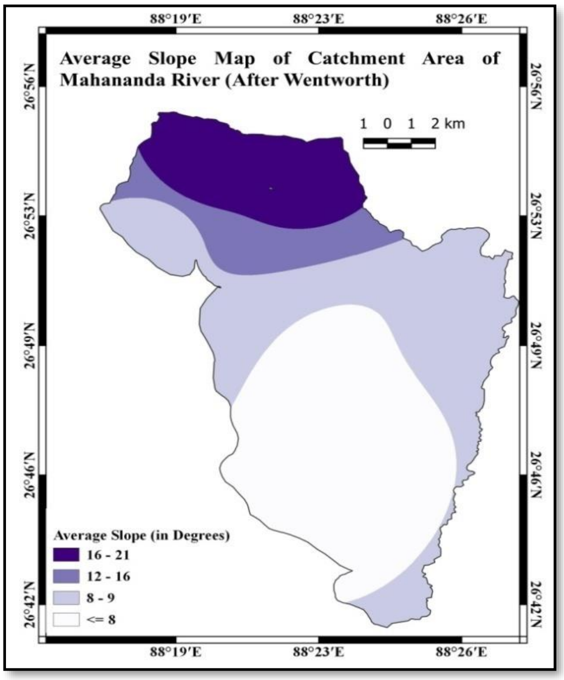
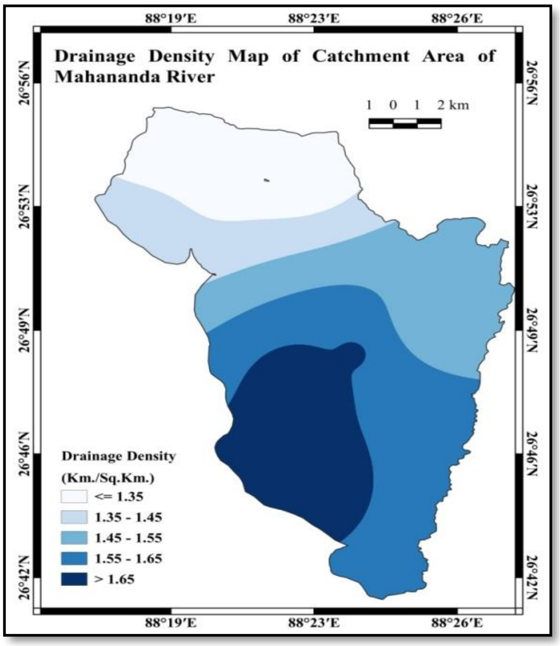


Figure 03: Relative Relief

Figure 04: Average Slope



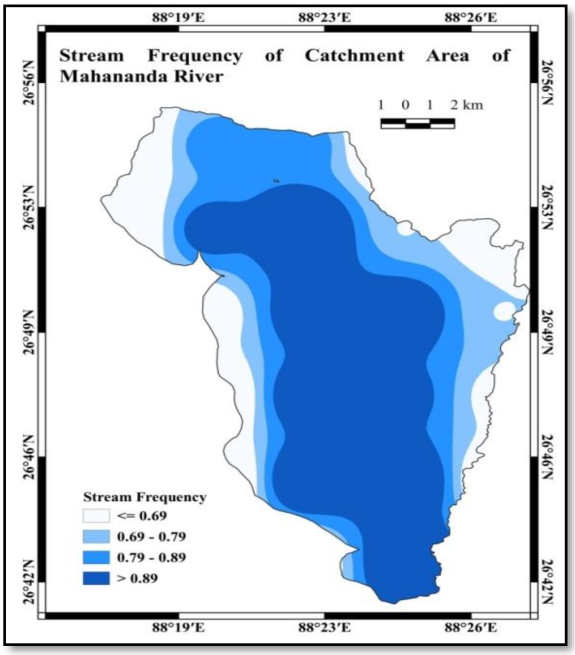


Figure 05: Drainage Density

Figure 06: Stream Frequency

Stream Frequency (F_s)

SW2, SW7 and SW4 have higher number of streams as 2.045, 2.007 and 2.004 streams per square kilometres respectively while the remaining have lower frequency. Higher frequency results more soil erosion with higher relief, lower vegetation and less permeable rocks (Table-4).

Drainage Texture (T)

SW4, SW6 and SW7 represent very fine drainage texture which influence more run off and more erosional activities while SW5 and SW2 have moderately coarse and remaining has more coarse drainage texture. SW1 and SW3 have greater vegetation cover and for this the drainage texture becomes coarse in this area (Table-4).

Form Factor (R_f)

It varies from 0 to 1. If the value is nearer to 1 that means the shape of basins more circular and if it is near about 0 then it reveals the elongated shape of the basins (Choudhari, et al., 2018). Here, SW2, SW1 and SW3 are represented as circular forms which have less chance to get higher peak of discharge in short duration and less run off. SW4 has lowest value and represented as elongated basins with maximum chances for erosions. The remaining water shades are also closer to elongated nature (Table-4).

Elongation Ratio (R_e)

If the value of this ratio is closer to 0 then the basin will be identified as highly elongated (Puno and Puno, 2019).Here all the watersheds (except SW1, SW2 and SW3) are fallen into this group which has less chances for erosional work. On the other hand, the northern water shades are more circular and are needed more attention in the sense of soil conservation (Table-4).

Table 05: Prioritization of Watersheds on the basis of Geomorphic Parameters

SW	Rank of Watersheds on the basis of Geomorphic Parameters										Compound Factor	Geomorphic Priority Index	Priority
	R_b	R_l	R_r (m.)	D_i	S_a	D_d	F_S	T	R_f	R_e			
1	3	2	1	4	2	6	7	7	6	6	44	4.4	Low
2	2	6	3	6	1	7	1	5	7	7	45	4.5	Low
3	1	7	2	5	3	5	6	6	5	5	45	4.5	Low
4	6	4	4	1	4	3	2	2	1	1	28	2.8	High
5	4	3	5	3	5	4	5	4	4	4	41	4.1	Moderate
6	7	1	6	2	6	2	4	3	3	3	37	3.7	High
7	5	5	7	7	7	1	3	1	2	2	40	4.0	Moderate

Prioritization on the Basis of Land use/ Land Cover (LULC) Parameters

The overall pattern of LULC reveals SW1, SW2, SW3 and SW5 get lower priority as large forest cover helps to check extensive soil erosion and southern watersheds (namely, SW7, SW4, SW6 and SW5) get higher priority due to Built-up area, Open grass land, Silted area, Agricultural land and Water bodies are also highly concentrated. Though other factors of Barren land and Tea plantation also influence soil erosion in northern part but dominating forest cover decrease the priority of northern watersheds (Table-6). The result shows that SW4, SW5 and SW7 have high priority while SW3 has low priority and SW1, SW2 and SW6 are represented as moderate priority (Table-7).

Table 06: Percentage of Different LULC Areas

SW	Percentage of Area under Different Major Categories of Land use/ Land Cover							
	Open Grass Land	Forest	Silted Area	Agricultural Land	Barren Land	Tea Plantation	Water Bodies	Built-up Area
1	5.60	69.13	0.15	0.67	10.61	10.29	2.32	1.22
2	5.67	77.93	0.01	0.19	7.95	5.46	2.27	0.53
3	5.08	63.52	0.24	1.29	16.90	11.14	1.01	0.82
4	8.88	44.65	4.97	3.23	7.54	2.01	5.20	23.53
5	5.41	68.52	2.92	0.64	3.77	2.18	4.47	12.08
6	11.69	51.21	2.78	8.43	7.86	3.38	1.94	12.71
7	39.89	7.84	2.47	7.46	3.54	2.35	0.93	35.52

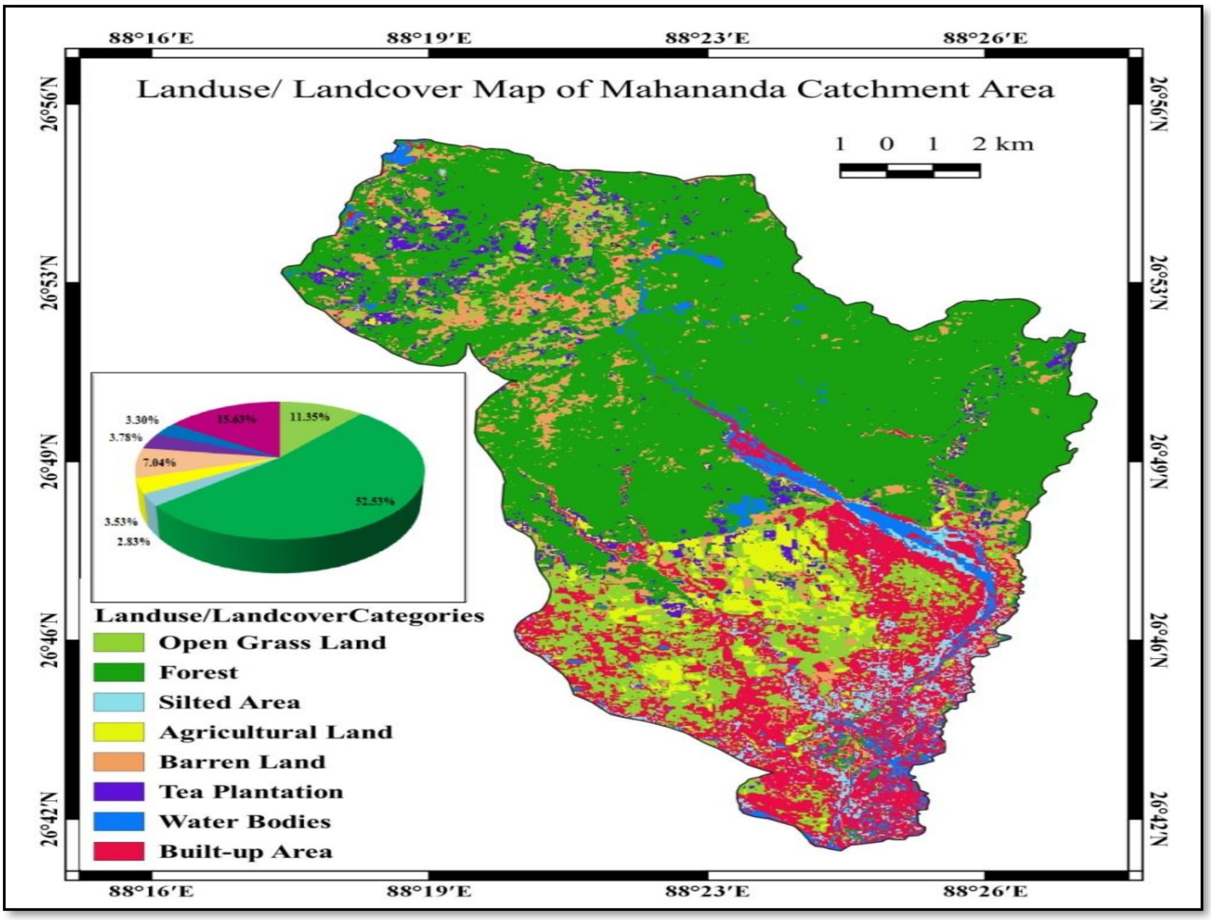


Figure 07: Land use/ Landcover Map of Mahananda Catchment Area.

Table 07: Prioritization of Watersheds on the basis of LULC

	Rank of Watersheds								**Compound Factor**	**Priority Index**	**Priority**
	Open Grass Land	Forest	Silted Area	Agricultural Land	Barren Land	Tea Plantation	Water Bodies	Built-up Area			
SW1	5	6	6	3	2	6	3	5	36	4.500	Moderate
SW2	4	7	7	1	3	5	4	7	38	4.750	Moderate
SW3	7	4	5	4	1	7	6	6	40	5.000	Low
SW4	3	2	1	5	5	1	1	2	20	2.500	High
SW5	6	5	2	2	6	2	2	4	29	3.625	High
SW6	2	3	3	7	4	4	5	3	31	3.875	Moderate
SW7	1	1	4	6	7	3	7	1	30	3.750	High

Prioritization on the Basis of Morphometric and Land use/ Land Cover Parameters

Geomorphic priority index of SW4 and SW6 draw special attention as their Dissection Index, Form factor, Elongation ratio, Drainage texture, Stream frequency, Stream length ratio and Drainage density represent more vulnerable conditions. Moreover, minimum forest cover and maximum area under settlement and water bodies of these watersheds comparing to other watersheds are also responsible for higher LULC priority index. The land use and land cover engaged with forest, plantation and agriculture protects soil from erosional work. So, the watersheds with higher areal coverage with such parameters will be given lower priority and vice versa. On the other hand, higher coverage of open land, barren land, built-up areas, silted area and water bodies lead to higher priority and vice versa (Iqbal and Sajjad, 2014).

Table 08: Prioritization of Watersheds on the basis of both Geomorphic and LULC Parameters

	Geomorphic Priority Index	LULC Priority Index	Average Priority Index	Overall Priority
SW1	4.4	4.50	4.45	Moderate
SW2	4.5	4.75	4.63	Low
SW3	4.5	5.00	4.75	Low
SW4	2.8	2.50	2.65	High
SW5	4.1	3.62	3.86	High
SW6	3.7	3.88	3.79	High
SW7	4.0	3.75	3.88	Moderate

Conclusion

The average value of geomorphic and land use/ land cover priority index of each watershed are considered as overall priority (Table-8) which represents highest priority to SW4 and lowest priority to SW3. There is total three watersheds namely SW4, SW5 and SW6 which should give more attention for soil conservation due to especially high drainage density, drainage texture and stream frequency with low vegetation and high concentration of settlement. For these conditions, the population, lumbering of these three watersheds should be checked and dams should be constructed which will help extensive run off and regular supply water for agriculture. SW1 and SW7 have marked as moderate priority zone. Though these two moderate priority zones have needed to give more priority in the context of relief and areal aspects but LULC parameters and form factors (like maximum vegetation coverage, medium concentration of settlement, form factor and elongation ratio) decrease the priority. At the tri-junction point of SW1, SW2 and SW3, a water reservoir with check dam should be constructed with considering geological conditions which helps agriculture of the southern part as well as soil conservation in the northern part also.

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