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Watershed Prioritization using Morphometric and Land Use/Land Cover Parameters of Dudhganga Catchment Kashmir Valley India using Spatial Technology

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Abstract

Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management. Morphometric and land use analysis has been commonly applied to prioritization of watersheds. In the present study, prioritization on the basis of morphometricand land use analysis of watersheds have been performed for the Dudhganga catchment of Kashmir Valley J&K. Various morphometric parameters, namely linear and shape have been determined for each watersheds and assigned ranks on the basis of value/relationship so as to arrive at a compound value for a final ranking of the watershed. Land use/land cover change analysis of the watersheds has been carried out using multi-temporal data of Land sat TM of 1991 and Land sat TM of 2010. The study demonstrates the significant land use changes especially in built up land, agricultural lands, plantation, forest, scrubland, and wastelands from 1991 to 2010. Based on morphometric and land use/land cover analysis, the watersheds have been classified into three categories as high, medium and low in terms of priority for conservation and management of natural resources.

Keywords: Prioritization; Land use/Land cover; Morphometric; Dudhganga; Catchment

Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [1-4]. A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behaviour of surface drainage networks [5-7]. Most previous morphometric analyses were based on arbitrary areas or individual channel segments. Using watershed as a basic unit in morphometric analysis is the most logical choice. A watershed is the surface area drained by a part or the totality of one or several given water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. In fact, they are the fundamental units of the fluvial landscape and a great amount of research has focused on their geometric characteristics, including the topology of the stream networks and quantitative description of drainage texture, pattern and shape [7]. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed [8].

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level. Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds [9]. The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods [5,10,11]. Geographical Information System (GIS) techniques are now a day used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information.

Land use and land cover (LULC) change is a major issue of global environment change. Land use/land cover mapping is essential component wherein other parameters are integrated on the requirement basis to drive various developmental index for land and water resource. Land cover is defined as the biophysical state of Earth's surface and immediate subsurface. The term refers to the type of vegetation that covers the land surface, other aspects of the physical environment, such as soils, biodiversity as well as human structures, such as buildings or pavement. Land use, involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation-the purpose for which land is used [12]. Anthropogenic altercations of the natural landscape by means of urbanization, agriculture and forestry have been a continuous and increasing process for millennia. Regions of natural vegetation and land cover are removed and replaced with numerous human-managed systems of altered structure. The resulting land use and land cover patterns are composed of both the natural and human-developed environments. Studies have shown that there remain only few landscapes on the earth those are still in their natural state. Due to anthropogenic activities, the earth surface is being significantly altered in some manner or the other and man's presence on the earth and his use of land has had a profound effect upon the natural environment thus resulting into an observable pattern in the land use/land cover over time. In this research an attempt has been made to assess the land

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use/land cover dynamics and prioritize the watersheds on the basis of changes in land use categories of Dudhganga catchment.

The resource development programs are applied generally on watershed basis and thus prioritization is essential for proper planning and management of the natural resources for sustainable development [13]. Drainage basins, catchments and sub catchments are the fundamental units of the management of the land and water, identified as planning units for administrative purposes to conserve natural resources [14,15]. Thus the integrated approach plays an important role for sustainable development and management of natural resources. Watershed prioritization is the ranking of different watersheds of a catchment according to the order in which they have to be taken for treatment and soil conservation measures. Morphometric analysis and land use parameters could be used for prioritization of watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps. However, while considering watershed conservation work, it is not feasible to take the whole area at once. Thus the whole catchment is divided into several smaller units, as watersheds D1A, D1B, D1C, D2A, and D2B, according to All India Land Use Survey [16], by considering its drainage system. In the present study integration of the morphometric and the land use/land cover analysis has been carried out at the watershed level using modern geospatial tools which could be the vital importance for the conservation and management strategies of Dudhganga catchment Kashmir Valley.

Study Area

Dudhganga catchment of Kashmir Valley (Figure 1), located in the northern part of India between 33° 42′ to 34°50′ N and 74°24′to 74°54′ E, covers an area of 660 km². The area supports a varied topography exhibiting altitudinal extremes of 1557 to 4663 m above mean sea level. The area consists of the lofty Pir-Panjal and flat-topped karewas as foothills and plains. The Pir-Panjal mountain range covers the Kashmir Valley on the south and southwest, separating it from the Chenab valley and the Jammu region. The karewa formation is a unique physiographic feature of this area. These are lacustrine deposits of the Pleistocene age composed of clays, sands, and silts. The soils in the area are generally of three types, viz., loamy soil, karewa soil and poorly developed mountain soil [17]. Climate of the area is temperate type with warm summers and cold winters. The mean annual temperature is 20°C. Average annual rainfall in the area is 669 mm and maximum precipitation occurs during March to April when westerly winds strike the northern face of the Pir-Panjal Mountains. The geology of the area is quite diverse ranging from Archean to Recent; Pir-Panjal represents rocks of a wide range in age. The commonest of the rocks present in the area are Panjal traps, karewa and alluvium. Drainage of the area is quite significant as most of the drainage flows into river Jhelum. Dudhganga is the important tributaries of river Jhelum which originates near Tatakuti Mountain. (Figure 1)

Methodology

Morphometric analysis of a drainage system requires delineation of all existing streams. The stream delineation was done digitally in GIS (Arc view 3.2a) system. All tributaries of different extents and patterns were digitized from survey of India to posheets 1961 (1:50,000 scale) and the catchment boundary was also determined for Dudhganga catchment. Similarly, five watersheds (D1A, D1B, D1C, D2A and D2B) were also delineated and measured for intensive study. Digitization work was carried out for entire analysis of drainage morphometry. The different morphometric parameters have been determined as shown in

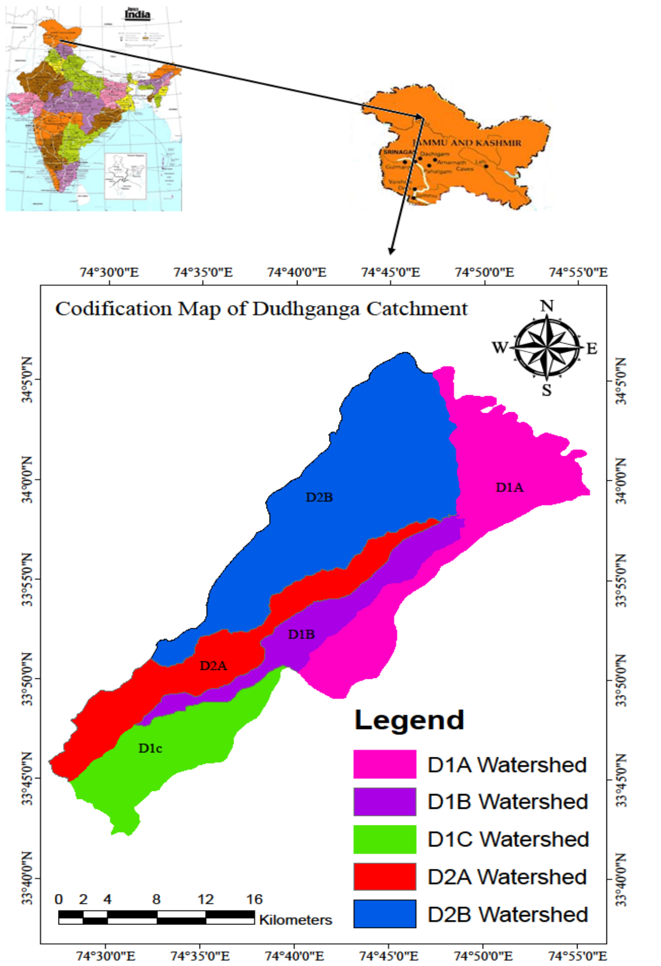

Figure 1: Geographical location of Dudhganga Catchment, Kashmir Valley, India.

Table1. The study involved detecting changes in the LULC for which, multi-date satellite images were used that included two sets of Landsat-Thematic Mapper images dated 15 October 1991 and 31 October 2010. Image-to-image registration of the two selected images was carried out with the help of base map coordinates. The linear contrast stretching and band-to band ratioing enhancement were applied to the images for increasing the interpretability. The digital image classification helped in identifying, delineating and mapping of the land use/land cover into a number of classes. The image classification was performed using the maximum likelihood classifier decision rule of the supervised classification method. The overall accuracy was determined as 86 per cent. Land use/land cover changes were determined using the post classification change detection method and the land use/land cover statistics derived from data sets were computed and compared for quantification of change.

Results and Discussion

Drainage pattern is characterized by irregular branching of tributaries in many directions with an angle less than 90º. The Catchment is divided into five watersheds with codes D1A, D1B, D1C, D2A, and D2B.

Morphometric Parameters	Formula	Reference
Stream order	Hierarchical rank	Strahler [9]
Stream length (Lu)	Length of the stream	Horton [5]
Bifurcation ratio (Rb)	Rb=Nu / Nu+1 where Nu=Total no. of stream segments of order 'u' Nu+1=Number of segments of the next higher order	Schumn [21]
Drainage density (Dd)	Dd=Lu /A where Dd=drainage density Lu=total stream length of all orders A=area of the basin(km²)	Horton [5]
Stream frequency (Fs)	Fs=Nu/A where Fs=stream frequency Nu=total number of streams of streams of all orders A=area of the basin, km²	Horton [5]
Circulatory ratio (Rc)	Rc=4 *π *A/P² where Rc=circularity ratio π=π value i.e., 3.141 A=area of the basin, km² P²=square of the perimeter, km	Miller [24]
Elongation ratio (Re)	Re=2√A /π/Lb where Re=elongation ratio A=area of the basin, km² π=π value i.e., 3.141 Lb=basin length	Miller [24]
Form factor (Ff)	Ff=A/Lb² where, Ff=form factor A=area of the basin, km² Lb=basin length	Schumn [21]
Drainage texture (T)	T=Nu/P where Nu=total no. of streams of all orders P=basin perimeter, km	Horton [5]
Compactness coefficient (Cc)	Cc=0.2821 P/A 0.5 where Cc=Compactness coefficient A=Area of the basin, km² P=basin perimeter, km	Horton [5]

Table 1: Formulae for computation of morphometric parameters.

Watersheds	Stream number in different orders						Total number of streams	Percentage of streams by different stream orders to total number of streams.					
	1th	2nd	3rd	4th	5th	6th		1th	2nd	3rd	4th	5th	6th
D1A	156	19	4	1	-	1	181	86.18	10.49	2.20	0.55	-	0.55
D1B	134	24	4	2	1	-	165	81.21	14.54	2.42	1.21	0.60	-
D1C	242	44	11	3	1	-	301	78.06	14.61	3.65	0.99	0.33	-
D2A	278	57	12	2	1	-	350	79.42	16.28	3.42	0.57	0.28	-
D2B	56	16	6	2	1	-	81	69.13	19.75	7.40	2.46	1.23	-
Dudhganga Catchment	**866**	**160**	**37**	**8**	**2**	**1**	**1074**	**80.63**	**14.89**	**3.44**	**0.74**	**0.18**	**0.09**

Table 2: Stream analysis.

Watersheds	Stream number in different orders						Total number of streams	Percentage of streams by different stream orders to total number of streams.					
	1th	2nd	3rd	4th	5th	6th		1th	2nd	3rd	4th	5th	6th
D1A	85.66	19.51	14.66	12.77	-	17.07	149.67	57.25	13.03	9.79	8.53	-	11.40
D1B	79.57	24.06	16.39	1.27	26.53	-	147.82	53.82	16.27	11.08	0.85	17.94	-
D1C	160.05	39.31	18.69	15.76	10.10	-	243.91	65.61	16.11	7.66	6.46	4.14	-
D2A	170.93	51.92	23.29	14.24	9.63	-	270.01	63.30	19.22	8.62	5.27	3.56	-
D2B	32.40	6.35	3.94	2.26	15.88	-	60.83	53.26	10.43	6.47	3.71	26.10	-
Dudhganga Catchment	**528.61**	**141.15**	**76.97**	**46.3**	**62.14**	**17.07**	**872.24**	**60.60**	**16.18**	**8.82**	**5.30**	**7.12**	**1.95**

Table 3: Order wise total stream length.

Linear aspects of Dudhgangariver

Stream order (U): The designation of stream order is the first step in morphometric analysis of a drainage basin, based on the hierarchic making of streams proposed by Strahler [9]. It is defined as a measure of the position of a stream in the hierarchy of tributaries. There are 1074 streams linked with 6th order of streams sprawled over an area of 660 km². A perusal of Table 2 indicates that the DudhgangaRiver which is the trunk stream in Dudhganga catchment is of the Sixth

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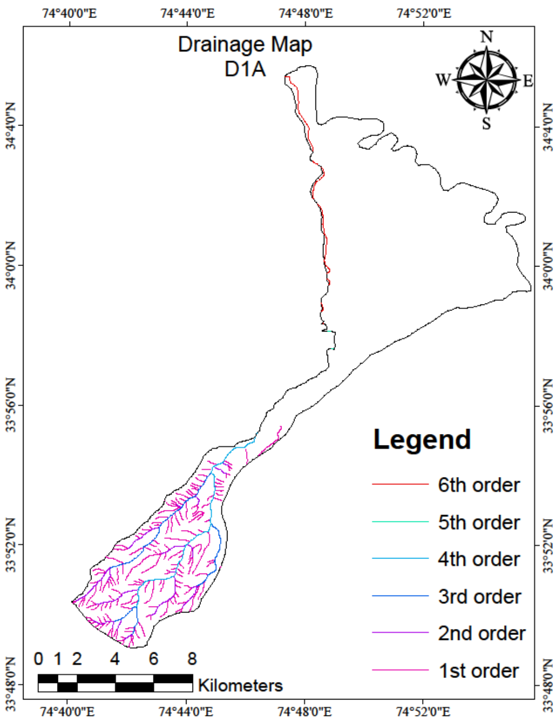

Figure 2: Drainage maps of watersheds of Dudhganga.

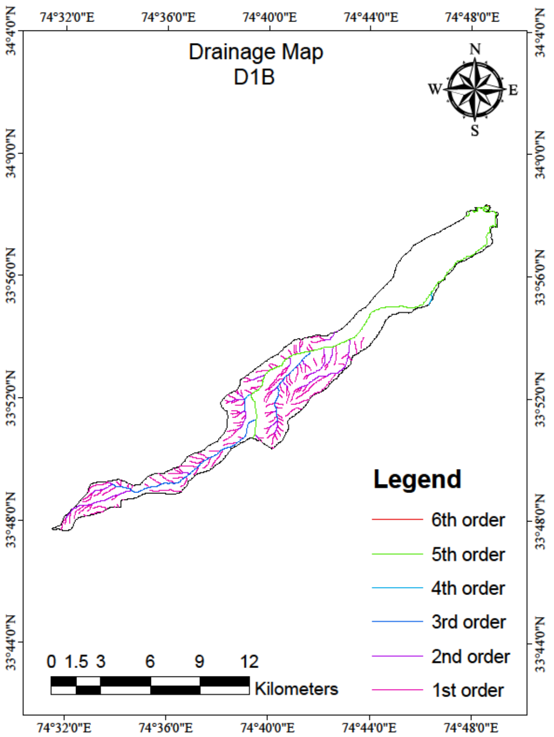

Figure 3: Drainage maps of watersheds of Dudhganga.

order. The watershed D1A having 6th order streams covering an area of 149 Km². The watersheds D1B, D1C, D2A and D2B having 5th order streams covering an area of 69 km², 88 km², 111 Km² and 243. Km² respectively. The highest number of stream segments is found in watershed D2A (350 stream segments) followed by watershed D1C (301 stream segments) while the lowest number of stream segments is found in watershed D2B (81). In whole Dudhganga catchment the first order

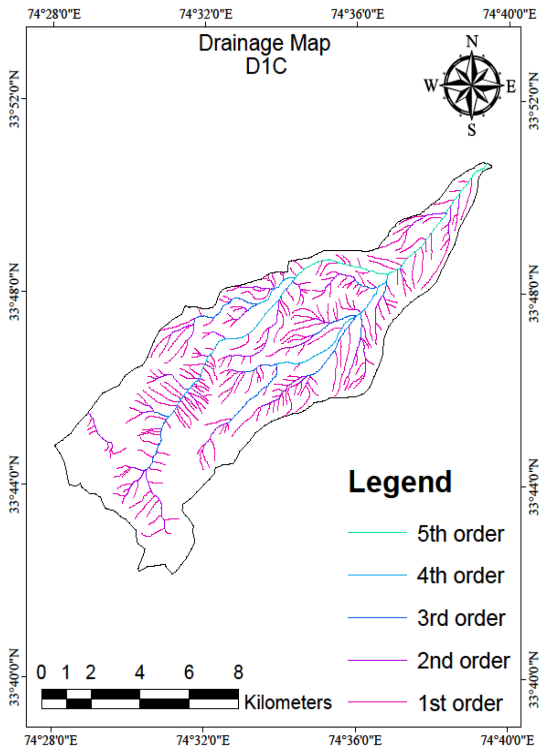

Figure 4: Drainage maps of watersheds of Dudhganga.

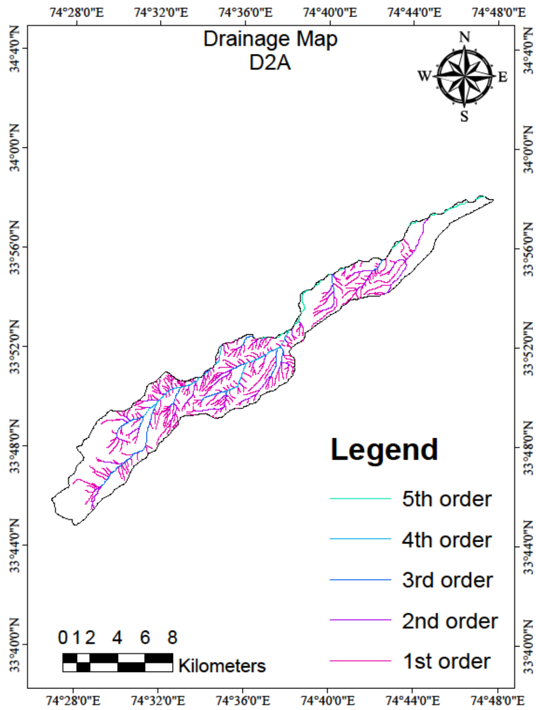

Figure 5: Drainage maps of watersheds of Dudhganga.

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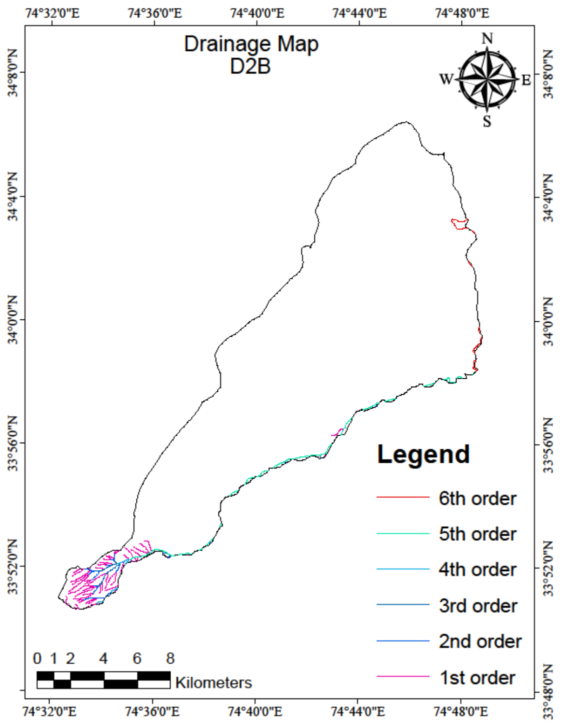

Figure 6: Drainage maps of watersheds of Dudhganga.

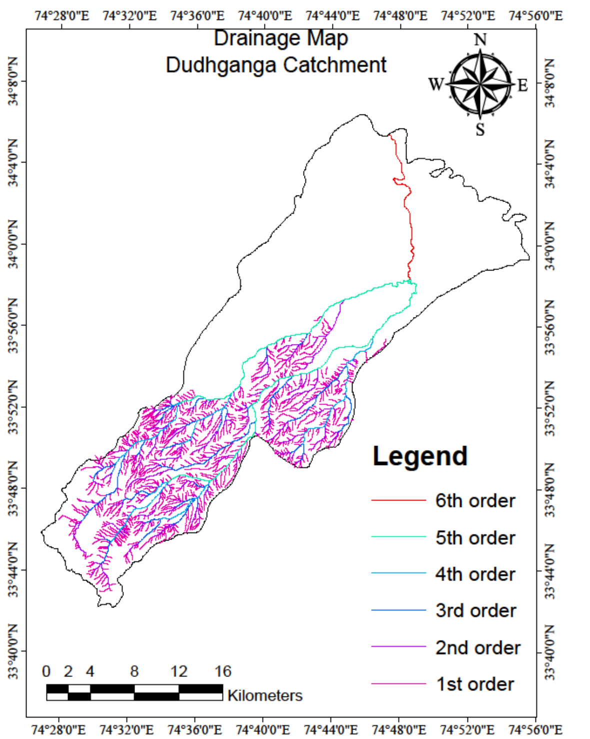

Figure 7: Drainage maps of watersheds of Dudhganga.

streams constitute 80.63 per cent while second order streams constitute 14.89 per cent of the total number of streams. Third and fourth order streams constitute 3.44 per cent and 0.74 per cent of the total number of streams respectively while fifth and sixth order streams constitute only 0.18 per cent and 0.09 per cent respectively of the total number of streams. Thus the law of lower the order higher the number of streams is implied throughout the catchment. It is observed that thevariation in order and size of the watersheds is largely due to physiographic, structural conditions of the region and infiltration capacity of the soil (Figures 2-7).

Stream length (Lu): The stream length was computed on the basis of the law proposed by Horton [5], for all the five watersheds. Generally, the total length of stream segments decrease as the stream order increase. In 2 watersheds D1C and D2A the stream length followed Horton's law. But in 3 watersheds D1A, D1B and D2B, the stream segments of various orders showed variation from general observation. It is evident in the (Table 3) that in Dudhganga catchment the length of first order streams constitute 60.60 per cent of the total stream length with second order (16.18 per cent), third order (8.82 per cent), fourth order (5.30 per cent), fifth order (7.12 per cent) and the sixth order (1.95 per cent). The total length of 1st and 2nd order streams constitutes 76.78 percent of the total stream length. It can be inferred that the total length of stream segments is maximum in first order streams and decreases as the stream order increases. However fifth order is an exception where the total stream length (62.14 kms) is more than that of the fourth order (46.03 kms). This change may indicate flowing of streams from high altitude, lithological variations and moderately steep slopes [18,19].

Bifurcation ratios (Rb): Horton [5] considered Rb as an index of reliefs and dissections. Strahler [10] demonstrated that Rb shows only a small variation for different regions with different environments except where powerful geological control dominates. Lower Rb values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern [20]. Bifurcation ratio is related to the branching pattern of a drainage network and is defined as the ratio between the total number of stream segments of one order to that of the next higher order in a drainage basin [21]. The mean bifurcation ratio values of different watersheds of Dudhganga catchment (Table 5) shown variation from 2.79 to 5.65 indicates less structural control on the drainage development.

Stream frequency (Fs): Stream frequency is the total number of stream segments of all orders per unit area [22]. Fs valves indicate positive correlation with the Dd of all five watersheds of Dudhganga catchment. The stream frequencies of all the watersheds are mentioned in Table 4. The study revealed that the D1C and D2A watersheds have high stream frequency because of the fact that it falls in the zone of fluvial channels and the presence of ridges on both sides of the valley which results in highest Fs. The watersheds D1A and D1B have medium stream frequency and watershed D2B has poor stream frequency because of low relief.

Drainage density (Dd): It indicates the closeness of spacing between channels and is a measure of the total length of the stream segment of all orders per unit area. Drainage density in all the watersheds varies from 0.25 to 2.77 respectively (Table 5). In general it has been observed over a wide range of geologic and climatic types, that low drainage density is more likely to occur in regions of highly permeable subsoil material under dense vegetative cover, and where relief is low. In contrast, high Dd is favored in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief [20]. Hence in this study high drainage density was found in D1C and D2A because of weak and impermeable sub surface material and mountainous relief. Figure 8 shows the drainage density of Dudhganga catchment. Low Dd value for watershed D1A and D1B indicates that it

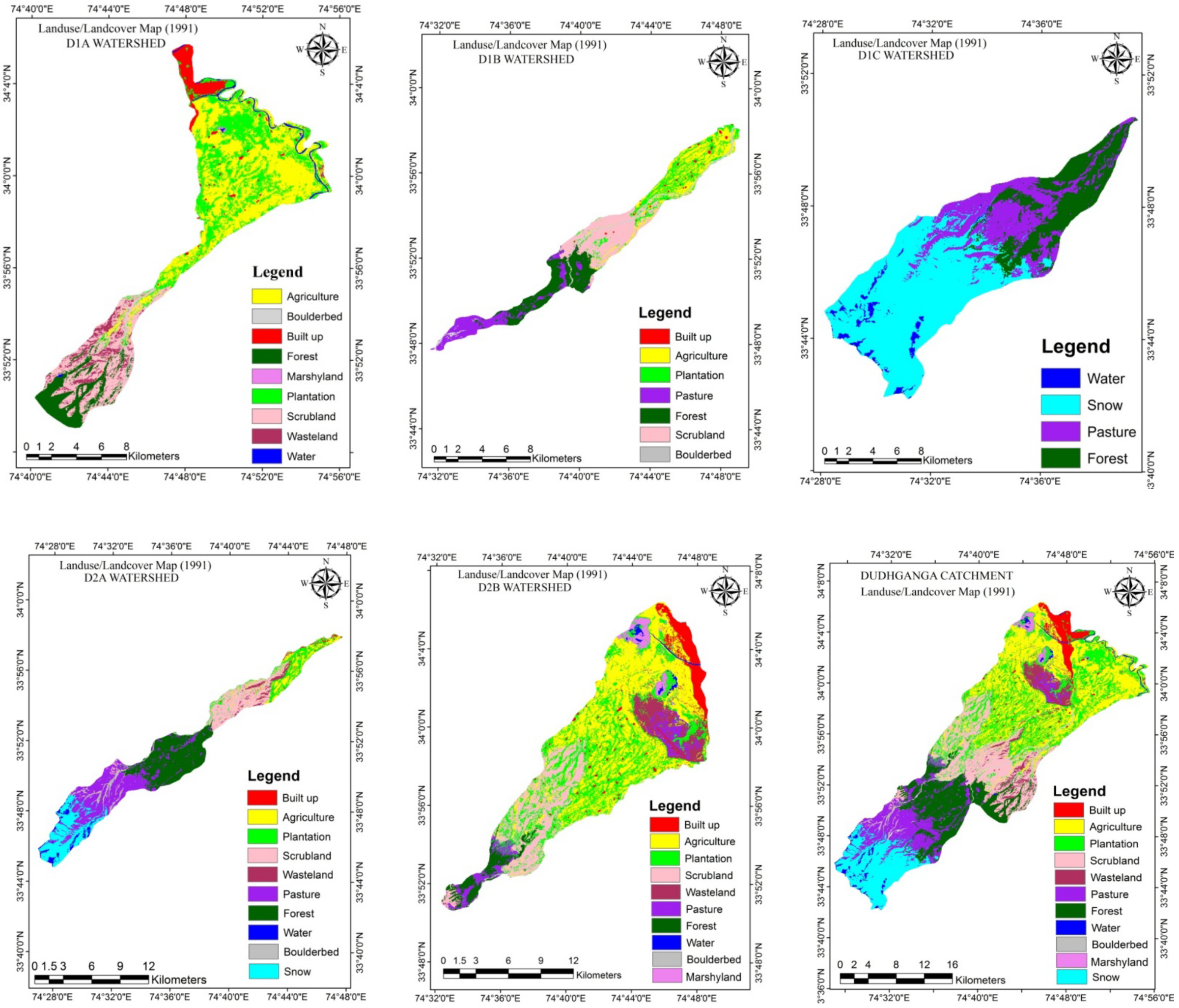

Figure 8: Land use/land cover maps (1991) of watersheds of Dudhganga catchment.

Watersheds	Area (km²)	Stream Frequency (km/ km²)	Basin Length (km)	Form Factor	Elongation Ratio	Circularity Ratio	Compactness constant
D1A	149	1.21	36.60	0.11	0.37	0.17	0.39
D1B	69	2.39	35.94	0.05	0.26	0.15	0.62
D1C	88	3.42	23.15	0.16	0.46	0.38	0.34
D2A	111	3.15	42.65	0.06	0.28	0.16	0.47
D2B	243	0.33	32.55	0.23	0.54	0.36	0.21
Dudhganga Catchment	**660**	**1.63**	**62.56**	**0.17**	**0.46**	**0.33**	**0.13**

Table 4: Morphometric parameters of Dudhganga catchment.

Watersheds	Perimeter (km²)	Drainage Density	Drainage Texture	Bifurcation Ratios					Mean Rb
				Rb1	Rb2	Rb3	Rb4	Rb5	
D1A	103.37	1.00	1.75	8.21	4.75	4	-	-	5.65
D1B	75.73	2.14	2.17	5.58	6	2	2	-	3.89
D1C	53.86	2.77	5.58	5.5	4	3.66	3	-	4.04
D2A	92.35	2.43	3.79	4.87	4.75	6	2	-	4.40
D2B	91.53	0.25	0.88	3.5	2.66	3	2	-	2.79
Bifurcation Ratios	**157.51**	**1.32**	**6.81**	**5.41**	**4.32**	**4.62**	**4**	**2**	**4.07**

Table 5: Values of drainage density, texture and bifurcation ratios for Dudhganga catchment.

has highly permeable sub surface material and low relief. While as poor Dd is found in D2B watershed. It has been observed that low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture.

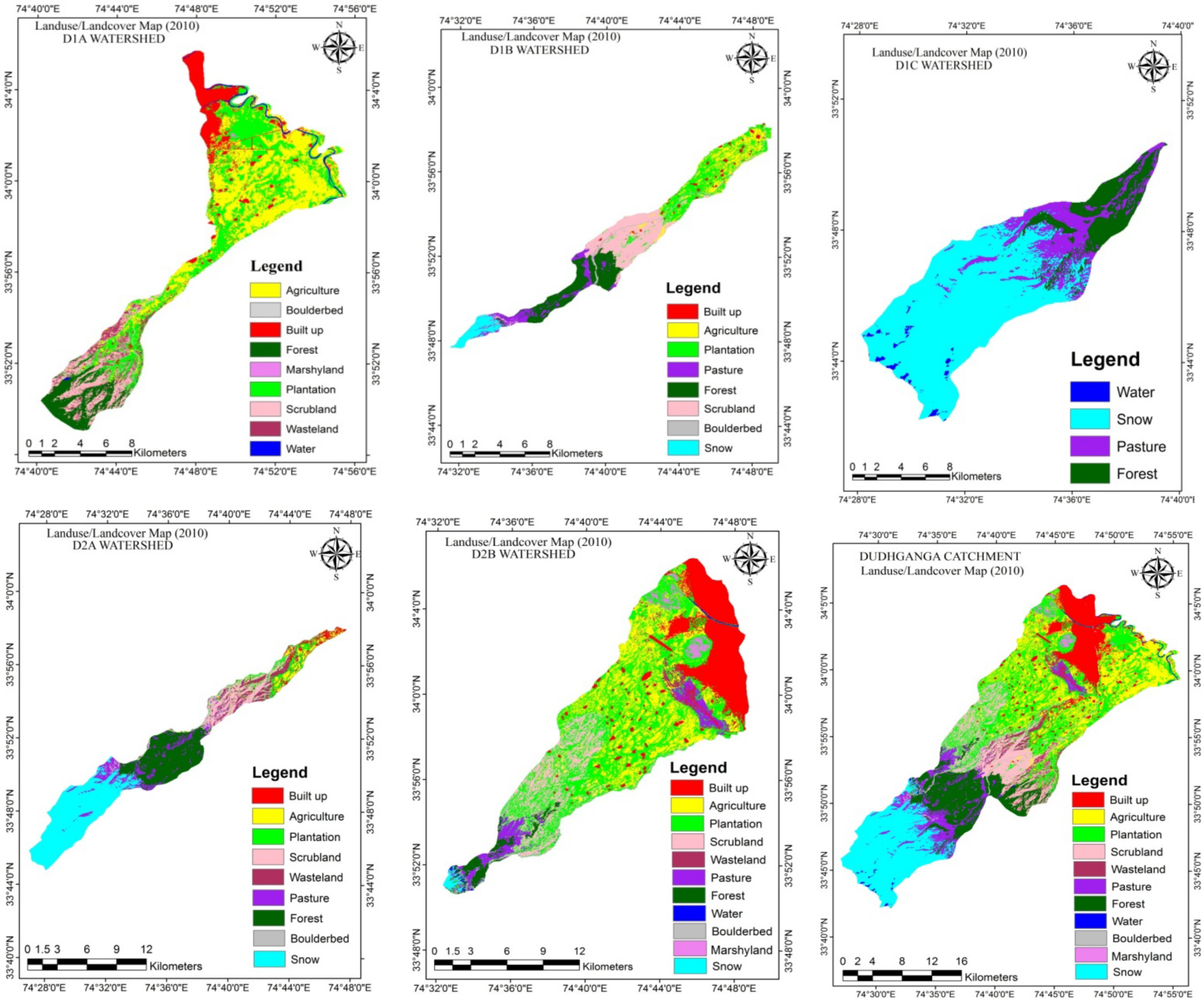

Figure 9: Land use/land cover maps (2010) of watersheds of Dudhganga catchment.

Classes	1991 (Area in Hectares)	Percentage	2010 (Area in Hectares)	Percentage	Change Detection in (Hectares)
Wasteland	679.45	4.56	650.77	4.37	-28.68
Scrub land	2304.7	15.47	1677.1	11.26	-627.6
Built up	790.16	5.30	1812.2	12.16	1022.1
Marshy land	14.458	0.09	9.016	0.06	-5.442
Water bodies	250.34	1.68	221.42	1.48	-28.92
Plantation	3681.1	24.71	5300.1	35.57	1619
Agriculture	5821.4	39.07	4198.7	28.18	-1622.7
Boulder bed	68.148	0.46	45.405	0.30	-22.74
Forest	1290.3	8.66	985.26	6.62	-305
Total	14900	100	14900	100	2641.1

Source: Author's estimation

Table 6: Land use/Land cover change in D1A watershed (1991-2010).

Drainage texture (Dt): The drainage texture depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development [23]. The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate. Drainage texture is defined as the total number of stream segments of all orders per perimeter of the area (Horton). Smith [23] classified drainage into five classes i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). Horton [5] recognized infiltration capacity as the single important factor which influences drainage texture and considered drainage texture which includes drainage density and stream frequency. The drainage density values of watersheds range from 0.25 to 2.77 indicating very coarse to coarse drainage texture for Dudhganga catchment.

Areal aspects of the drainage basin

Form factor (Ff): Form factor is defined as the ratio of basin area to the square of the basin length [22]. The values of form factor would always be less than 0.7854 (perfectly for a circular basin). Smaller the value of (Ff) more elongated will be the basin. The form factor for all watersheds varies from 0.05-0.16, But the whole Dudhganga catchment have 0.17 Ff (Table 4). The observation shows that the D1B and D2A watersheds are highly elongated while as the watersheds D1C and D2B are less elongated. The values of Ff for Dudhganga catchment indicates that the whole catchment is elongated. The elongated watershed with low value of Ff indicates that the basin will have a flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin.

Elongation ratio (Re): Schumn [21] defined elongation ratio as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin [18]. The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climate and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope [9]. These values can be grouped in to three categories namely (a) circular (>0.9), (b) oval (0.9 to 0.80, (c) less elongated (<0.7). The values of Re varies from 0.26 to 0.46 indicates that the catchment falls in the less elongated category.

Circularity ratio (Rc): Circularity ratio is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin [24]. It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate, relief and slope of the watershed. In the present study (Table 4), the Rc values for all watersheds vary from 0.15 to 0.38 which shows that the watersheds are almost elongated. This anomaly is due to diversity of slope, relief and structural conditions prevailing in these watersheds.

Compactness coefficient (Cc): Compactness coefficient is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin. The values of Cc in the five watersheds of Dudhganga catchment vary from 0.21 to 0.62 showing variations across the watersheds. But the overall value of Cc of Dudhganga catchment is 0.13 which is lesser than all five watersheds.

Land use/land cover analysis

There are few landscapes remaining on the earth's surface that have not been significantly altered or are not being altered by humans in some manner. Mankind's presence on the earth and his modification of the landscape has had a profound effect upon the natural environment. These anthropogenic influences on changing patterns of land use are a primary component of many current environmental concerns as land use and land cover change is gaining recognition as a key driver of environmental change [25]. The classified images have categorized into built up, agriculture, forest, boulder bed, plantation, pasture, scrub land, wasteland, marshy land, snow and water bodies. The Figures 8 and 9 present land use/land cover mapsof the catchment. The Dudhganga catchment as a whole presents a grim scenario as the land use/cover changes from 1991 to 2010 period indicate degradation of land and other natural resources. It was found that cultivated land decreased by 2.08 per cent per year, where as built up land increased by 9.06 per cent per year during the same period. Moreover, decrease in the forest cover 1.05 per cent per year and scrubland 1.20 per cent has been observed. However, 1.17 per cent per year reduction has observed in the wasteland area. The details of land use/land cover and the changes in area under each category in hectares as well as in percentage for each watershed from 1991 to 2010 period are presented in Tables 6-11. Since the Dudhganga catchment have five watersheds having agriculture as a primel and use activity supporting the livelihood of the local people, an increase in cultivated land, plantation and forest area can be considered as a positive change, as this is likely to bring environmental, economic and social benefits. Similarly, decrease in wasteland and scrubland is also regarded as a positive change as it will indicate reclamation and rehabilitation of degraded and unproductive land. In contrast, decrease in are a under forest, cultivated land, marshy land can be

Classes	1991 (Area in Hectares)	Percentage	2010 (Area in Hectares)	Percentage	Change Detection in (Hectares)
Pasture	945.95	13.71	720.3	10.44	-225.6
Boulder bed	295.5	4.29	156.85	2.27	-138.7
Scrubland	1798.6	26.06	1702.6	24.67	-96.01
Agriculture	1277.4	18.51	767.98	11.13	-509.4
Built up	147.68	2.15	338.89	4.92	191.2
Plantation	1029	14.91	1611.6	23.36	582.63
Forest	1405.8	20.37	1189.8	17.24	-216.1
Snow	0	0	411.97	5.97	411.97
Total	6900	100	6900	100	1185.8

Source: Author's estimation

Table 7: Land use/Land cover change in D1B watershed (1991-2010).

Classes	1991 (Area in Hectares)	Percentage	2010 (Area in Hectares)	Percentage	Change Detection in (Hectares)
Pasture	2046	23.25	1510.84	17.17	-535.2
Forest	1742	19.79	1179.72	13.39	-562.4
Water	249	2.83	115	1.30	-134
Snow	4763	54.13	5994.44	68.11	1231
Total	8800	100	8800	100	1231
Plantation	1029	14.91	1611.6	23.36	582.63

Source: Author's estimation

Table 8: Land use/Land cover change in D1C watershed (1991-2010).

Classes	1991 (Area in Hectares)	Percentage	2010 (Area in Hectares)	Percentage	Change Detection in (Hectares)
Built up	215.72	1.94	458.5	4.13	242.78
Agriculture	610.57	5.50	383.46	3.45	-227.11
Forest	2679.2	24.14	2400.2	21.62	-279
Boulder bed	339.68	3.07	145.88	1.33	-193.8
Plantation	787.31	7.09	763.68	6.88	-23.63
Pasture	2743.2	24.71	1095.3	9.87	-1647.9
Scrub land	1624.7	14.64	1205.2	10.86	-419.5
Wasteland	261.95	2.36	685.21	6.17	423.26
Snow	1562.4	14.07	3962.5	35.69	2400.1
Water	275.27	2.48	0	0	-275.27
Total	11100	100	11100	100	3066.2

Source: Author's estimation

Table 9: Land use/Land cover change in D2A watershed (1991-2010).

Classes	1991 (Area in Hectares)	Percentage	2010 (Area in Hectares)	Percentage	Change Detection in (Hectares)
Built up	1502.7	6.18	4860.7	20.00	3358
Agriculture	8982.6	36.96	4380.2	18.02	-4602
Forest	854.65	3.52	540.88	2.23	-313.8
Scrubland	3267.3	13.45	2239.6	9.22	-1028
Plantation	5818.8	23.95	9778	40.24	3959.2
Pasture	1162.9	4.78	1135.9	4.67	-26.97
Boulder bed	203.06	0.84	204.04	0.84	0.9747
Water	199.73	0.82	33.059	0.14	-166.7
Wasteland	1615	6.65	616.66	2.54	-998.3
Marshy land	693.34	2.85	373.96	1.54	-319.4
Snow	0	0	136.95	0.56	136.95
Total	24300	100	24300	100	7455.2

Source: Author's estimation

Table 10: Land use/Land cover change in D2B watershed (1991-2010).

Classes	1991 (Area in Hectares)	Percentage	2010 (Area in Hectares)	Percentage	Change Detection in (Hectares)
Built up	2656	4.02	7470	11.32	4814
Agriculture	16692	25.29	9730	14.74	-6962
Forest	7972	12.08	6296	9.54	-1676
Boulder bed	906.4	1.36	552.2	0.84	-354.2
Plantation	11316	17.15	17453	26.44	6137
Pasture	6898	10.45	4463	6.76	-2436
Scrubland	8995	13.63	6825	10.34	-2171
Wasteland	2556	3.87	1953	2.96	-603.7
Snow	6324	9.58	10505	15.91	4181
Water	975	1.47	370	0.56	-605
Marshy land	707.8	1.1	383	0.58	-324.8
Total	66000	100	66000	100	15132

Source: Author's estimation

Table 11: Land use/Land cover change in Dudhganga catchment (1991-2010).

taken as a negative change, indicating anthropogenic pressures and lack of conservation measures, similarly increase in the wasteland and pastureland is also regarded as a negative change. A general decrease in cultivated land area and increase in area built up area is common a cross all the five watersheds indicating negative change. There is also a general decline in forest areainD1a, D1b, D1c, D2a and D2b watersheds of the catchment. (Figures 8 and 9).

Prioritization of watersheds

Based on morphometric analysis: The morphometric parameters i.e., bifurcation ratio (Rb), compactness coefficient (Cc), drainage density (Dd), stream frequency (Fs), drainage texture (Dt), form factor (Ff), circularity ratio (Rc), and elongation ratio (Re) are also termed as erosion risk assessment parameters and have been used for prioritizing watersheds [26]. The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture have a direct relationship with erodibility, higher the value, more is the erodibility. Hence for prioritization of watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, and form factor have an inverse relationship with erodibility [27], lower the value, more is the erodibility. Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Hence, the ranking of the watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters (Table 12). After the ranking has been done

S. No.	Morphometric Parameters	D1A	D1B	D1C	D2A	D2B
Linear parameters						
1	Bifurcation Ratios (Rb)	5.65 (1)	3.89 (4)	4.04 (3)	4.40 (2)	2.79 (5)
2	Drainage density (Dd)	1 (4)	2.14 (3)	2.77 (1)	2.43 (2)	0.25 (5)
3	Drainage texture (Dt)	1.75 (4)	2.17 (3)	5.58 (1)	3.79 (2)	0.33 (5)
4	Stream frequency (Fs)	1.21 (4)	2.39 (3)	3.42 (1)	3.15 (2)	0.33 (5)
Shape parameters						
5	Circularity Ratio (Rc)	0.17 (3)	0.15 (1)	0.38 (5)	0.16 (2)	0.36 (4)
6	Compactness coefficient (Cc)	0.39 (3)	0.62 (5)	0.34 (2)	0.47 (4)	0.21 (1)
7	Form factor (Ff)	0.11 (3)	0.05 (1)	0.16 (4)	0.06 (2)	0.23 (5)
8	Elongation Ratio (Re)	0.37 (3)	0.26 (1)	0.46 (4)	0.28 (2)	0.54 (5)
Compound scores		3.13	2.63	2.63	2.25	4.38
priority		Medium	High	High	High	Low
Land use category and change in area (Hectares)						
9	Wasteland	-28 (2)	-	-	+423 (1)	-998 (3)
10	Scrubland	-627 (2)	-96 (4)	-	-419 (3)	-1028 (1)
11	Built up	1022 (2)	191 (4)	-	242 (3)	3358 (1)
12	Agriculture	-1622 (2)	-509 (3)	-	-227 (4)	-4602 (1)
13	Marshy land	-5.4 (2)	-	-	-	-319 (1)
14	Forest	-305 (3)	-216 (5)	-562 (1)	-279 (4)	-313 (2)
15	Pasture	-	-225 (3)	-535 (2)	-1647 (1)	-26 (4)
16	Plantation	1619 (3)	582 (2)	-	-23 (1)	3939 (4)
Compound scores		2.28	3.5	1.5	2.43	2.12
priority		Medium	Low	High	Medium	High
Common priority		**Medium**	**-**	**High**	-	-

Note: Values in parenthesis indicate priority/rank

Table 12: Priorities of watersheds and their ranks.

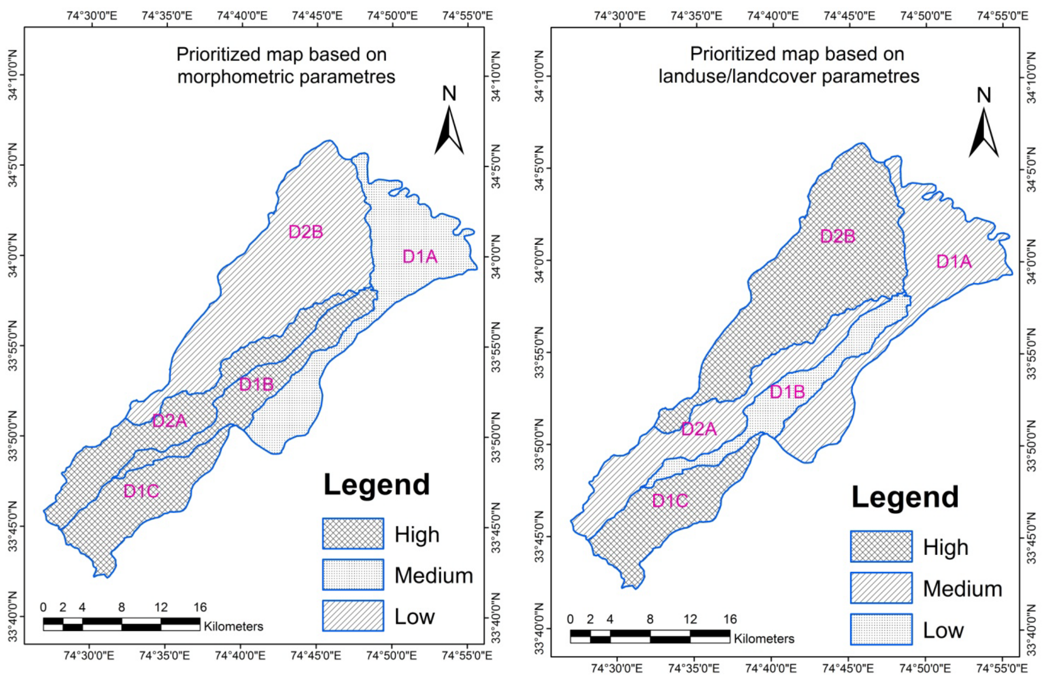

Figure 10: Priority of watersheds based on morphometric and land use/land cover analysis.

based on every single parameter, the ranking values for all the linear and shape parameters of each watershed were added up for each of the five watersheds to arrive at compound value (Cp). Based on average value of these parameters, the watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on. The watershed which got the highest Cp value was assigned last priority. The watersheds were then categorized into three classes as high (<2.63), medium (2.64-3.13) and low (>3.13) priority on the basis of the range of Cp value. Hence, on the basis of morphometric analysis, D1B, D1C and D2A fall in the high priority, D1Afallin medium priority and D2B in the low priority category (Table 12).

Based on land use/land cover analysis: Common land use categories i.e., wasteland, cultivated land, built up, agricultural land,

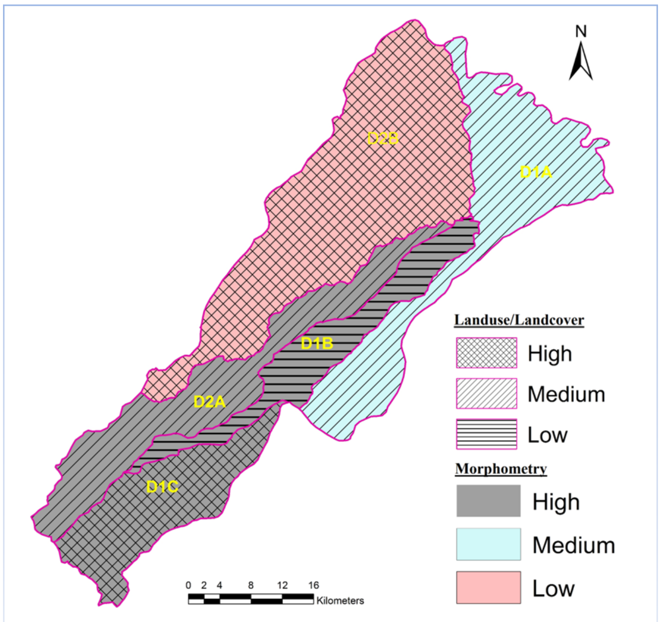

Figure 11: Priority of watersheds based on superimposition of morphometric and land use/land cover parameters.

pasture, forest, plantation, marshy land andscrubland in all the five watersheds were considered for prioritization of watersheds based on land use/land cover change analysis. The change in area (hectares) under each category of land use was ranked and assigned ranks (Table 12). All watersheds have reported negative change in respect of agricultural land, pasture, scrubland and forest cover, i.e., there has been overall decrease in agricultural land, pasture, scrubland and forest cover across all watersheds from 1991 to 2010. However, wasteland shows some positive change, since the area under wasteland has reduced in two watersheds (D1A and D2B), besides there has been tremendous increase in area under plantation and built up are as in all waterheds.

For prioritization of watersheds the highest value (in hectares) under land use categories of built up, agricultural land, marshy land, forest cover pasture and scrubland were rated as rank 1, second highest value as rank 2 and so on. However, highest ranking was given to the highest value among the land use category showing positive change, i.e., increase in plantation (Table 12). Finally, the ranking under each land use category was added up to arrive at compound value (Cp), lower the Cp value higher is the priority. The priority was given by classifying the highest and lowest range of Cp value into three classes as high (<2.16), medium (2.16-2.82) and low (>2.82) priority. Hence, on the basis of land use change analysis D1C and D2B fall in the high priority, D1A and D2A fall in medium priority and D1B in the low priority category (Table12 and Figure 10).

The results obtained from morphometric and land use/land cover analysis have been correlated to find out the common watersheds falling under each priority. The correlation shows that D1C and D1A being the common watersheds which falls under high priority and medium priority respectively based on morphometric as well as land use/cover analysis. The other three watersheds exhibit little correlation and differ in their priority under morphometric and land use/land cover analysis (Table 12). Figure 11 shows correlation of watersheds based on integration of morphometric and land use/land cover parameters after both the themes are superimposed in GIS.

Conclusion

Watershed prioritization is considered as one of the most important aspects of planning and development for natural resources for water conservation measures. The present study recapitulates the integrated approach for developing a preliminary prioritization of watersheds in Dudhganga catchment. The result of prioritization on the basis of morphometric analysis revealed that D1B, D1C and D2A watersheds fall under very high priority, where as D1C and D2B also fall under very high priority on the basis of land use/land cover analysis. However, on the superimposition of the thematic layers of morphometric and land use/land cover in GIS environment, only two watersheds D1C and D1A being the common watersheds which fall under high priority and medium priority respectively, whereas the rest of watersheds show little or no correlation. The watersheds which are falling under very high priority may be taken up for implementation of soil and water conservation measures. The study demonstrates the utility of remote sensing and GIS techniques in prioritization of watersheds which may be helpful for planners and decision makers for planning at watershed level.

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