



## Prioritization of sub-watersheds in barchha nala area of Narsinghpur district (India) based on land use, drainage density and slope analysis using remote sensing and GIS

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(Received: June 29, 2015; Revised received: February 11, 2016; Accepted: February 16, 2016)

**Abstract:** In the present study, prioritization of watershed was carried out using remote sensing and geographic information system (GIS), for Barchha nala watershed which lies the Narmada river basin in Narsinghpur district of Madhya Pradesh. Contour map was prepared with a contour interval of 20M in a scale of 1:50000 using ARC MAP module. The basin morphometric parameters such as linear and aerial aspects were determined and computed using ArcInfo i.e. stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio and elongation ratio. LISS-III Satellite Image of the year 2000 has been utilized for generating land use/land cover data. Sub-watershed was prioritized on the basis of percentage cultivable area, drainage density and slope. Out of the six sub-watersheds, SWS2 qualify for high priority, whereas SWS3 has been categorized as Low priority based on the integration of these parameters.

**Key words :** Watershed prioritization, Land use/Land cover, average Slope, Morphometry, Remote sensing, GIS

### Introduction

Land and water are the two most valuable and vital resources essentially required not only for sustenance of life but also the economic and social progress of a region. India is basically an agrarian country with geographical area of total 329 M ha and gross cropped area of 175 M ha (Reddy, 1999). Population pressure is increasing over the years which resulted in the scarcity of availability of land and water resources. Industrial expansion is also a need of the time, which requires infrastructural facilities; which in turn forms a feedback resulting in further pressure on finite land and water resources. There may be various considerations for the implementation of management programs in the few sub-watersheds only. It is always better to start management measures from the most critical sub-watershed. Watershed prioritization is, thus, the ranking of different critical sub-watersheds according to the order in which they have to be taken up for the treatment by soil and water conservation measures. A particular sub-watershed may get top priority due to various reasons but often the intensity of land degradation is taken as the basis. This approach of prioritization of watersheds based on actual sediment yield rates may be possible only when the necessary data is available. Such data are hardly available in India for small watersheds. In the absence of sediment yield data geomorphologic parameters along with the satellite based land use / land cover information of watershed may be helpful in prioritization of the sub-watersheds. The morphometric characterization was obtained through the measurement of three distinct linear, areal and relief aspects over the eleven sub-watersheds.

The major factors responsible for erosion include rainfall, soil type and vegetation, topographic and geomorphological

characteristics of basin (Kothari and Jain, 1997) where there is lack of data on rainfall and sediment yield the relative vulnerability of watersheds can be assessed, with respect to time independent factors (soil type topography and geomorphology). With the advancement of remote sensing (RS) technique and data acquisition, it is now possible to generate and revise vegetation resource maps at the scale of even a few meters. The effect of vegetation can also be incorporated in such analysis. A geographical information system (GIS) is a computer based system designed to store, process and analysis geo-referenced spatial data and their attributes (Jain and Kothari, 2000).

The watershed under study receives more than 80 per cent of the rainfall in the monsoon season (June-September). Due to undulated topography much of the naturally incoming water flows out quickly and results in soil erosion and poor recharge of underground water resource. The light textured and permeable soil are easily erodible and able to hold limited quantity of water in root zone. A monsoon gap of even one week can cause moisture stress to the crops. There is generally cessation of rainfall during last week of September and first week of October as a result flowering and maturity of crops suffers badly due to lack of moisture and fails to bear good yield. Farmers are lacking interest in the farming due to lack of poor returns from cultivated land.

### Materials and Methods

**Study area and data:** The study area Barchha nala watershed which lies within the Narmada river basin is situated between 78° 54' 59.44" to 78° 51' 25.47"E longitude and 22° 34' 18.70" to 22° 26' 56.64" latitude (Fig 1) with elevation range between 680 to 1020 m above Mean Sea Level (MSL) and extends a total area of 66.85 KM<sup>2</sup>. The study area belongs to Central Narmada valley,

agro climatic zone VI of M.P. It has a typical sub humid climate with hot dry summers and cool dry winters. Temperature extremes vary between the minimum of 8.2°C during December or January months to the maximum of 42.5°C in May or June. Average annual precipitation is 1192 mm, which is concentrated mostly between mid June to mid September with scattered winter rains during late December and January months. Soil in the watershed is medium deep black and it is usually clay to loamy in texture.

**Data used:** The survey of India (SOI) toposheet number 55N/14 and 55N/15 on 1:50000 scale were procured from Survey of India, Dehradun in the form of paper map. Satellite data was downloaded from GLCF (Global Land Cover Facility), for 29<sup>th</sup> December 2000, with the help of satellite data drainage layer and land use / land cover map is prepared. The resolution, path, row and date of pass are given in table-1.

Scanned Survey of India (SOI) toposheets are rectified and the IRS LISS III imagery of the area was registered with the SOI toposheets. On screen digitization tools of ArcGIS was used to extract the drainage layer from the toposheets and was updated from the satellite imagery. The ordering was given to each stream segments by following the Strahler (1957) stream ordering method. The drainage network was used to demarcate the boundary of the study area. The study area was divided into six sub-watersheds and the boundaries of the sub-watersheds were demarcated on the basis of drainage flow direction, elevation values and relief.

**Land use/land cover classification:** The land use /land cover classification was done using satellite data of IRS-ID LISS-III. The image of the watershed was registered with original satellite scene and the mask of image was prepared. The standard False Color Composite (FCC) map of the entire watershed was extracted from the original scene.

**Morphometric analysis:** The variable derived from morphometric analysis are in the form of ratio and dimension numbers thus providing an effective comparison, regardless of scale. The morphometric of the sub-watershed were calculated in GIS environment. For morphometric analysis, perimeter, maximum length, number of stream of each of each order and watershed relief value required. These input were extracted from the drainage map and the necessary parameters for morphometric analysis were calculated by using the equation as presented in Table 2. Finally, thematic maps such as satellite based land use/land cover, soil and drainage network maps were integrated by overlay technique of GIS for identifying the suitable sites for construction of soil conservation structures.

**Prioritization of watershed:** Prioritization of watershed means selection of those watersheds, which need immediate attention from soil conservation point of view. In case of ungauged watershed, there is no information on sediment production rate. Therefore, it will be appropriate to use these parameters i.e. drainage density, average slope and the cultivated area for prioritization of watershed. If a sub-watershed is having percentage cultivable area > 75 per cent, between 51-74 per cent and < 50 per cent and drainage density (Dd) > 3.5, between 2.5 – 3.5 and < 2.5 were grouped in three classes namely High (H), Moderate (M) and Low (L) respectively. Further, on the basis of percentage cultivated area

and drainage density of the sub watersheds, the rating has been done into four priority categories namely A (Severe Erosion), B (High Erosion), C (Moderate Erosion) and D (Low Erosion). Similar criteria were suggested by Durbude *et al.* (2001) for the prioritization of sub-watersheds of Banswara district of Rajasthan, India. This approach may not be helpful when the two sub watersheds are having similar priority category. Pandey *et al.* (2007) suggested percentage cultivated area, drainage density and slope information for the prioritization of sub watersheds of Karso, Hazaribagh, India. When two or more watersheds falls under same category, average slope (or maximum relief of the sub watershed) were taken into account for priority fixation. Maximum relief is the maximum elevation difference between a point near the mouth and a point on the divide.

## Results and Discussion

**Land use/ land cover:** Ground features are identified on the basis of reflectance recorded by the sensor and converted into digital values which are classified by supervise and unsupervised classification. In the present study unsupervised classification method has been adopted. In Barchha nala watershed, land use/land cover classes were identified i.e. river, agriculture, pond, open/fallow and forest using unsupervised classification. Sub-watershed wise land use/land cover of study area can be depicted from table 3.

**Morphometric analysis:** Morphometric analysis of parameters namely area and perimeter of sub watershed, basin and stream length, stream order, farm factor, elongation and circulatory ratio, drainage density drainage frequency, bifurcation ratio relief ratio, relative relief and ruggedness number of the sub watershed has been carried out using the mathematical formula given in Table 2 and their results are summarized in table 4, 5 and 6. ). Finally the sub-watersheds boundary and drainage network is presented in Fig 2. These sub-watersheds boundary, drainage networks and

**Table-1:** Details of satellite image used for the study

Row path	Date	Satellite	Resolution
144/044	29 <sup>th</sup> Dec. 2000	LANDSAT	28meter

**Table-2:** Formula for computation of morphometric parameters

Area	A
Perimeter	P
Stream length	L
No of streams of order u	$N_u$
Basin length	$L_b$
Bifurcation ratio ( $R_b$ ):	$R_b = N_u / N_{u+1}$
Form Factor ( $R_f$ ):	$R_f = A / L_b^2$
Elongation ratio ( $R_e$ ):	$R_e = 2 / L_b \cdot \sqrt{A} / \Pi$
Circulatory ratio ( $R_c$ ):	$R_c = 12.57 / P_r^2$
Drainage density ( $D_d$ ):	$D_d = L / A$
Stream frequency ( $F_u$ ):	$F_u = \sum N_u / A$
Relief Ratio ( $R_h$ ):	$R_h = H / L_b$
Ruggedness Number ( $R_N$ ):	$R_N = H \times D_d$
Relative Relief ( $R_r$ ):	$R_r = H / P$
Average slope of watershed ( $S_a$ )	Total length of contours within the Sub watershed (m) x contour interval (m) x 100 / Sub watershed area (m <sup>2</sup> )

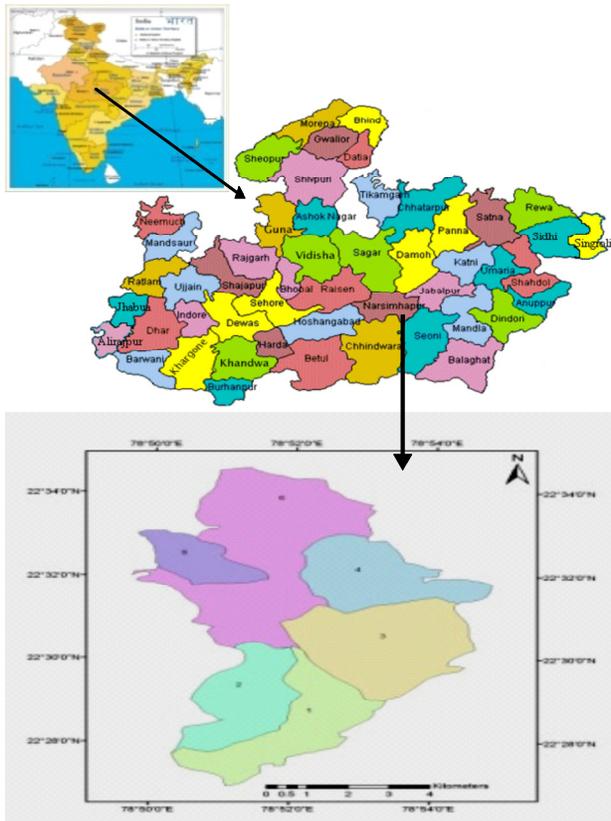


Fig. 1: Location barchha nala watershed

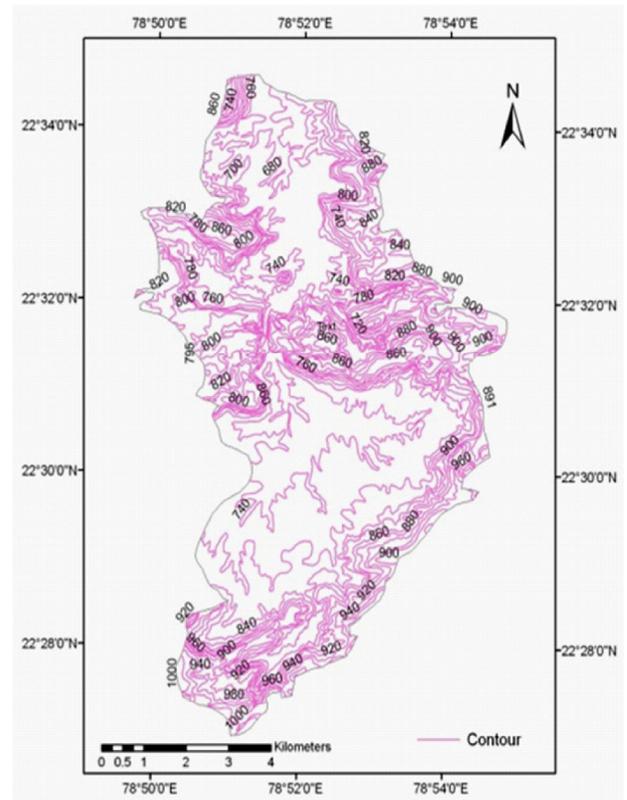


Fig 3 Watershed Boundary and Contour

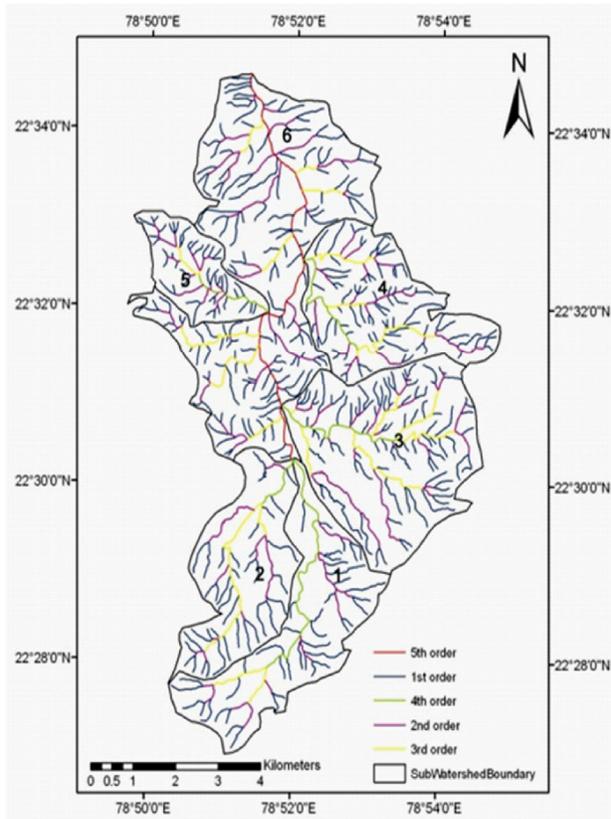


Fig 2 Sub-watersheds Boundary and Drainage network

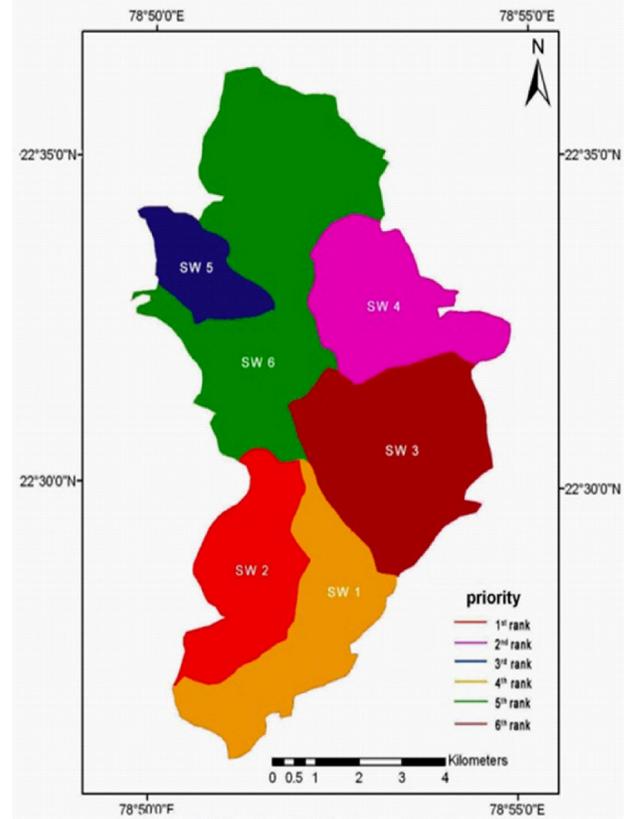


Fig 4 Final Priority map of Study area

**Table- 3:** Sub-watershed wise land use/land cover in study area

Sub-watershed No.	Land use/Land cover area (km <sup>2</sup> )							Land use/Land cover area (%)					
	River	Agri-culture	Habit-ation	Open/ Fallow	Waste-land	Forest	Total	River	Agri-culture	Habit-ation	Waste-land	Open/ Fallow	Forest
1	0.028	0.178	0.006	2.839	.09	6.786	9.930	0.28	1.80	0.07	0.91	28.60	68.34
2	0.005	0.846	0.049	3.896	0.317	3.367	8.482	0.06	9.97	0.58	3.75	45.94	39.70
3	0	0.330	0.018	4.374	0.416	8.773	13.912	0.00	2.37	0.13	2.99	31.44	63.06
4	0	0.165	0	1.454	0.118	7.643	9.381	0.00	1.76	0.00	0.12	15.50	82.41
5	0.005	0	0	0	0	3.991	3.996	0.11	0.00	0.00	0.00	0.00	99.89
6	0.129	0.385	0.001	3.294	0.227	17.111	21.147	0.61	1.82	0.002	1.07	15.57	81.05

**Table-4:** Sub-watershed wise morphometric parameters of study area

Sub-watershed No.	Area (Km <sup>2</sup> )	Perimeter (Km)	Maximum Elevation (m)	Minimum Elevation (m)	Total Relief (m)	No. of stream	Maximum Llngh of watershed (Km)	Total stream length (Km)
1	9.93	19.45	1020	740	280	57	7.01	35.68
2	8.48	15.16	1000	740	260	50	5.63	31.89
3	13.91	15.76	1020	740	280	42	4.99	60.45
4	9.27	14.92	956	700	256	106	4.89	43.47
5	3.94	9.22	860	700	160	79	3.69	19.55
6	21.31	32.09	880	680	200	185	8.20	92.29

**Table-5:** Stream analysis of sub-watersheds of study area

S.No.	Number of stream					Stream length (Km)					Cumulative stream length (Km) (sub-watershed wise)				
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	4 <sup>th</sup>	5 <sup>th</sup>
	1	42	12	2	1		21.51	6.00	2.22	5.96		21.51	27.50	29.72	35.68
2	38	9	2	1		20.21	5.35	5.00	1.33		20.21	25.56	30.56	31.89	31.89
3	12	23	6	1		36.48	12.21	8.32	3.44		36.48	48.69	57.01	60.45	60.45
4	85	16	4	1		26.28	8.73	5.41	3.06		26.28	35.01	40.41	43.47	43.47
5	63	13	2	1		12.00	4.56	0.95	2.05		12.00	16.56	17.51	19.55	19.55
6	148	29	7		1	57.00	16.43	9.07	9.79		57.00	73.43	82.50	82.50	92.29

**Table-6:** Sub-watershed wise computed morphometric parameter of study area

Sub-Water-shed No.	R <sub>h</sub>	R <sub>N</sub>	R <sub>b</sub>	D <sub>d</sub>	D <sub>f</sub>	R <sub>c</sub>	R <sub>f</sub>	C <sub>c</sub>	R <sub>e</sub>	S <sub>a</sub> (%)
1	0.04	1.01	3.83	3.83	5.74	0.33	0.20	1.74	0.51	20.04
2	0.05	0.98	3.57	3.57	5.89	0.46	0.27	1.47	0.58	11.09
3	0.06	1.22	3.45	3.45	3.02	0.70	0.56	1.19	0.84	14.62
4	0.05	1.20	4.44	4.44	11.43	0.52	0.39	1.38	0.70	24.64
5	0.04	0.79	4.45	4.45	20.04	0.58	0.29	1.31	0.61	21.06
6	0.02	0.87	4.62	4.62	8.68	0.26	0.32	1.96	0.64	18.61

**Table-7:** Prioritization of sub-watershed based on drainage density, percentage cultivatable area and average slope

Sub-water-shed No.	Cultivated area (%)	Drainage Density	Cate-gory	Average slope (Sa) (%)	Final Ranking
1	30.4 (L)	3.59(H)	D	20.04	4
2	55.91 (M)	3.75(H)	B	11.09	1
3	33.81 (L)	4.34(H)	D	14.62	6
4	17.46 (L)	4.68(H)	D	24.64	2
5	0 (L)	4.95(H)	D	21.06	3
6	17.27 (L)	4.33(H)	D	18.61	5

contour were used for further morphometric analysis. Watershed boundary and contour map is presented in Fig 3.

**Stream order:** After analysis of the drainage map (Fig.2), it was found that the Barchha nala watershed is of 5<sup>th</sup> order type. The planimetric arrangement of stream channel is studied and is

dominantly characterized by dendritic pattern of drainage and sub-dendritic patten at few places. GIS analysis shows that the number of 1st order streams are 388,2nd order streams are 102 3rd order streams are 23, 4th order streams are 5. Total stream length in the study area is 387.72. It is evident from Table 5 that the number of streams decreases with increasing stream order.

**Bifurcation ratio (R<sub>b</sub>):** Horton (1945) considered bifurcation ratio is an index of relief and dissection. Strahler (1957) demonstrated that R<sub>b</sub> shown only small variation for different region on different environment except where powerful geological control dominates. Lower R<sub>b</sub> values are the characteristics of structurally less disturbed watershed without any distortion in drainage pattern (Nag, 1998). Values of bifurcation ratio for six sub-watersheds are presented in Table 6. The sub-watershed 6 has maximum (R<sub>b</sub> = 4.62) while sub-watershed 3 has minimum (R<sub>b</sub> = 3.45). R<sub>b</sub> characteristically range between 3.0 and 5.0 for watershed where the influence of geological structure on the drainage network is negligible (Verstappen, 1983).

**Farm factor (R<sub>f</sub>):** Value of farm factor of six sub-watersheds are presented in Table 6. The sub-watershed 3 has maximum value (R<sub>f</sub> = 0.56) while sub-watershed 1 has minimum value R<sub>f</sub> (R<sub>f</sub> = 0.2). Low value of farm factor indicates elongated shape of sub-watersheds. The elongated basin with farm factor indicates that the sub-watersheds will have flatter peaks for longer duration. Flood flows of such elongated sub-watersheds are easier to manage then of the circular watershed (Nautiyal, 1994).

**Elongation ratio ( $R_e$ ):** Schumm (1956) proposed an elongation ratio to characterize basin shape. It is a ratio of diameter of a circle having the same area as the basin and maximum basin length. The value of elongation ratio generally ranges from 0.6 to 1.0 over a wide variety of climate and geologic type (Schumm, 1956). The value close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are generally associated with high relief and steep slope (Strahler, 1964, Zavoian, 1985, and Singh, 1979.). These values can be grouped into four categories namely 1. Circular (above 0.9) 2.oval (0.8 - 0.9) 3.less elongated (0.7 - 0.8) 4.elongated (below 0.7).

Values of elongation ratio of six sub-watersheds are presented in Table 6. The sub-watershed 3 has maximum value ( $R_e = 0.84$ ) while sub-watershed 1 has minimum value of  $R_e$  ( $R_e = 0.578$ ). These values shows the elongation of sub watersheds.

**Circulatory ratio ( $R_c$ ):** Introduced the circulatory ratio to quantify the basin shape. The ratio is equal to unity when the basin shape is perfect circle, decreasing to 0.785 in case of square shape and continuous to decrease to the extent which the basin becomes elongated (Zavoianu, 1985). The circulatory ratio is influenced by the length and the frequency of stream, geological structure, vegetation cover, climatic, relief and slope of the basin. Values of circulatory ratio of six sub-watersheds are presented in Table 6. The sub-watershed 3 has maximum value ( $R_c = 0.7$ ) while sub-watershed 6 has minimum value ( $R_c = 0.26$ ).

**Drainage density ( $D_d$ ):** Drainage density ( $D_d$ ) expresses the closeness of spacing of channels.  $D_d$  is the indicator of drainage efficiency of the watershed. Langbein (1947) recognized the significance of  $D_d$  as a factor determining the time of travel by water within the basin. The  $D_d$  was computed for all the sub watersheds and are given in Table 6. The lowest and highest values of  $D_d$  are found to be 3.59 and 4.96 for sub-watershed 1 and sub-watershed 5 respectively. High drainage density from the sub-watershed 5 revealed the well defined channel network and would produce more runoff and cause serious erosion problem in area.

Low  $D_d$  values for sub-watershed 1 and sub-watershed 2 indicates that it has the region underlain by highly permeable subsoil material with dense vegetated cover the sub-watersheds, with high values of  $D_d$  have well-developed network and torrential run-off resulting in intense flood. In addition, high  $D_d$  value for sub-watershed 3, 4, 5 and 6 indicates a situation conducive for quick disposal of run-off and characterized by a region of weak subsurface materials. Thus, the study of various factors which control drainage density such as lithology, compactness of the surface, vegetative covers, relief etc. for the study area shows that the results are consistent with  $D_d$  measurements made in similar terrain.

**Stream frequency ( $F_u$ ):** Values of stream frequency for six sub-watersheds are presented in Table 6. The sub-watershed 5 has maximum ( $F_u = 20.04$ ), while sub-watershed 3 has minimum  $F_u$  ( $F_u = 3.02$ ). The stream frequency relates to permeability, infiltration capability and relief of watershed. Values of stream frequency of sub-watershed area exhibits positive correlation with drainage density values of the area indicating the increase in drains population with respect to drainage density.

**Relief ratio ( $R_r$ ):** Relief ratio is a measure of potential energy available to move water and sediment down slope. It can be inferred from table 6, the relief ratio value ranges from 0.02 to 0.06 for sub-watershed 6 and 3 respectively. High value of relief is an indication of quick depletion of water which results in large peak and steep limb hydrograph and higher soil loss. It is noticed that high value of  $R_r$  indicates steep slope and high relief, while the lower value may indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with the lower degree of slope (GSI, 1981).

**Ruggedness Number ( $R_N$ ):** This number suggests steepness of slope implicitly if drainage density is increases and relief remains is constant so slope steepness will also increased. If relief increases and drainage density remains constant the slope will be steeper and longer for high relief and high drainage density the  $R_N$  attains high value. The values of  $R_N$  for six sub-watersheds are shown in Table 6. The sub-watershed 3 has maximum ruggedness number ( $R_N = 1.22$ ) while sub-watershed 5 has the minimum value of  $R_N$  ( $R_N = 0.79$ ). The sub-watershed 3 has overall high roughness, which indicates the structural complexity of the terrain in association with relief and drainage density. It also implies that the area is susceptible to more soil erosion.

**Relative relief ( $R_r$ ):** The value of relative relief for six sub-watersheds are shown in Table 6. Sub-watershed 6 has the highest relative relief ( $R_r = 0.01$ ), while sub-watershed 4 and 5 has minimum value of  $R_r$  ( $R_r = 0.02$ ). Sub watershed with high  $R_r$  are consider critical form erosion point of view and should be provided with suitable soil and water conservation measures.

**Average Slope of watershed ( $S_a$ ):** It is seen from computed value (table 6) the average slope of sub-watershed varies from 11.09 percent for sub-watershed 2 to 24.64 percent for sub-watershed 4.

**Compactness Coefficient ( $C_c$ ):** Values of compactness coefficient of six sub-watersheds are presented in Table 6. The sub-watershed 6 has maximum value ( $C_c = 1.96$ ) while sub-watershed 3 has minimum value of  $C_c$  ( $C_c = 1$ )

To facilitate phase wise implementation by State Government / NGOs, all the sub watersheds were prioritized into four categories based on percentage of cultivated area and drainage density of each sub watershed as suggested by Durbude *et al.* (2001) and Pandey *et al.* (2007). Further these categorized sub watersheds were ranked on the basis of average slope (Pandey *et al.*, 2007).

It may be seen from the Table 7 that the sub-watershed 2 have 55.91% of cultivated area and drainage density 3.75, therefore it has been categorized in group B. It is also evident from Table 7 that cultivated area for sub-watershed 1, 3, 4, 5 and 6 is 30.4%, 33.81%, 17.46%, 0% and 17.27% respectively, however drainage density for these sub watersheds is 3.59, 4.34, 4.68, 4.95, 4.33 respectively. Therefore these sub watersheds falls under 'D' category in general it has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly permeable sub soil material under dense vegetation cover. In contrast high drainage density is favored in regions of week or

impermeable subsurface materials and sparse vegetation (Nag and Chakraborty, 2003).

On the basis of drainage density and percent cultivated area of sub watersheds, it was found that none of the sub watersheds is falling under category A (severe erosion) and C (Moderate erosion). The sub-watershed 2 falls under high erosion i.e. B category and sub-watersheds 1, 3, 4, 5 and 6 are under low erosion category i.e. D. So average slope criterion is required because five sub-watersheds are coming in the same category therefore at this stage their priority ranking cannot be done. Hence, according to Pandey *et al.* (2007) these sub watersheds were prioritized and their ranking (Table 7) is given accordingly. The sub-watershed 2 is on top and sub-watershed 3 is at the last priority to start the soil conservation works. This ranking can act as a guiding tool in phase wise implementation of soil and water conservation program in Barchha Nala watershed. The final priority map is presented in Fig 4.

GIS has proved to be efficient tool in drainage delineation in the present study. It also demonstrated the role of remote sensing and GIS in combination for prioritizing the sub-watersheds in management and conservation of the natural resources for their sustainable development. Based on this study, it has been observed that SWS 2 is found to be the most critical (because of higher slope per cent). The watershed falling under high erosion (SWS 2) class need immediate attention for soil and water conservation treatment followed by sub watershed number (SWS4, SWS5, SWS1, SWS6, SWS3) should be given top priority for developing of soil and water in an integrated manner. Recommended soil conservation measures are conversion of check dams in II<sup>nd</sup> and III<sup>rd</sup> order streams. contour bund are also suggested to increase the ground water recharge as well as cultivation of paddy. These measures are expected to bring down the soil erosion rates as well as improvement in water resources regime in the study area.

#### Acknowledgement

I would like to extend sincere thanks to my advisor, Dr. S.K. Sharma, for the knowledge, guidance and freedom he provided throughout the course of this project.

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