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Prioritization of Sub-Watersheds for Conservation Measures in a Semi Arid Watershed Using Remote Sensing and GIS

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Abstract: Land and water resources development plans are generally adopted at watershed level. Delineation of watersheds and their prioritization within large river basins requires host of terrain parameters to be studied and analysed. Chopan watershed in Central India has been studied for sub-watershed delineation and prioritization based on drainage morphometry, land use/land cover and sediment yield index analysis using remote sensing and GIS techniques. The watershed was demarcated into five sub-watersheds on the basis of drainage flow directions, contour value, slope, elevation. Geocoded satellite data of 1989 and 2001 on 1:50 000 scale were visually interpreted to prepare land use/land cover and drainage maps which were later digitized using Arcview/ArcGIS. Linear and shape aspects of the sub-watersheds were computed and used for prioritization. The results show widespread variation in drainage characteristics, land cover changes and sediment yield rates across sub-watersheds. On the basis of morphometric, land use/land cover change and sediment yield index, sub-watersheds were grouped into low, medium and high priority. A correlation of results show that SW1 and SW5 are common sub-watersheds falling under high and low priority based on morphometric, land use change analysis and SYI. The priority list of sub-watersheds will be crucial for decision making and implementation of land and water resource conservation projects.

Keywords: Prioritization, Morphometry, Land use/Land cover, Sediment Yield Index, Conservation measures, Remote Sensing and GIS

INTRODUCTION

Land and water resources management is generally adopted at basin, sub-basin or watershed level. Nevertheless, land degradation is a global phenomenon which results due to improper and inexpedient utilization of watershed resources without any conservation work, which is more severe in developing countries like India (FAO 1985). Soil and water conservation are key issues in watershed management in India. Watershed development programmes aim to conserve land and water resources within a hydrologic unit, i.e. watershed. This calls to divide watershed into smaller units, i.e. sub-watershed by considering natural terrain conditions such as drainage network, contour values, relief and spot height. Micro level development planning is adopted at sub-watershed or micro-watershed units for land and water conservation measures. However, sub-watersheds vary in their area, terrain characteristics, climate, topography, land use etc. and hence require prioritization to select sub-watersheds requiring immediate intervention for conservation of land and water resources. Prioritization of watersheds has gained scientific importance in the recent past, with advanced techniques of remote sensing and Geographical Information System (GIS) being employed using various parameters such as drainage morphometry, universal soil loss equation (USLE), silt yield index (SYI), land use/land cover etc. (Chakraborty, 1991; Prasad et al. 1997; Biswas et al. 1999; Shrimali et al 2001; Khan et al. 2001; Allen et al. 2001; Reddy et al. 2004a; Suresh et al. 2004; Nooka Ratnam et al. 2005; Arun et al. 2005; Katiyar et al. 2006; Martin and Saha, 2007; Thakkar and Dhiman, 2007; Vittala et al. 2008; Javed et al. 2009). The present study makes an attempt to prioritize sub-watersheds based on morphometric parameters, land use/land cover analysis and sediment yield index, using remote sensing and GIS techniques. The prioritization results obtained using these parameters have been correlated to find out common watersheds falling in the same priority, which may be taken up for conservation measures.

The study area, the Chopan watershed, lies in Guna district of Madhya Pradesh State (Central India), covers an area of 133.38 km^2 lying between 77°15'10" to 77°23'20" E longitudes and 24°29'20" to 24°38'09" N latitudes. The maximum and minimum elevation in the watershed is 570 m and 420 m above mean sea level respectively. The watershed has gentle to moderate slope from south to north, defined by the course of Chopan main stream (Fig. 1) which flows almost south to north for a distance of about 16 km but abruptly changes its course to east-west (24º35' N and 77º20' E). The Chopan stream and its tributaries are perennial in nature and carry sediment load throughout the year. Black and lateritic soils are developed on steep, moderate and gently sloping lands, and the thickness of soil varies from 1 m to 4.5 m below ground level (Singh et al, 2002). The watershed is dominated by recent alluvium of Quaternary age; however some laterite deposits of Pleistocene age and few deeply weathered exposures of Deccan traps of upper Cretaceous to Eocene age are also exposed. The drainage pattern is dendritic to sub-dendritic, however parallel to sub-parallel pattern has also developed locally. The climate of the study area is generally dry except during the southwest monsoon (June-August) and the average annual rainfall is about 821 mm.

Chopan watershed is mainly rain-fed and hardly has any irrigation facilities, resulting in low agricultural output. Since agriculture is the mainstay of local people, it becomes difficult for them to sustain their livelihood. This calls for assessment of terrain characteristics including morphometry, land use/land cover and sediment yield index at sub-watershed level. Hence, the watershed was sub-divided into smaller units (sub-watersheds) to know the variations in terrain characteristics within the watershed. The sub-watersheds were then finally prioritized based on drainage morphometry, land use/land cover change analysis and sediment yield index rate. The results of the study may be useful for the local administrators and planners in implementing watershed development programmes at micro-level.

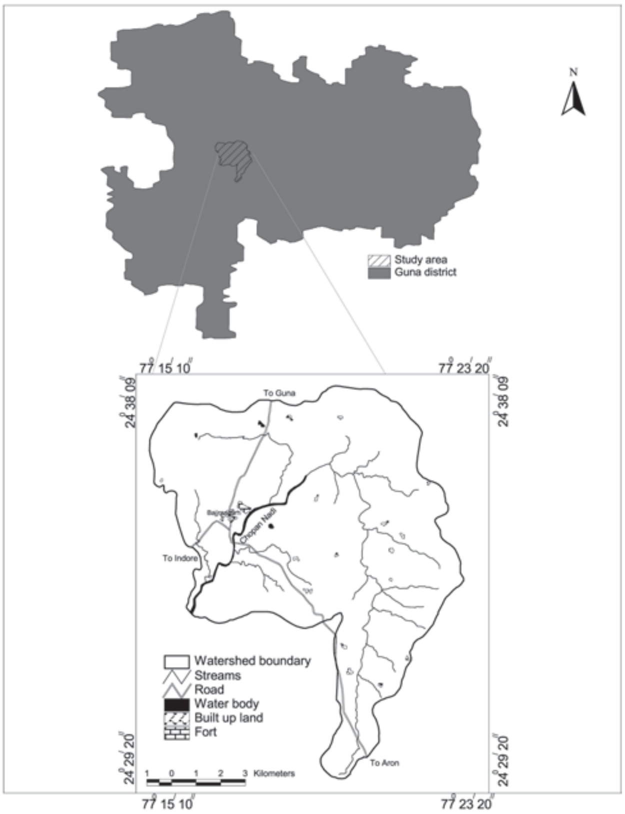

Fig.1. Location map of the Chopan watershed.

MATERIALS AND METHODS

Satellite data pertaining to geocoded false colour composites (FCCs) of IRS 1A LISS II (Path-Row: 28-50) of 8th February, 1989 and IRS 1D LISS III (Path-Row: 97-54) of 27th February, 2001 of band combinations green (2), red (3) and near infra-red (4) were utilized for interpretation to generate thematic maps. FCCs correspond to nearly the same month/season so as to minimize seasonal variations. The Survey of India (SOI) topographic maps (54 H/6 and 54 H/7) on 1:50 000 scale were used for obtaining basic information such as contour value, drainage, spot height, settlements, roads, railway lines etc. Shuttle radar topography mission (SRTM) data of 90 meter resolution was downloaded from the website http://www.srtm.csi.cgiar.org, and was subsequently used for generating slope map of the watershed. Various modules available in Arc-View 3.2a and ArcGIS 9.1 software were utilized for data input, data editing, spatial analysis and cartographic output of the thematic maps. Secondary information on the study area was collected and collated from published and unpublished government reports and data bases from district headquarter. Besides ground truth data collected during field surveys/verification was also taken as one of the inputs in the final analysis.

The Survey of India (SOI) topographic maps of 1982 were used for the preparation of base map. The drainage network was also extracted from SOI topographic maps and later updated using IRS LISS III FCC data (Fig. 2). On the basis of drainage flow directions, slope, contour values, elevation etc. the watershed and sub-watershed boundaries were demarcated on the toposheets and then transferred onto the drainage map, and sub-watersheds were designated as SW1 to SW5. The smallest and the largest sub-watershed covers 10.16 km^2 (SW4) and 41.62 km^2 (SW1) area respectively. The drainage map along with sub-watershed boundaries were digitized as a line coverage giving unique

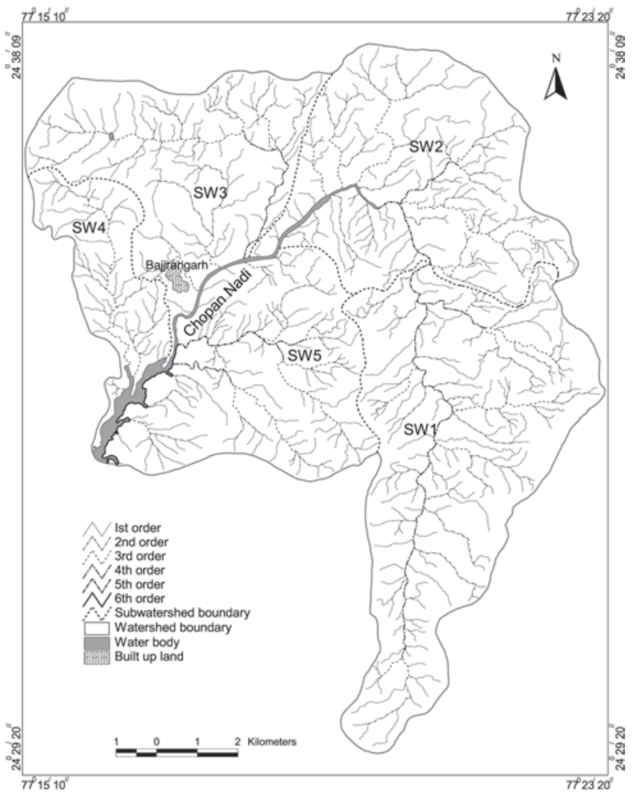

Fig.2. Drainage network of the Chopan watershed.

id for each order of stream. The digitized map was edited, cleaned and saved as line coverage in GIS.

Designation of stream order is the first step in drainage morphometry. Morphometric parameters for each sub-watershed were computed using standard methods and formulae (Horton, 1932; 1945; Smith, 1954; Strahler, 1964). Drainage layer in the GIS was used to compute various parameters such as stream order, bifurcation ratio, drainage density, stream frequency, drainage texture, length of over land flow, circularity ratio, elongation ratio, form factor, basin shape, compactness coefficient etc. The drainage parameters were grouped into linear and shape parameters and ranking for individual parameter was assigned on the basis of their relationship with erodibility (Nooka Ratnam et al. 2005). The sub-watersheds then were classified into low, moderate and high priority based on the final ranking or compound value.

Base map of the area was overlaid on satellite data and land use/land cover details of 1989 and 2001, were derived through standard visual image interpretation method based on photo-recognition elements such as tone, texture, size, shape, pattern, association and field knowledge. Land use/land cover categories such as cultivated land, uncultivated land, dense forest, open forest, open scrub, wasteland, water body, built up land and fort, were delineated and supplemented by limited ground truth verification. Land use/land cover maps derived through satellite data of 1989 and 2001 were imported to Arc-View GIS software, digitized as polygon entity and assigned a unique id for each land cover type in the polygon coverage. Polygon topology was built after editing and cleaning, the coverage then projected and transformed into UTM projection (zone 43N) using sub-modules available in Arc-View GIS. Land use/land cover change information can be obtained by either image to image comparison or map to map comparison (Forster 1985: Green et al .1994). Image to image comparison involves subtracting two images; however for the present study map to map comparison was used for land use/land cover change analysis. Area under each category of land use/land cover was calculated both in square kilometer as well as percentage of the total area for the years 1989 and 2001. The change (decrease or increase) in area under each category of land use/land cover from 1989 to 2001 was computed and used for assigning ranking of the sub-watersheds. The sub-watersheds were prioritized based on average ranking value as low, medium and high.

Sediment Yield Index (SYI) was computed to predict sub-watershed wise sediment yield rate to prioritize sub-watersheds on frequency distribution of data range. The empirical model proposed by Kumar (1985) was used to calculate sediment yield at sub-watershed level. Most of the parameters required for computing SYI were derived from drainage morphometry, land use/land cover map and slope map. Based on SYI value the sub-watersheds were prioritized into low, medium and high.

Slope map was prepared using shuttle radar topography mission (SRTM) data of 90 meter resolution. Employing the standard procedure given by Borough (1986) for calculating the slope in degrees, three classes were identified, comprising gentle (0 to 5°), moderate (5 to 10°) and steep (10 to 16°). Slope map was correlated with land use/land cover maps to ascertain the role of slope in land cover changes especially vegetation.

RESULTS AND DISCUSSION

Drainage Morphometry and Sub-watershed Priority

The designation of stream order is the first step in morphometric analysis of a drainage basin, based on hierarchic ranking of streams as proposed by Strahler (1964). Out of the five sub-watersheds, SW3 and SW4 are of fourth order whereas, SW1, SW2 and SW5 are of fifth order. The whole Chopan watershed is of sixth order. The sub-watersheds have low drainage density (D) values which indicates highly permeable sub-soil material and vegetative

Table 1 Results of morphometric analysis of the sub-watersheds

Basin Parameters	SW1	SW2	SW3	SW4	SW5	Whole Chopan watershed
Sub-watershed area (A) (km^2)	41.62	31.27	24.78	10.16	25.55	133.38
Bifurcation ratio (Rb) I/II	3.47	3.6	4	4.25	3.93	3.75
Bifurcation ratio (Rb) II/III	5.5	5	4.6	4	2.9	4.33
Bifurcation ratio (Rb) III/IV	4	3.5	5	3	3.33	3.67
Bifurcation ratio (Rb) IV/V	2	2	-	-	3	3
Bifurcation ratio (Rb) V/VI	-	-	-	-	-	3
Mean bifurcation ratio (Rbm)	3.74	3.52	4.53	3.75	3.29	3.55
Stream length ratio (RL) II/I	0.27	0.52	0.5	0.2	0.5	0.40
Stream length ratio (RL) III/II	0.44	0.73	0.75	1	0.5	0.64
Stream length ratio (RL) IV/III	0.75	0.25	0.5	1	1	0.52
Stream length ratio (RL) V/IV	0.33	0.4	1.5	0.5	0.4	1
Stream length ratio (RL) VI/V	0.5	2.5	-	-	2.5	3.67
Perimeter (P) (km)	34.67	26.25	26.61	19.86	22.13	60.04
Basin length (Lb) (km)	7.5	6.5	5.5	4.5	5.5	17.25
Basin width (Lw) (km)	5.0	6.0	5.5	2.0	4.5	13.41
Drainage density (D) (km/km^2)	2.99	2.62	2.68	2.65	2.68	2.77
Stream frequency (Fs)	4.99	5.46	4.88	6.59	6.14	5.43
Drainage texture (Rt)	5.99	6.51	4.55	3.37	7.09	12.07
Basin shape (Bs)	1.35	1.35	1.22	1.99	1.18	2.23
Form factor (Rf)	0.74	0.74	0.82	0.50	0.84	0.48
Circularity ratio (Rc)	0.44	0.57	0.43	0.32	0.65	0.46
Elongation ratio (Re)	0.28	0.33	0.34	0.31	0.38	0.17
Compactness coefficient (Cc)	0.46	0.47	0.60	1.10	0.48	0.24
Length of overland flow (Lo) (km)	0.67	0.76	0.75	0.75	0.75	0.72

cover giving enough scope for infiltration. The values of drainage texture indicate coarse drainage. The basin shape (Bs) values of sub-watersheds (Table 1) indicate, SW3 has weaker flood discharge periods, whereas SW1, SW2, SW4 and SW5 have sharply peaked flood discharge. High circularity ratio (Rc) indicate that these sub-watersheds are more or less circular (Fig. 2), and tend to concentrate water to the outlet simultaneously, so flood peak will be higher. Elongation ratio (Re) indicates that there is substantial structural/tectonic influence in the basin. The impact is visible in flood magnitude and timings. A longer basin will tend to have lower peak flood magnitude and longer flood duration, as compared to a circular basin of the same area (Reddy et al. 2004b).

The morphometric parameters i.e. bifurcation ratio (Rb), basin shape (Bs), compactness coefficient (Cc), drainage density (D), stream frequency (Fs), drainage texture (Rt), length of overland flow (Lo), form factor (Rf), circularity ratio (Rc), and elongation ratio (Re) are also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds (Biswas *et al* 1999). The linear parameters i.e. drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow possess a direct relationship with erodibility, higher the value, more the erodibility. Hence for prioritization of sub-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 i.e. elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor possess an inverse relationship with erodibility; lower the value, more the erodibility (Nooka Ratnam et al., 2005). 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. Therefore, ranking of the sub-watersheds has been carried out by assigning highest priority/ rank to the highest value for linear parameters and lowest value for shape parameters (Table 4). Subsequently, rank for individual linear and shape parameters were added up to arrive at compound value (Cp) for each of five sub-watersheds. Based on the highest and lowest Cp value the sub-watersheds were categorized into low, medium and high priority (Table 4). Hence, on the basis of morphometric parameters SW1 and SW4 fall under high priority, SW2 fall under medium priority, whereas SW3 and SW5 fall under low priority category (Fig. 3).

Land Use/Land Cover and Sub-watershed Priority

Land use /land cover mapping was carried out using IRS 1A LISS II geocoded FCC of 1989 and IRS 1D LISS III FCC of 2001. The visual interpretation of the IRS data led to the identification and delineation of land use/land cover categories such as cultivated land, uncultivated land, dense forest, open forest, open scrub, wasteland, water bodies, built

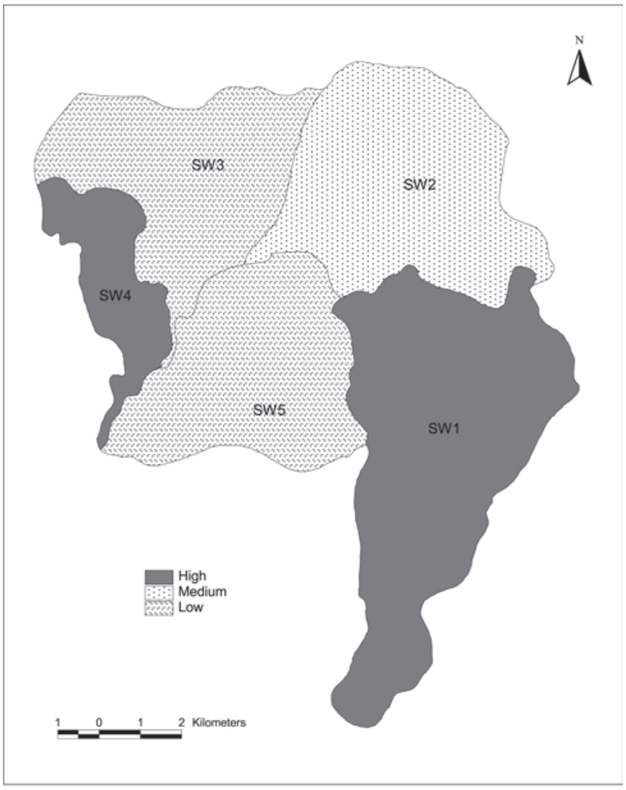

Fig.3. Priority of sub-watersheds based on morphometric analysis

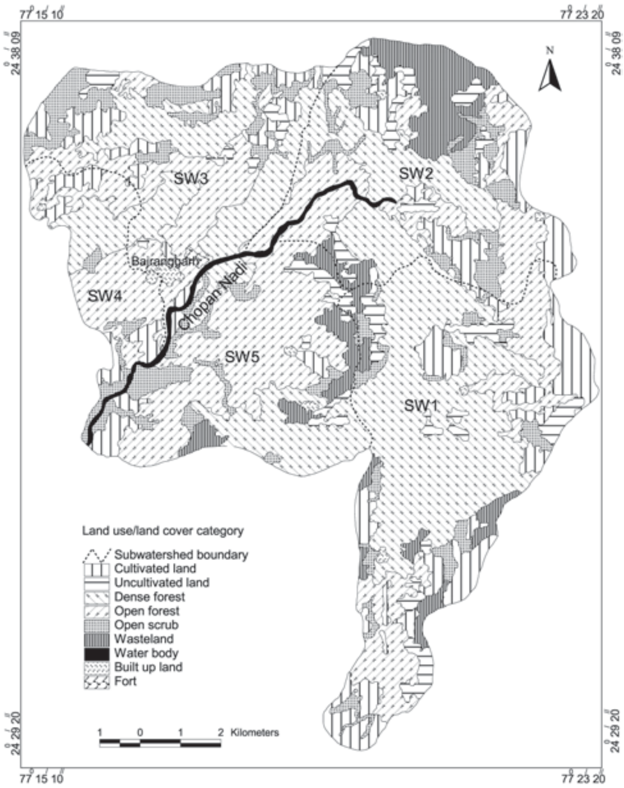

Fig.4. Land use/land use cover map based on IRS LISS II (1989)

up land and fort. Figures 4 and 5 present land use/ land cover maps of the study area derived from IRS data of 1989 and 2001, respectively. Area wise statistics of 1989 and 2001 land use data (Table 2) reveals that, dense forest, open forest was reduced. In 12 years period the watershed has lost green cover (Table 2) due to a combination of natural and anthropogenic factors. Dense forest was degraded to open forest at selective locations due to felling of trees for economic gains, however, at some places dense forest was slowly and gradually cleared and converted into cultivable land. In some of the cases where terrain doesn't permit cultivation, it was left as such and later became wasteland. The dense and open forests in SW4 are associated with steep slopes (10° to 15°), whereas in other four sub-watersheds they occur on moderate slopes. The other notable land use changes in the watershed include increase in area of uncultivated land, wasteland. The decrease in the vegetative cover i.e. cultivated land, forested land and open scrub and increase in uncultivated land and wasteland represent negative environmental changes and have been considered for prioritizing sub-watersheds. However, area occupied by water has increased by 1.01% primarily due to the construction of a dam and its reservoirs on the western periphery of the watershed. Table 2 presents the details of land use/land cover and their changes from 1989 to 2001.

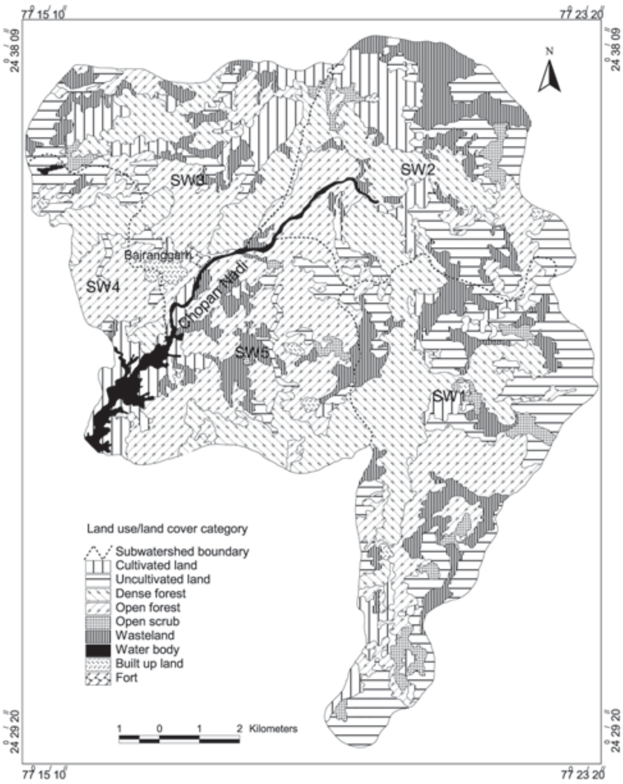

Fig.5. Land use/land use cover map based on IRS LISS III (2001)

Table 2. Results of the land use/land cover analysis of the sub-watersheds

Land use/land cover category		Land use/land cover 1989		Land use/land cover 2001		Land use change analysis 2001 - 1989	
		Area in (km^2)	Area in (%)	Area in (km^2)	Area in (%)	Difference in (km^2)	Difference in (%)
SW1	Cultivated land	8.09	19.44	4.16	9.99	-3.93	-9.44
	Uncultivated land	3.09	7.42	11.19	26.89	8.1	19.46
	Dense forest	18.0	43.25	9.31	22.37	-8.69	-20.88
	Open forest	6.81	16.36	8.15	19.58	1.34	3.22
	Open scrub	2.94	7.06	2.34	5.63	-0.6	-1.44
	Wasteland	2.58	6.21	6.31	15.16	3.73	8.96
	Built up land	0.11	0.26	0.16	0.38	0.05	0.12
	Total	**41.62**	**100.00**	**41.62**	**100.00**		
SW2	Cultivated land	4.12	13.18	4.12	13.18	No change	No change
	Uncultivated land	2.19	7.0	6.83	21.84	4.64	14.84
	Dense forest	7.75	24.78	6.93	22.16	-0.82	-2.62
	Open forest	8.03	25.68	5.99	19.16	-2.04	-6.52
	Open scrub	3.71	11.86	0.98	3.13	-2.73	-8.73
	Wasteland	5.01	16.02	5.96	19.06	0.95	3.04
	Water body	0.38	1.22	0.32	1.02	-0.06	-0.19
	Built up land	0.08	0.26	0.14	0.45	0.06	0.19
	Total	**31.27**	**100.00**	**31.27**	**100.00**		
SW3	Cultivated land	3.37	13.60	4.64	18.72	1.27	5.13
	Uncultivated land	1.88	7.59	2.86	11.54	0.98	3.95
	Dense forest	8.79	35.47	6.62	26.71	-2.17	-8.76
	Open forest	6.37	25.70	6.36	25.67	-0.01	-0.04
	Open scrub	3.75	15.13	0.34	1.37	-3.41	-13.76
	Wasteland	-	-	3.16	12.75	3.61	14.57
	Water body	0.18	0.73	0.20	0.81	0.02	0.08
	Built up land	0.28	1.13	0.44	1.78	0.16	0.65
	Fort	0.16	0.65	0.16	0.65	No change	No change
	Total	**24.78**	**100.00**	**24.78**	**100.00**		
SW4	Cultivated land	1.68	16.54	1.03	10.14	-0.65	-6.40
	Uncultivated land	-	-	1.76	17.32	1.76	17.32
	Dense forest	2.02	19.88	2.15	21.16	0.13	1.28
	Open forest	4.81	47.34	4.13	40.65	-0.68	-6.69
	Open scrub	1.42	13.98	0.02	0.20	-1.4	-13.78
	Wasteland	-	-	0.20	1.96	0.20	1.97
	Water body	0.13	1.28	0.72	7.09	0.59	5.81
	Built up land	0.10	0.98	0.15	1.48	0.05	0.49
	Total	**10.16**	**100.00**	**10.16**	**100.00**		
SW5	Cultivated land	1.03	4.03	2.4	9.39	1.37	5.36
	Uncultivated land	1.08	4.23	1.64	6.42	0.56	2.19
	Dense forest	5.59	21.88	4.20	16.44	-1.39	-5.44
	Open forest	12.03	47.08	12.32	48.22	0.29	1.14
	Open scrub	3.04	11.90	0.12	0.47	-2.92	-11.43
	Wasteland	2.32	9.08	3.40	13.31	1.08	4.23
	Water body	0.33	1.29	1.13	4.42	0.8	3.13
	Built up land	0.13	0.51	0.34	1.33	0.21	0.82
	Total	**25.55**	**100.00**	**25.55**	**100.00**		
Whole Chopan watershed	Cultivated land	18.29	13.71	16.35	12.26	-1.94	-1.45
	Uncultivated land	8.24	6.18	24.28	18.20	16.04	12.03
	Dense forest	42.15	31.60	29.21	21.90	-15.94	-11.95
	Open forest	38.05	28.53	36.95	27.70	-1.10	-0.82
	Open scrub	14.86	11.14	3.80	2.85	-11.06	-8.29
	Wasteland	9.91	7.43	19.03	14.27	9.12	6.84
	Water body	1.02	0.76	2.37	1.78	1.35	1.01
	Built up land	0.70	0.52	1.23	0.92	0.53	0.40
	Fort	0.16	0.12	0.16	0.12	No change	No change
	Total	**133.38**	**100.00**	**133.38**	**100.00**		

Note: Negative values here do not necessarily show negative changes as referred in the text

Common land use/land cover categories i.e. cultivated, uncultivated, dense forest, open forest, open scrub, wasteland and water body were considered for prioritization of sub-watersheds based on their change from 1989 to 2001. A comparative analysis across the sub-watersheds indicate a general decrease in cultivated land area and increase in uncultivated land. Sub-watersheds also reported a general decline in natural vegetation i.e. dense forest, open forest and open scrubs across all sub-watersheds. A close analysis of the land use/land cover change matrix shows that sub-watershed SW2 represents mainly negative change; however, rest of the four sub-watersheds show some positive change as well. The positive change is reflected by the increase in aerial extent of cultivated land, open forest and open scrub. The basic premise adopted for assigning positive and negative change is as under:

Positive change = increase in cultivated land/dense forest/ open forest/ open scrub/water body
and/or
decrease in wasteland/uncultivated land

Negative change =increase in wasteland/uncultivated land
and/or
decrease in cultivated land/dense forest/ open forest/ open scrub/water body

The change in area under each category of land use was converted in percentage and a rank was assigned on the basis of area under each land use category (Table 4). Higher the value of land cover category showing positive change, lower the rank assigned to it. Whereas, higher the value of land cover category showing negative change, higher the rank assigned to it (Javed et al. 2009). Based on the above premise, rankings of individual land use/land cover category for each sub-watershed was assigned. The rankings were then averaged together to arrive at compound value (Cp) as given in Table 4. The difference in the lowest and highest compound value was divided into three equal intervals and sub-watersheds were categorized into low, medium and high priority. On the basis of land use/land cover analysis SW1 and SW3 fall under high priority, SW2 under medium priority, whereas SW4 and SW5 under low priority category (Fig. 6).

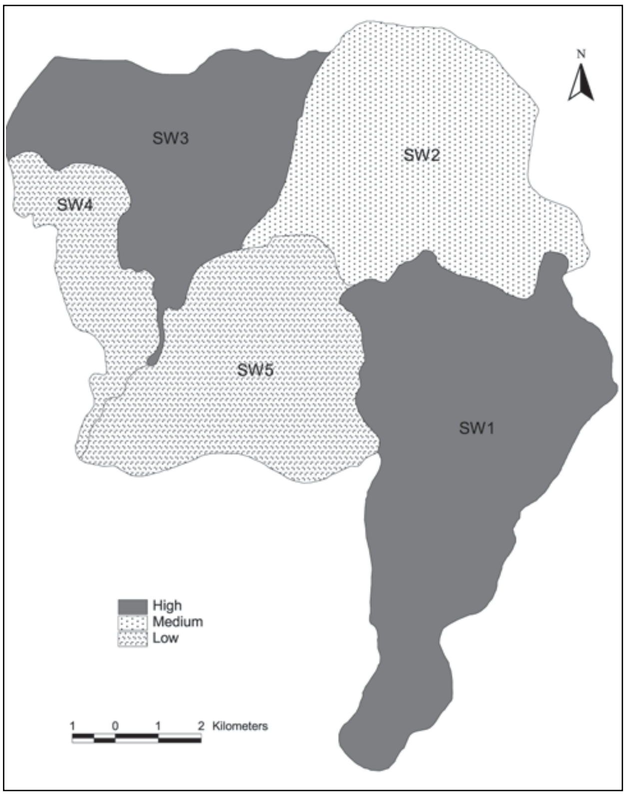

Fig.6. Priority of sub-watersheds based on land use/land cover analysis

Sediment Yield Index and Sub-watershed Priority

A number of sediment yield models, both empirical and conceptual are in practice to assess soil and water related management problems. Soil and water conservation in large river basins is difficult, expensive and unmanageable hence, requires a selective approach to demarcate smaller hydrological units, i.e. watershed/sub-watershed for more efficient and targeted resource management programmes. The identification and selection of sub-watersheds which require soil and water conservation measures on preferential

Table 3. Estimation of sediment yield using sediment yield model

Sub watersheds	Area (A) (km^2)	Drainage density (D) (km/km^2)	Slope (S) (degree)	Precipitation (P) (cm)	Vegetative factor (F) (km^2)	Sediment yield rate (ha.m/100 km^2/year)
SW1	41.62	2.99	2.50	82.14	6.20	9.93
SW2	31.27	2.62	3.00	82.14	4.14	2.42
SW3	24.78	2.68	8.50	82.14	2.95	0.88
SW4	10.16	2.65	7.50	82.14	1.50	0.05
SW5	25.55	2.68	4.00	82.14	3.42	1.21

basis is particularly important in semi arid basins subjected to short duration of heavy rainfall. To prioritize sub-watersheds for conservation planning maximum sediment yield could be one of the criteria (Adinarayana and Rama Krishna, 1995). The sediment yield index (SYI) model developed by All India Soil and Land Use Survey (1991) is another criteria for priority delineation in river valley projects and flood prone rivers. Another empirical model employed under Indian conditions by Kumar (1985) and Rao & Mahabaleswara (1990) is as follows:

$$Vs = 1.067 * 10^{-6} P^{1.384} A^{1.292} D^{0.392} S^{0.129} F^{2.51} \quad (1)$$

Vs = sediment yield (Nm^3/ year), P = annual precipitation, (cm), A = watershed area (km^2), D = drainage density, (km/km^2), S = watershed average slope (degrees), F = vegetative cover factor (km^2)

Where, F can be determined as:

$$F = \frac{(0.21F1+0.2F2+0.6F3+0.8F4+F5+F6+F7+F8+F9)}{9} \quad (2)$$

F1: cultivated land, F2: uncultivated land, F3: dense forest, F4: open forest, F5: open scrub, F6: wasteland, F7: water body, F8: built up land, F9: fort.

Parameters like A, D, S and F in equation (1) are essential mapping units out of which, A and D can be conventionally derived from stream drainage network map, 'S' from slope map and 'F' from land use/land cover map. Parameter 'F', however, needs to be redefined based on land use/land cover information that can be extracted from satellite images. Soil loss due to erosion is a continuous process that brings down the soil productivity. Sediment yield index (SYI) is helpful to assess the rate of soil loss at a watershed level and can be derived through equations (1) and (2). The sediment yield of each sub-watershed was computed using the above formulae by putting values of various parameters derived from thematic maps. The results of the SYI analysis of sub-watersheds are presented in Table 3. It is found that SW1 has maximum sediment yield rate, whereas, SW4 has lowest sediment yield rate. Sediment yield index was computed to predict sub-watershed wise sediment yield rate to prioritize sub-watersheds on frequency distribution of data range. The highest value of sediment yield rate in a particular sub-watershed, was assigned highest priority/rank and the lower value was given low priority/rank and so on. It was based on the general assumption that higher the sediment yield rate, higher the priority and vice versa. The highest and lowest sediment yield rates in the sub-watersheds are given in Table 4. The sediment yield rate was classified into three equal intervals as low, medium and high priority.

Table 4. Priorities of sub-watersheds and their ranks based on

Sub-watersheds [area]	Morphometric analysis												Land use category and change in area [percent]									Sediment yield index rate [ha.m/100km²/year]	
	Linear parameters				Shape parameters																		
	D	Fs	Lo	Rbm	Rt	Rc	Re	Rf	Bs	Cc	Cp value	Priority	WL [%]	UCL [%]	CL [%]	OF [%]	DF [%]	OS [%]	WB [%]	Cp value	Priority	Priority value	Range
SW1 [41.62]	2.99 [1]	4.99 [4]	0.67 [3]	3.74 [3]	5.99 [3]	0.44 [3]	0.28 [1]	0.74 [2]	1.35 [3]	0.46 [1]	8.96 2.4	19.46 *High*	9.44 [2]	**3.22** [1]	20.88 [1]	1.44 ***[5]***	- [1]	[4]	2.3	9.93	*High*	[1]	*High*
SW2 [31.27]	2.62 [4]	5.46 [3]	0.76 [1]	3.52 [4]	6.51 [2]	0.57 [4]	0.33 [3]	0.74 [2]	1.35 [3]	0.47 [2]	3.04 2.8	14.84 Medium	– [4]	6.25 [3]	2.62 [2]	8.37 [4]	0.19 [3]	2.42 [1]	2.8		Medium	[2]	Low
SW3 [24.78]	2.68 [2]	4.88 [5]	0.75 [2]	4.53 [1]	4.55 [4]	0.43 [2]	0.34 [4]	0.82 [3]	1.22 [2]	0.60 [4]	14.57 2.9	3.95 Low	**5.13** [1]	0.04 [4]	8.76 ***[3]***	13.76 [3]	0.08 [2]	0.88 [1]	[2]	2.3	High	[4]	Low
SW4 [10.16]	2.65 [3]	6.56 [1]	0.75 [2]	3.75 [2]	3.37 [5]	0.32 [1]	0.31 [2]	0.50 [1]	1.99 [4]	1.10 [5]	1.97 2.6	17.32 High	6.4 [5]	6.69 [2]	**1.28** [2]	**13.78** [1]	**5.81** ***[5]***	0.05 ***[5]***	***[4]***	3.4	Low	[5]	Low
SW5 [25.55]	2.68 [2]	6.14 [2]	0.75 [2]	3.29 [5]	7.09 [1]	0.65 [5]	0.38 [5]	0.84 [4]	1.18 [1]	0.48 [3]	4.23 3.0	2.19 *Low*	**5.36** [3]	**1.14** [5]	5.44 ***[4]***	11.43 ***[4]***	**3.13** [3]	1.21 [2]	***[3]***	3.4	*Low*	[3]	*Low*

Note: Bold values indicate positive change i.e. reclamation of wasteland or increase in open forest/dense forest/open scrub/water body
Values in parenthesis indicate priority/rank; Where: WL = wasteland; UCL = uncultivated land; CL = cultivated land; OF = Openforest; DF = dense forest; OS = open scrub and WB = waterbody

Table 5: Integration of Morphometric, Land use/Land cover and Sediment Yield Index, showing prioritization of sub-watersheds

Priority	Subwatersheds categorized from morphometric analysis (a)	Subwatersheds categorized from land use/land cover analysis (b)	Subwatersheds categorized from sediment yield index analysis (c)	Sub-watersheds categorized through integration of morphometric & land use/land cover analysis (a+b)	Sub-watersheds categorized through integration of morphometric & SYI analysis (a+c)	Sub-watersheds categorized through integration of land use/land cover & SYI analysis (b+c)	Sub-watersheds categorized through integration of morphometric, land use/land cover & SYI analysis (a+b+c)
High	SW1 & SW4	SW1 & SW3	SW1	SW1	SW1	SW1	SW1
Medium	SW2	SW2	-	SW2	-	-	-
Low	SW3 & SW5	SW4 & SW5	SW2, SW3, SW4 & SW5	SW5	SW3 & SW5	SW4 & SW5	SW5

On the basis of sediment yield rate, SW1 falls under high priority, whereas SW2, SW3, SW4 and SW5 fall in low priority category (Fig. 7).

Common Sub-watersheds

The prioritization of sub-watersheds on morphometric, land use/land cover change and sediment yield index basis were correlated to find out common sub-watersheds falling under each priority. The correlation shows that SW1 & SW5 being the common sub-watersheds falling under high and low priority based on all the three parameters mentioned above (Table 5). However, the common sub-watersheds on morphometric and land use/land cover analysis include SW1 under high priority, SW2 under medium priority and SW5 under low priority (Fig. 8a). Based on land use/land cover and SYI analysis, there are three common sub-watersheds, i.e. SW1 under high priority and SW4 & SW5 under low priority (Fig. 8b). whereas, three sub-watershed show common priority based on morphometric and SYI analysis i.e. SW1 under high priority, whereas SW3 & SW5 under low priority (Fig. 8c). SW2, SW3 and SW4 show little correlation and they differ in their priority on morphometric, land use/land cover change and sediment yield index analysis (Table 5).

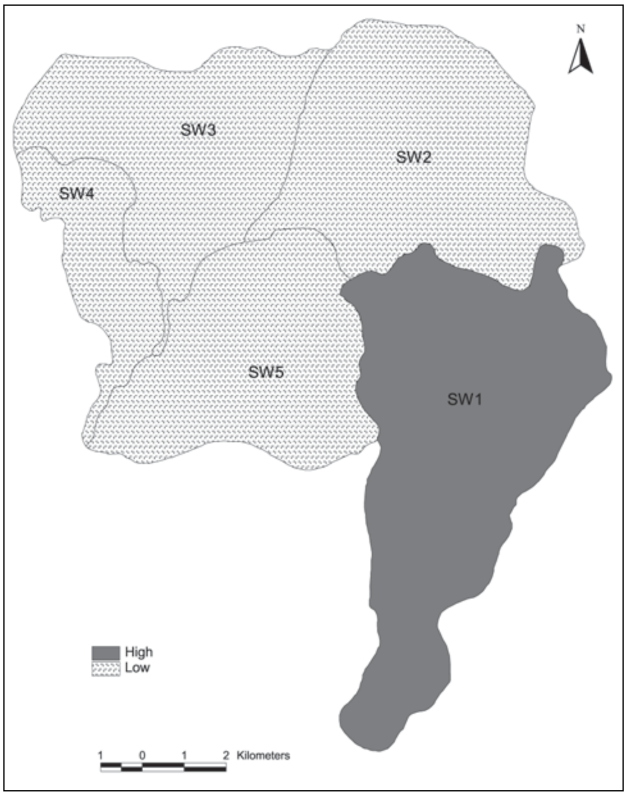

Fig.7. Priority of sub-watersheds based on sediment yield index analysis

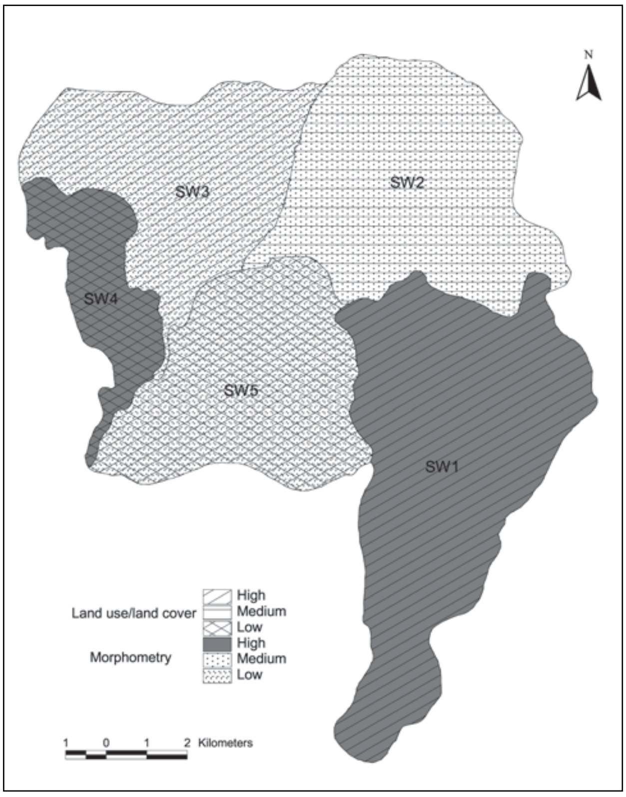

Fig.8(a). Priority of sub-watersheds based on integration of morphometric and land use/land cover analysis

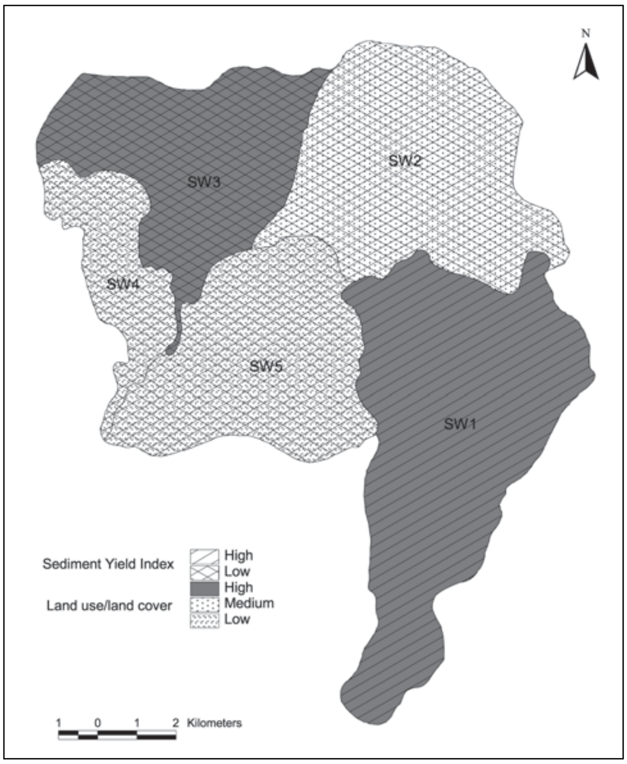

Fig.8b. Priority of sub-watersheds based on integration of land use/land cover and sediment yield index analysis

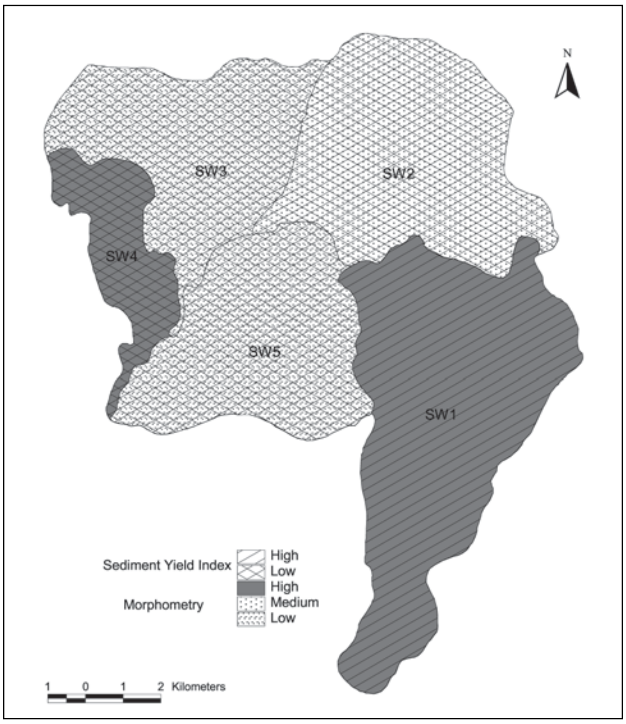

Fig.8c. Priority of sub-watersheds based on integration of morphometric and sediment yield index analysis

CONCLUSION

The present study demonstrates the utility of remote sensing and GIS techniques in prioritization of sub-watersheds. Multiple thematic mapping and data analysis, adopted here has the advantage of analysing terrain parameters of watershed derived from satellite data. The study also demonstrates that computation of morphometric parameters at sub-watershed level in GIS is very useful in prioritization. The study has provided new data and insights on land use/cover changes from 1989 to 2001 at watershed level. Sediment yield model adopted here may be immensely useful for conservation planning purposes on watershed basis. However, a more global approach would be adopted to build sufficient data base using the methodology enunciated here to arrive at optimum threshold for prioritization of watersheds. Correlation of result show that SW1 & SW5 are the only common sub-watersheds based on morphometric, land use/land cover change and SYI analysis and lies under high and low priority. However, the other three sub-watersheds differ in their priority on the basis of morphometric, land use/land cover change and SYI analysis (Fig. 9). This study has scientifically proved that the priority list gives the ‘potential’ of the sub-watersheds towards land & water degradation, based on morphometric,

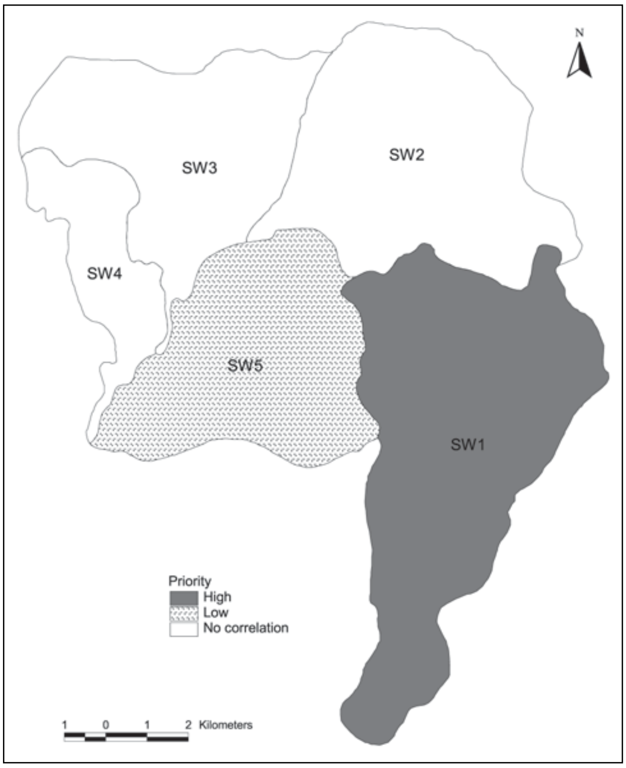

Fig.9. Priority of sub-watersheds based on correlation of morphometric, land use/land cover and sediment yield index analysis

land use/land cover and sediment yield index analysis for immediate conservation measures.

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