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RESEARCH ARTICLE

# Prioritization of Sub-watersheds based on Morphometric and Land Use Analysis using Remote Sensing and GIS Techniques

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**Abstract** Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management. Morphometric analysis has been commonly applied to prioritization of watersheds. The present study makes an attempt to prioritize sub-watersheds based on morphometric and land use characteristics using remote sensing and GIS techniques in Kanera watershed of Guna district, Madhya Pradesh. Various morphometric parameters, namely linear and shape have been determined for each sub-watershed and assigned ranks on the basis of value/relationship so as to arrive at a computed value for a final ranking of the sub-watersheds. Land use/land cover change analysis of the sub-watersheds has been carried out using multi-temporal data of IRS LISS II of 1989 and IRS LISS III of 2001. The study demonstrates the significant land use changes especially in cultivated lands, open scrub, open forest, water bodies and wastelands from 1989 to 2001. Based on morphometric and land use/land cover analysis, the sub-watersheds have been classified into three categories as high, medium and low in terms of priority for conservation and management of natural resources. Out of the seven sub-watersheds, two sub-watersheds viz., SW1 and SW6 qualify for high priority, whereas SW7 has been categorised as medium priority based on the integration of morphometric and land use change analysis.

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## Introduction

A watershed is an area from which runoff resulting from precipitation flows past a single point into large streams, rivers, lakes or oceans. Thus, 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 naturally occurring hydrologic unit characterized by a set of similar topographic, climatic and physical conditions. Various terms have been used in order of their rank/hierarchy, i.e., sub-watershed, watershed, sub-basin and basin. The Watershed Atlas prepared by AIS LUS (1990), describes the mean area of watershed as being less than 500 $km^2$ (±50%). The National Remote Sensing Agency (1995) has further classified the watershed into sub-watershed (30–50 $km^2$), mini-watershed (10–30 $km^2$) and micro-watershed (5–10 $km^2$) (Chopra *et al.*, 2005).

Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). Morphometric analysis requires measurement of linear features, areal aspects, gradient of channel network and contributing ground slopes of the drainage basin (Nautiyal, 1994). The remote sensing technique is a convenient method for morphometric analysis as the satellite images provide a synoptic view of a large area and is very useful in the analysis of drainage basin morphometry. Pioneering work on the drainage basin morphometry has been carried out by Horton (1932, 1945), Miller (1953), Smith (1950), Strahler (1964) and others. In India, some of the recent studies on morphometric analysis using remote sensing technique were carried out by Nautiyal (1994), Srivastava (1997), Nag (1998), Srinivasa *et al.* (2004). More recently, Chopra *et al.* (2005) have carried out morphometric analysis of sub-watersheds in Gurdaspur district, Punjab. A study on characterization and management of watersheds in Ganeshapur watershed of Nagpur district was carried out by Solanke *et al.* (2005).

Prioritization of sub-watersheds based on morphometric analysis of drainage basins using remote sensing and GIS techniques, was attempted by Biswas *et al.* (1999). Nooka Ratnam *et al.* (2005) carried out check dam positioning by prioritization of micro-watersheds using Silt Yield Index (SYI) model and morphometric analysis using remote sensing and GIS in Midnapur district of West Bengal. Arun *et al.* (2005) attempted a rule-based physiographic characterization of a drought-prone watershed applying remote sensing and GIS techniques in Gandeshwari watershed in Bankura district of West Bengal. In the present study, morphometric and land use/land cover analysis has been carried out in Kanera watershed, of Guna district, Madhya Pradesh using remote sensing and GIS techniques.

## Study area

Kanera watershed is located in Guna district of Madhya Pradesh and covers an area of 69.01 $km^2$ and is bound between 77° 22' to 77° 29' E and 24° 40' to 24° 37' N. The maximum and minimum elevations encountered in the watershed are 532m and 472m above MSL, respectively. The main Kanera stream flows almost west to east and joins the Sind river at Kothia (24°30' 45" N and 77°29' E). A small check dam was built in the western part of the watershed, which primarily serves as a source of irrigation. Apart from this structure there is no other source of irrigation, and agriculture is mainly rain-fed. The area is represented by shallow to deep black soils, developed on gentle to moderately gentle sloping lands. The clay content varies from 35–50%, showing clayey to clayey loamy texture, sometimes with gravely, stony or rocky phase. Alkalinity ranges from slight to strong. Soils of the area respond to management and support a variety of crops under rain-fed and irrigated conditions. Geologically the area is represented by recent alluvium. However, a few deeply weathered exposures of Deccan traps are reported in sub-watersheds SW2, SW3 and SW4. The drainage in the area is dendritic to sub-dendritic.

Locally, parallel to sub-parallel pattern has also developed. The climate of the study area is warm and semi-arid with an average annual rainfall of about 600 mm. The maximum temperature rises up to 42°C in June, while minimum temperature can be as low as 17.5°C in January. Kanera watershed represents a typical rain fed watershed, with a gentle and uniform slope from west to east, defined by the course of Kanera trunk stream (Fig. 1).

### Data used

Geocoded False Colour Composites (FCCs) of IRS 1A LISS II (Path-Row: 28-50) of 8 February, 1989 and IRS 1C LISS III (Path-Row: 97-54) of 27 February, 2001 of band combinations green, red and near IR were used for deriving information on various parameters of watershed. The data correspond to nearly the same period/season in order to minimize seasonal variations. The Survey of India (SOI) topographic sheet No. 54 H/6 (Scale 1:50,000) of 1982-83 was used for preparation of the base map. Besides, secondary information on the study area was collected from published and unpublished government sources and ground truth data was also taken as one of the inputs in the final analysis.

### Methodology

The drainage was initially derived from SOI toposheet and later updated using IRS-1C LISS III FCC. The sub-watershed boundaries were demarcated

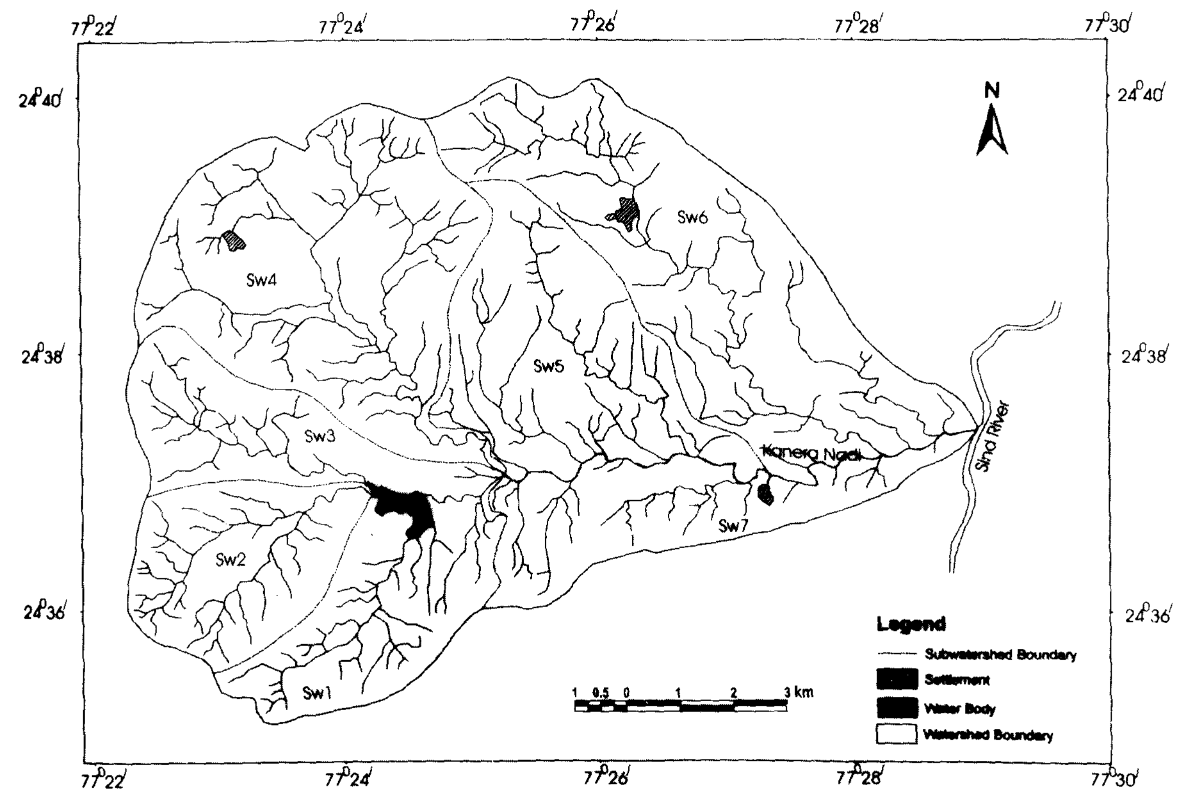


**Fig. 1** Drainage map of the Kanera watershed.

on the basis of contour value, slope, relief, and drainage flow directions and the Kanera watershed was divided into seven sub-watersheds designated as SW1 to SW7 (Fig. 1). The smallest (SW3) and the largest (SW6) sub-watersheds measure 5.91 and 16.59 $km^2$, respectively. The morphometric parameters such as stream length, bifurcation ratio, drainage density, stream frequency, drainage texture, relief ratio, basin shape, form factor, circularity ratio, elongation ratio, length of overland flow and constant of channel maintenance were computed using standard methods and formulae (Horton, 1932, 1945; Miller, 1953; Schumn, 1956; Strahler, 1957, 1964; Chopra *et al.*, 2005; Nooka Ratnam *et al.*, 2005; Solanke *et al.*, 2005).

Standard visual image interpretation method based on photographic and geotechnical elements such as tone, texture, size, shape, association and field knowledge was followed to delineate various land use/land cover categories using the IRS LISS II data of 1989 and IRS LISS III data of 2001. Limited ground truth verification was carried out before the finalization of maps. Land use/land cover categories such as cultivated land, uncultivated land, open forest, open scrub, wasteland, water body, rocky area, built up land etc., were delineated on the basis of image interpretation. The land use/land cover details of 1989 and 2001 were imported to ARC GIS software for spatial analysis. Each land use/land cover category was assigned a unique id in the polygon coverage. The polygon coverage was then projected and transformed using sub-modules available in the Arc GIS 9.0 version. Polygon topology was built after editing and cleaning, and the area under each category of land use/land cover was calculated both, $km^2$ as well as percentage of the total area for 1989 and 2001. Land use/land cover change information can be obtained by either image to image comparison or map to map comparison (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.

## Results and discussion

### *Morphometric analysis*

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 (1964). In the study area SW1, SW3, SW5 and SW6 are of third order where as, SW2, SW4 and SW7 are of fourth order. The whole Kanera watershed is of fifth order.

#### *Bifurcation ratio (Rb)*

Horton (1945) considered Rb as an index of reliefs and dissections. Strahler (1957) 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 (Nag, 1998). The mean bifurcation ratio values (Table 1) of Kanera watershed indicate less structural control on the drainage development. However, irregular Rb values do not subscribe to Horton's law of streams numbers which probably represent local variations in the drainage development, except for SW3 and SW6 in which the drainage development is structural controlled, primarily due to the presence of joints/fractures observed in the exposed rocks facilitating first order channels.

#### *Relief ratio (Rh)*

Schumn (1956) defined relief ratio as the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line. It measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on the slopes of the basin. In the present study the Rh values of the sub-watersheds vary from 0.008 to 0.013 (Table 1) suggesting gentle slope of the Kanera main watershed.

**Table 1** Results of the morphometric analysis of the sub-watersheds

| Basin parameters | SW1 | SW2 | SW3 | SW4 | SW5 | SW6 | SW7 | Whole Kanera watershed |
|---|---|---|---|---|---|---|---|---|
| Basin area (A) ($km^2$) | 7.10 | 6.38 | 5.91 | 16.22 | 10.17 | 16.59 | 6.64 | 69.01 |
| Bifurcation ratio (Rb) I/II | 4.00 | 4.57 | 2.55 | 3.44 | 4.38 | 6.71 | 5.40 | 4.18 |
| Bifurcation ratio (Rb) II/III | 4.00 | 3.50 | 9.00 | 2.67 | 4.00 | 3.50 | 2.50 | 3.53 |
| Bifurcation ratio (Rb) III/IV | - | 2.00 | - | 6.00 | - | - | 2.00 | 5.67 |
| Bifurcation ratio (Rb) IV/V | - | - | - | - | - | - | - | 3.00 |
| Mean bifurcation ratio (Rbm) | 4.00 | 3.36 | 5.77 | 4.04 | 4.19 | 5.11 | 3.30 | 4.09 |
| Stream length ratio (RL) II/I | 0.35 | 0.24 | 0.82 | 0.33 | 0.44 | 0.31 | 0.52 | 0.41 |
| Stream length ratio (RL) III/II | 0.66 | 1.50 | 1.11 | 0.80 | 0.32 | 1.27 | 0.55 | 0.76 |
| Stream length ratio (RL) IV/III | - | 0.33 | - | 1.25 | - | - | 1.33 | 0.30 |
| Stream length ratio (RL) V/IV | - | - | - | - | - | - | - | 0.73 |
| Perimeter (P) (km) | 12.50 | 9.50 | 12.50 | 17.50 | 15.00 | 20.00 | 15.50 | 33.50 |
| Basin length (Lb) (km) | 4.50 | 3.00 | 5.00 | 5.50 | 5.00 | 7.50 | 5.50 | 11.00 |
| Basin width (Lw) (km) | 2.00 | 2.50 | 2.00 | 4.90 | 3.00 | 4.00 | 2.50 | 8.50 |
| Drainage density (D) (km/$km^2$) | 2.88 | 3.37 | 2.53 | 2.71 | 2.80 | 2.50 | 3.46 | 2.92 |
| Stream frequency (Fs) | 5.91 | 6.59 | 5.58 | 4.80 | 4.42 | 3.37 | 5.27 | 4.81 |
| Relief ratio (Rh) | 0.013 | 0.02 | 0.012 | 0.011 | 0.012 | 0.008 | 0.011 | 0.005 |
| Drainage texture (Rt) | 9.33 | 14.00 | 6.60 | 15.60 | 9.00 | 7.47 | 6.36 | 9.91 |
| Infiltration number (If) | 17.02 | 22.22 | 14.11 | 13.00 | 12.37 | 8.42 | 18.23 | 14.04 |
| Basin shape (Bs) | 2.85 | 1.41 | 4.23 | 1.86 | 2.45 | 3.39 | 4.55 | 1.75 |
| Form factor (Rf) | 0.35 | 0.71 | 0.23 | 0.53 | 0.41 | 0.30 | 0.22 | 0.57 |
| Circularity ratio (Rc) | 0.57 | 0.88 | 0.47 | 0.66 | 0.57 | 0.52 | 0.35 | 0.77 |
| Elongation ratio (Re) | 0.66 | 0.95 | 0.55 | 0.82 | 0.72 | 0.61 | 0.53 | 0.85 |
| Compactness coefficient (Cc) | 0.99 | 0.84 | 1.19 | 0.60 | 0.41 | 0.68 | 1.31 | 0.27 |
| Length of overland flow (Lo) (km) | 0.69 | 0.15 | 0.79 | 0.73 | 0.17 | 0.80 | 0.57 | 0.68 |
| Constant of channel maintenance (C) (per sq ft) | 34.70 | 29.70 | 39.50 | 36.90 | 35.70 | 40.00 | 28.90 | 34.20 |

*Drainage density (D)*

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. It is affected by factors such as resistance to weathering, permeability of rock formation, climate, vegetation etc. In general, low values of 'D' are the characteristics of regions underlain by highly permeable material with vegetative cover and low relief. Whereas, high values of D indicate regions of weak and impermeable subsurface material, sparse vegetation and mountainous relief (Nautiyal, 1994). The D values of sub-watersheds (Table 1) suggest that the Kanera watershed as a whole is underlain by highly permeable material and represents low relief.

*Stream frequency (Fs)*

Stream frequency is the total number of stream segments of all orders per unit area (Horton, 1932). Fs values indicate positive correlation with the drainage density of all the sub-watersheds suggesting increase in stream population with respect to increase in drainage density (Table 1).

*Drainage texture (Rt)*

It is the total number of stream segments of all orders per perimeter of the area (Horton, 1945). Smith (1950) classified drainage density into five classes i.e., very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8) and very fine (>8). The drainage density values of sub-watersheds range from 2.50 to 3.46 indicating coarse drainage texture.

*Basin shape (Bs)*

Basin shape is the ratio of the square of basin length (Lb) to the area of the basin (A). The Bs values of sub-watersheds (Table 1) indicate that SW1, SW3, SW5, SW6 and SW7 have weaker flood discharge periods, whereas SW2 and SW4 have sharply peaked flood discharge.

*Form factor (Rf)*

Form factor is defined as the ratio of basin area to the square of the basin length (Horton, 1932). The value of form factor would always be less than 0.7854 (perfectly for a circular basin). Smaller the value of form factor, more elongated will be the basin. Lower Rf values of the sub-watersheds in the study area indicate elongated shape except SW2, which is close to a circular basin (0.71) and suggests lower peak flows of longer duration.

*Circularity ratio (Rc)*

Circularity ratio is the ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate and slope of the basin. The circularity ratios of sub-watersheds range from 0.35 to 0.88, indicating SW2 nearing circle (Table 1) whereas all other sub-watersheds represent an elongated shape.

*Elongation ratio (Re)*

The values of elongation ratio (Re) generally vary from 0.6 to 1.0 associated with a wide variety of climate and geology and can be grouped into three categories i.e., circular (>0.9), oval (0.9–0.8) and less elongated (<0.7). Re values of sub-watersheds (Table 1) indicate that SW2 is circular, SW4 and the whole of Kanera watershed represent oval shape, characterised by low relief, whereas rest of the sub-watersheds fall in the elongated category.

*Length of Overland flow (Lo)*

Length of Overland Flow is the length of water over the ground before it gets concentrated into definite stream channels (Horton, 1945). This factor relating inversely to the average shape of the channel is quite synonymous with the length of sheet flow to a large degree. The Lo values of the sub-watersheds range from 0.15 for SW2 to 0.80 for SW6, whereas the whole of Kanera watershed has a value of 0.68.

*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 study area vary from 0.41 to 1.31 showing wide variations across the sub-watersheds (Table 1).

***Land use/land cover analysis***

Land use/land cover change analysis is one of the important phenomena which have been dealt with great emphasis in the recent past (Amba Shetty *et al.*, 2005; Chauhan and Nayak, 2005; Jaiswal *et al.*, 1999; Joshi *et al.*, 2005; Kam, 1995; King, 2002; Mahajan and Panwar, 2005; Minakshi *et al.*, 1999; Shamsudheen *et al.*, 2005). Remote sensing can be a very good tool for studying the changes because of its synoptic view capability and repetitive coverage (Luque, 2000).

Land use/land cover mapping was carried out using IRS 1A LISS II geocoded FCC of 1989 and IRS 1C 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, open forest, open scrub, wasteland, water bodies, rocky area, built up land etc. Figures 2 and 3 present land use/land cover maps f the study area derived from IRS data of 1989 and 001, respectively. The study reveals that Kanera 'atershed has a single source of surface water in ie south-western part of the watershed, which too as shrunk in area from 0.64 km$^2$ in 1989 to 0.25 km$^2$ ı 2001. This indicates the paucity of surface water sources in the study area. The Kanera watershed as a whole presents a grim scenario as the land use/cover changes from 1989 to 2001 period indicate degradation of land and other natural resources. It was found that cultivated land decreased by 12%, whereas uncultivated land increased by 24% during the same period. Moreover, decrease in the natural vegetative cover, i.e., open forest by 4% and open scrub by 3% has been observed. However, 5% reduction in the wasteland area which is distributed across SW2, SW3, SW4, SW5 and SW6 can be attributed to the reclamation of wasteland. The details of land use/land cover and the changes in area under each category in km$^2$ as well as in percentage for each sub-watershed from 1989 to 2001 period are presented in Table 2.

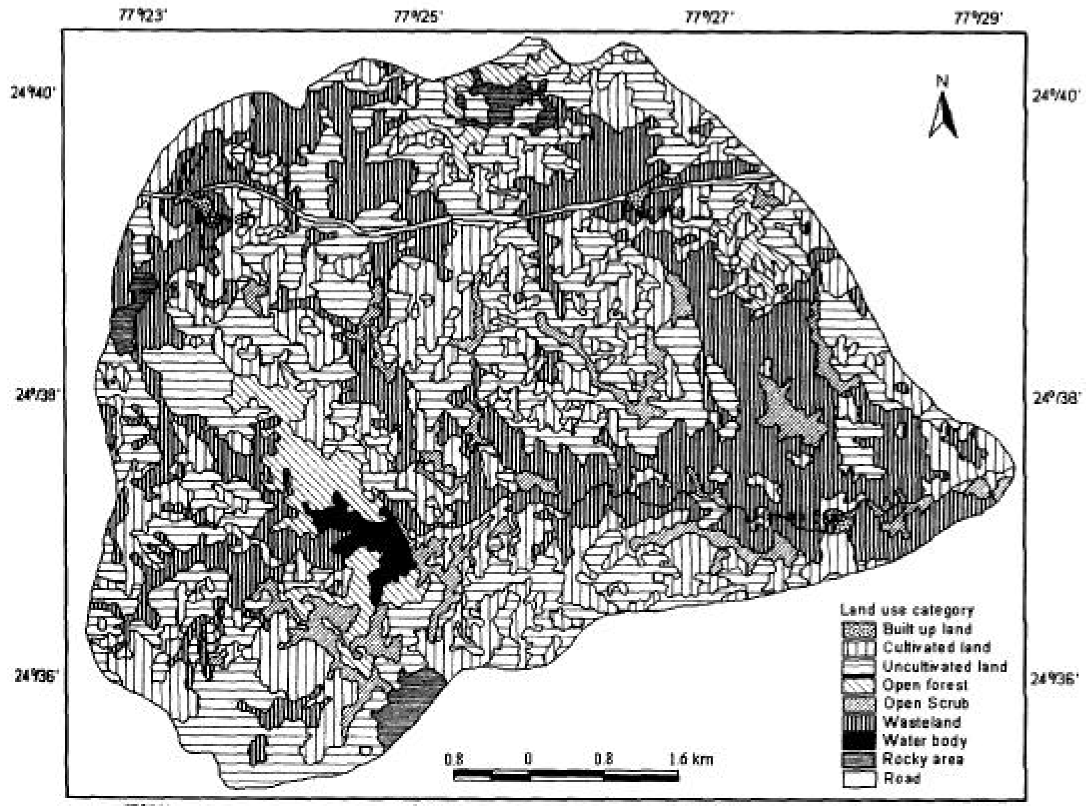


**Fig. 2** Land use/land cover map of Kanera watershed based on 1989 IRS LISS II FCC data.

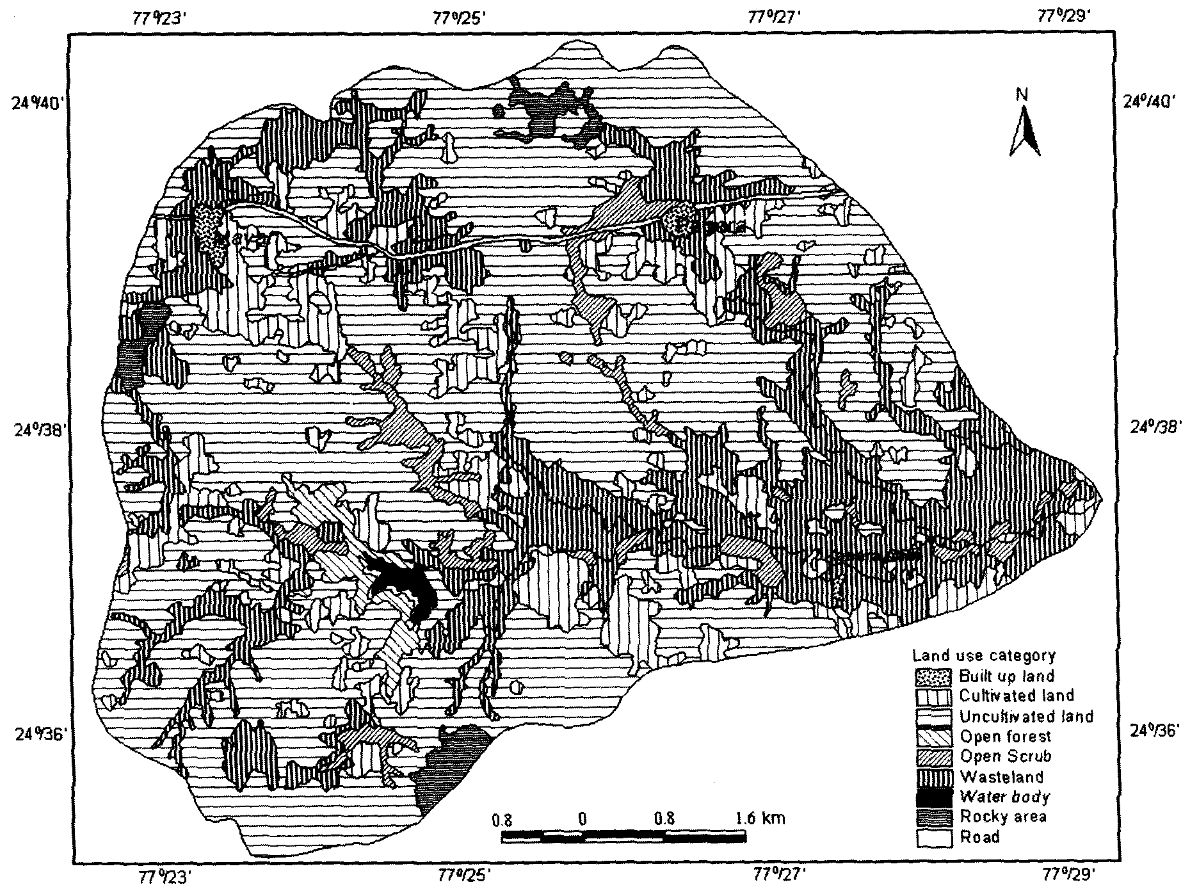


**Fig. 3** Land use/land cover map of Kanera watershed based on IRS LISS III FCC data.

Since the Kanera watershed represents a typical rain-fed watershed, where agriculture is the prime land use activity supporting the livelihood of the local people, an increase in cultivated land, open scrub and open 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 uncultivated land is also regarded as a positive change as it will indicate reclamation and rehabilitation of degraded and unproductive land. In contrast, decrease in area under open forest, open scrub, cultivated land can be taken as a negative change, indicating anthropogenic pressures and lack of conservation measures, similarly increase in the wasteland and uncultivated land is also regarded as a negative change.

A general decrease in cultivated land area and increase in area under uncultivated land is common across all the seven sub-watersheds indicating negative change. There is also a general decline in natural vegetation i.e., open forest and open scrub barring SW2, SW3 and SW4 which have reported a marginal increase in the vegetative cover. A close analysis of the land use/land cover change shows that sub-watersheds SW1 and SW7 reported 100% negative change showing overall degradation of the

**Table 2** Results of the land use/land cover analysis of the sub-watersheds and whole Kanera watershed

| Land use/land cover category | Land use/land cover 1989 | | Land use/land cover 2001 | | Land use change analysis 2001 – 1989 | |
|---|---|---|---|---|---|---|
| **SW1** | Area in ($km^2$) | Area in (%) | Area in ($km^2$) | Area in (%) | Difference in ($km^2$) | Difference in (%) |
| Cultivated land | 1.39 | 19.60 | 0.84 | 11.80 | -0.55 | -7.75 |
| Uncultivated land | 2.38 | 33.50 | 4.13 | 58.20 | 1.75 | 24.70 |
| Open forest | 1.09 | 15.30 | 0.28 | 3.90 | -0.81 | -11.40 |
| Open scrub | 1.09 | 15.30 | 0.22 | 3.10 | -0.87 | -12.25 |
| Wasteland | 0.29 | 4.10 | 0.98 | 13.8 | 0.69 | 9.70 |
| Water body | 0.41 | 5.80 | 0.20 | 2.80 | -0.21 | -2.95 |
| Rocky area | 0.45 | 6.40 | 0.45 | 6.40 | No change | No change |
| **Total** | **7.10** | **100.00** | **7.10** | **100.00** | | |
| **SW2** | | | | | | |
| Cultivated land | 1.94 | 30.40 | 0.57 | 8.90 | -1.37 | -21.47 |
| Uncultivated land | 2.35 | 36.80 | 4.16 | 62.50 | 1.81 | 28.37 |
| Open forest | 0.20 | 3.10 | 0.23 | 3.60 | 0.03 | 0.47 |
| Open scrub | 0.19 | 3.00 | - | - | -0.19 | -2.98 |
| Wasteland | 1.59 | 24.90 | 1.37 | 21.50 | -0.22 | -3.40 |
| Water body | 0.11 | 1.80 | 0.05 | 0.80 | -0.06 | -0.94 |
| **Total** | **6.38** | **100.00** | **6.38** | **100.00** | | |
| **SW3** | | | | | | |
| Cultivated land | 1.09 | 18.40 | 0.96 | 16.20 | -0.13 | -2.20 |
| Uncultivated land | 1.86 | 31.50 | 3.13 | 56.00 | 1.27 | 21.49 |
| Open forest | 1.10 | 18.60 | 0.39 | 6.60 | -0.71 | -12.00 |
| Open scrub | 0.03 | 0.50 | 0.19 | 3.20 | 0.16 | 2.71 |
| Wasteland | 1.60 | 27.10 | 1.13 | 19.10 | -0.47 | -8.00 |
| Water body | 0.12 | 2.00 | - | - | -0.12 | -2.03 |
| Rocky area | 0.11 | 1.90 | 0.11 | 1.90 | No change | No change |
| **Total** | **5.91** | **100.00** | **5.91** | **100.00** | | |
| **SW4** | | | | | | |
| Cultivated land | 4.95 | 30.50 | 2.81 | 17.30 | -2.14 | -13.19 |
| Uncultivated land | 4.82 | 29.70 | 9.10 | 56.20 | 4.28 | 26.39 |
| Open forest | 0.40 | 2.50 | - | - | -0.40 | -2.47 |
| Open scrub | 0.39 | 2.40 | 0.57 | 3.50 | 0.18 | 1.11 |
| Wasteland | 5.14 | 31.70 | 3.12 | 19.30 | -2.02 | -12.40 |
| Rocky area | 0.17 | 1.00 | 0.17 | 1.00 | No change | No change |
| Built up land | 0.10 | 0.70 | 0.20 | 1.20 | 0.10 | 0.62 |
| Road | 0.25 | 1.50 | 0.25 | 1.50 | No change | No change |
| **Total** | **16.22** | **100.00** | **16.22** | **100.00** | | |

Table 2 (Continued) ...

| Land use/land cover category | Land use/land cover 1989 | | Land use/land cover 2001 | | Land use change analysis 2001 – 1989 | |
|---|---|---|---|---|---|---|
| **SW5** | Area in ($km^2$) | Area in (%) | Area in ($km^2$) | Area in (%) | Difference in ($km^2$) | Difference in (%) |
| Cultivated land | 2.59 | 25.50 | 0.99 | 9.70 | -1.60 | -15.73 |
| Uncultivated land | 3.88 | 38.10 | 5.94 | 58.40 | 2.06 | 20.26 |
| Open scrub | 0.78 | 7.70 | 0.58 | 5.70 | -0.20 | -1.97 |
| Wasteland | 2.86 | 28.10 | 2.60 | 25.60 | -0.26 | -2.50 |
| Road | 0.06 | 0.60 | 0.06 | 0.60 | No change | No change |
| **Total** | **10.17** | **100.00** | **10.17** | **100.00** | | |
| **SW6** | | | | | | |
| Cultivated land | 3.51 | 21.20 | 1.70 | 10.30 | -1.81 | -10.91 |
| Uncultivated land | 3.57 | 21.50 | 8.45 | 50.90 | 4.88 | 29.42 |
| Open forest | 1.03 | 6.20 | - | - | -1.03 | -6.21 |
| Open scrub | 1.53 | 9.20 | 0.71 | 4.30 | -0.82 | -4.94 |
| Wasteland | 6.37 | 38.40 | 5.00 | 30.10 | -1.37 | -8.30 |
| Rocky area | 0.40 | 2.40 | 0.40 | 2.40 | No change | No change |
| Built up land | 0.06 | 0.40 | 0.21 | 1.30 | 0.15 | 0.90 |
| Road | 0.12 | 0.70 | 0.12 | 0.70 | No change | No change |
| **Total** | **16.59** | **100.00** | **16.59** | **100.00** | | |
| **SW7** | | | | | | |
| Cultivated land | 2.45 | 36.90 | 1.60 | 24.10 | -0.85 | -12.80 |
| Uncultivated land | 2.00 | 30.10 | 2.89 | 43.50 | 0.89 | 13.40 |
| Open scrub | 0.60 | 9.00 | 0.32 | 4.80 | -0.28 | -4.22 |
| Wasteland | 1.56 | 23.50 | 1.79 | 27.00 | 0.23 | 3.50 |
| Built up land | 0.03 | 0.50 | 0.04 | 0.60 | 0.01 | 0.15 |
| **Total** | **6.64** | **100.00** | **6.64** | **100.00** | | |
| **Whole Kanera watershed** | | | | | | |
| Cultivated land | 17.92 | 26.00 | 9.47 | 13.70 | -8.45 | -12.24 |
| Uncultivated land | 20.86 | 30.20 | 37.8 | 54.70 | 16.94 | 24.55 |
| Open forest | 3.82 | 5.50 | 0.9 | 1.30 | -2.92 | -4.23 |
| Open scrub | 4.61 | 6.70 | 2.59 | 3.80 | -2.02 | -2.93 |
| Wasteland | 19.41 | 28.20 | 15.99 | 23.20 | -3.42 | -4.95 |
| Water body | 0.64 | 0.90 | 0.25 | 0.40 | -0.39 | -0.56 |
| Rocky area | 1.13 | 1.60 | 1.13 | 1.60 | No change | No change |
| Built up land | 0.19 | 0.30 | 0.45 | 0.70 | 0.26 | 0.38 |
| Road | 0.43 | 0.60 | 0.43 | 0.60 | No change | No change |
| **Total** | **69.01** | **100.00** | **69.01** | **100.00** | | |

*Note: Negative values here do not necessarily show negative change, as referred to in the text.*

land resources; however the rest five sub-watersheds show mainly negative but some positive change as well. The positive change is reflected in the reclamation/conversion of wasteland into open scrub and open forest in SW2, SW3 and SW4.

### *Prioritization of sub-watersheds*

(a) *Based on morphometric analysis*

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 such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility, higher the value, more is 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 such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility (Nooka Ratnam *et al.*, 2005), 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 sub-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 3). After the ranking has been done based on every single parameter, the ranking values for all the linear and shape parameters of each sub-watershed were added up for each of the seven sub-watersheds to arrive at compound value (Cp). Based on average value of these parameters, the sub-watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on. The sub-watershed which got the highest Cp value was assigned last priority. The sub-watersheds were then categorized into three classes as high (3.6 – 3.9), medium (4.0 – 4.3) and low (> 4.3) priority on the basis of the range of Cp value. Hence, on the basis of morphometric analysis, SW1, SW3, SW4 and SW6 fall in the high priority, SW2 and SW7 fall in medium priority and SW5 in the low priority category (Table 3).

(b) *Based on land use/land cover analysis*

Common land use categories i.e., wasteland, cultivated land, uncultivated land, open forest and open scrub in all the seven sub-watersheds were considered for prioritization of sub-watersheds based on land use/land cover change analysis. The change in area under each category of land use was converted in percentage and ranking was assigned on the basis of area under each land use category (Table 3). All sub-watersheds have reported negative change in respect of cultivated and uncultivated land, i.e., there has been overall increase in uncultivated land across all sub-watersheds and at the same time decrease in cultivated land area from 1989 to 2001. However, wasteland shows some positive change, since the area under wasteland has reduced in few sub-watersheds, besides there has been some increase in area under open forest and open scrub, reflecting little positive change in a few sub-watersheds. For prioritization of sub-watersheds the highest value (per cent area) under land use categories of cultivated land, uncultivated land, open scrub, open forest and wasteland were rated as rank 1, second highest value as rank 2 and so on. However, lowest ranking was given to the highest value among the land use category showing positive change, i.e., decrease in wasteland or increase in open forest/open scrub (values in bold-Table 3). Finally, the ranking under each land use

**Table 3** Priorities of sub-watersheds and their ranks

| Sub-watersheds & area ($km^2$) | Land use category and change in area (per cent) | | | | | | | Morphometric parameters | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Linear parameters | | | | Shape parameters | | | | | | | | |
| | WL (%) | UCL (%) | CL (%) | OF (%) | OS (%) | Cp value | Final priority | D | Fs | Lo | Rb | Rt | Rc | Re | Rf | Bs | Cc | Cp value | Final priority | Common priority |
| SW1 7.1 | 9.7 *(1)* | 24.7 *(4)* | 7.75 *(6)* | 11.4 *(2)* | 12.25 *(1)* | 2.8 | High | 2.88 *(3)* | 5.91 *(2)* | 0.69 *(4)* | 4.0 *(5)* | 9.33 *(3)* | 0.57 *(4)* | 0.66 *(4)* | 0.35 *(4)* | 2.85 *(4)* | 0.99 *(5)* | 3.8 | High | High |
| SW2 6.38 | **3.4** *(4)* | 28.37 *(2)* | 21.47 *(1)* | **0.47** *(5)* | 2.98 *(4)* | 3.2 | High | 3.37 *(2)* | 6.59 *(1)* | 0.15 *(7)* | 3.36 *(6)* | 14 *(2)* | 0.88 *(6)* | 0.95 *(7)* | 0.71 *(7)* | 1.41 *(1)* | 0.84 *(4)* | 4.3 | Medium | - |
| SW3 5.91 | **8.0** *(5)* | 21.49 *(5)* | 2.2 *(7)* | 12 *(1)* | **2.71** *(7)* | 5 | Low | 2.53 *(6)* | 5.58 *(3)* | 0.79 *(2)* | 5.77 *(1)* | 6.60 *(6)* | 0.47 *(2)* | 0.55 *(2)* | 0.23 *(2)* | 4.23 *(6)* | 1.19 *(6)* | 3.6 | High | - |
| SW4 16.22 | **12.4** *(7)* | 26.39 *(3)* | 13.19 *(3)* | 2.47 *(4)* | **1.11** *(6)* | 4.6 | Low | 2.71 *(5)* | 4.80 *(5)* | 0.73 *(3)* | 4.04 *(4)* | 15.6 *(1)* | 0.66 *(5)* | 0.82 *(6)* | 0.53 *(6)* | 1.86 *(2)* | 0.60 *(2)* | 3.9 | High | - |
| SW5 10.17 | **2.5** *(3)* | 20.26 *(6)* | 15.73 *(2)* | - | 1.97 *(5)* | 4 | Medium | 2.80 *(4)* | 4.42 *(6)* | 0.17 *(6)* | 4.19 *(3)* | 9 *(4)* | 0.57 *(7)* | 0.72 *(5)* | 0.41 *(5)* | 2.45 *(3)* | 0.41 *(1)* | 4.4 | Low | - |
| SW6 16.59 | **8.3** *(6)* | 29.42 *(1)* | 10.91 *(5)* | 6.21 *(3)* | 4.94 *(2)* | 3.4 | High | 2.50 *(7)* | 3.37 *(7)* | 0.80 *(1)* | 5.11 *(2)* | 7.47 *(5)* | 0.52 *(3)* | 0.61 *(3)* | 0.30 *(3)* | 3.39 *(5)* | 0.68 *(3)* | 3.9 | High | High |
| SW7 6.64 | 3.5 *(2)* | 13.4 *(7)* | 12.8 *(4)* | - | 4.22 *(3)* | 4 | Medium | 3.46 *(1)* | 5.27 *(4)* | 0.57 *(5)* | 3.30 *(7)* | 6.36 *(7)* | 0.35 *(1)* | 0.53 *(1)* | 0.22 *(1)* | 4.55 *(7)* | 1.31 *(7)* | 4.1 | Medium | Medium |

*Note: Bold values indicate positive change i.e., reclamation of wasteland or increase in open forest/open scrub.*
*Values in parenthesis indicate priority/rank.*

category was added up to arrive at compound value (Cp), lower the Cp value higher is the ranking/ priority. The final priority/ranking was given by classifying the highest and lowest range of Cp value into three classes as high (2.8 – 3.5), medium (3.6 – 4.3) and low (> 4.3) priority. Hence, on the basis of land use change analysis SW1, SW2 and SW6, fall in the high priority, SW5 and SW7 fall in medium priority and SW3 and SW4 in the low priority category (Table 3).

The results obtained from morphometric and land use/land cover change analysis were correlated to find out the common sub-watersheds falling under each priority. The correlation shows that SW1 and SW6 fall under high priority, whereas SW7 falls in medium priority based on morphometric as well as land use/cover analysis. However, the rest of the sub-watersheds exhibit little correlation and differ in their priority under morphometric and land use/cover change analysis (Table 3).

## Conclusion

The present study demonstrates the utility of remote sensing and GIS techniques in prioritizing sub-watersheds based on morphometric and land use change analysis as well as with the integration of these two. The study involved identifying and delineating changes which have taken place in Kanera watershed from 1989 to 2001. Since remote sensing data provide repetitive coverage, it can be used more effectively with multiple data sets to monitor the changes on a regular basis. This study has found that SW1 and SW6 are common sub-watersheds falling in the high priority category based on morphometric as well as land use/ land cover analysis; hence, these may be taken for conservation measures by planners and decision makers for locale-specific planning and development.

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