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Prioritization of agricultural sub-watersheds in semi arid middle region of Gujarat using remote sensing and GIS

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Abstract In this study, proven capability of remote sensing and GIS are used for watershed prioritization. 19 different sub-watersheds are prioritised through geomorphological analysis and suitable structures are proposed for soil and water conservation in a Limkheda agricultural watershed situated in semi arid middle region of Gujarat, India. Remote sensing images such as SRTM are used to delineate the watershed and to generate slope thematic maps, soil maps are applied to generate soil type, whereas LISS III remote sensing image is used for generating land use maps. Prioritization of sub-watersheds using geomorphological analysis is carried out by seven different linear and shape parameters. Then different sub-watersheds are prioritised by assigning ranks using compound parameter. After prioritization, land use, soil type and land slope categories of sub-watersheds are integrated to propose suitable soil and water conservation structures. In this study, it is proposed that soil conservation measures should be adopted as per the priority assigned to reduce the adverse effect on the land and environment. Overall, it is concluded in this study that delineation of watersheds into sub-watersheds and prioritization of these sub-watersheds are very relevant, helpful and important in semi-arid regions of middle Gujarat, where there is high diversity in agricultural practices and size of land holdings. Adaptation of soil conservation measures priority-wise will not only reduce the soil erosion but also increase the water availability in the surface and as groundwater and will further reduces the possibility of droughts as well as floods and finally environmental hazards.

Introduction

Rapid growth in industrialisation and demographic expansion has increased the pressure on land and water resources in India. About 175×10^6 ha of land that is about 53 % of the geographical area of the India is subjected to soil erosion and other forms of land degradation due to deforestation and other natural processes and anthropogenic activities (Biswas et al. 1999; Kumar et al. 2011). Soil erosion and degradation ultimately lead to change in river, morphology, reservoir sedimentation, reduction in reservoir storage capacity, low agricultural productivity, floods, etc. (Thakkar and Dhiman 2007). Therefore, conservation of these natural resources is essential for sustainable development. Watershed or drainage basin is considered as an ideal unit for sustainable development and natural resources management (Patel et al. 2012). It is a natural hydrological unit that allows surface runoff to a natural channel, drain, stream or river at a particular point (Chopra et al. 2005). Management of a complex system such as a watershed may also requires user participation in the research process itself (Johnson et al. 2002). It also implies for appropriate uses of land and water resources of a watershed for increased production associated with minimum hazard to natural resources (Osborne and Wiley 1988; Kessler et al. 1992). There are different classifications of watersheds as per its area. A watershed atlas prepared by AIS and LUS (1990) defines the mean

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area of watershed as being less than 500 km^2 ($\pm$250 km^2), whereas the National Remote Sensing Agency, Hyderabad has classified the watershed into sub-watershed with area ranging from 30 to 50 km^2, mini-watershed 10 to 30 km^2 and for micro-watershed 5 to 10 km^2 (Chopra et al. 2005).

Soil erosion removes upper layer of soil that is rich in nutrients for plant growth, and consequently, bringing down the productivity of soil. In India about 113.3 million ha of land is vulnerable to soil erosion due to water and about 5334 MT of soil is being detached annually in India (Narayan and Babu 1983). The extreme weather conditions due to climate change may further exacerbate the soil erosion in future in many parts of the world (Amore et al. 2004). Soil erosion deposits soil in the watershed in the form of sediment that reduces the designed reservoir storage capacity (Vito 1975). Watershed planning and management are important to prevent the damages due to soil erosion. Therefore, it is necessary to assess the soil erosion potential of watershed and to prioritize the watersheds for treatment that makes better planning to combat this menace. The watershed prioritization is the ranking of different areas or sub-watersheds of a watershed as per the order they have to be selected for suitable soil conservation measures adaptation.

Prioritization of watershed is very important for preparing a comprehensive plan for watershed conservation and management. Adaptation of soil conservation measures priority-wise will not only reduces the soil erosion but also increases the water availability in the surface and as groundwater and will further reduces the possibility of droughts as well as floods. There are several studies carried out on prioritization of watersheds based on morphometric analysis, geomorphology and sediment yield index (SYI) (Biswas et al. 1999; Khan et al. 2001; Nookaratnam et al. 2005; Thakkar and Dhiman 2007; Srinivasa Vittala et al. 2008; Javed et al. 2009; Kumar et al. 2011). Morphometric analysis is important for evaluation of hydrologic system in the watershed (Kumar et al. 2011). Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Clarke 1966). Geomorphometric analysis comprises of quantitative description of the drainage system of the watershed that is an important aspect of the watershed characterization (Strahler 1964). The geomorphometric parameters such as bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio and elongation ratio are also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds (Biswas et al. 1999).

Remote sensing (RS) and geographical information system (GIS) are found to be very effective in large area data collection and integration of spatial data to derive useful outputs through hydrologic modeling (Gupta and Srivastava 2010; Srivastava et al. 2010, 2012a, b; Pandey et al. 2012; Thakur et al. 2012). Some of the earlier studies on geomorphometric analysis using remote sensing technique were performed by Nautiyal (1994), Srivastava (1997), Nag (1998), and Srinivasa et al. (2004). Chopra et al. (2005) carried out morphometric analysis of sub-watersheds in Gurdaspur district, Punjab. Nookaratnam et al. (2005) carried out check dam positioning by prioritization of micro-watersheds using geomorphometric analysis. Through prioritization of watersheds, it could be found that which watershed can lead to higher amount of discharge due to excessive amount of rainfall (Thomas et al. 2012). Patel et al. (2012) reported a case study to select suitable sites for water harvesting structures in Varekhadi watershed, a part of Lower Tapi Basin (LTB), Surat district, Gujarat by application of RS and GIS approach using soil map and Shuttle Radar Topography Mission DEM (SRTM-DEM)-generated slope map. However, prioritization of different sub-watersheds is yet to be elucidate for water resource planning and management.

The technology of RS and GIS is gaining momentum as a powerful tool in the information management in agriculture, natural resources management and conservation, environmental protection, hazard mapping, etc. (Javed et al. 2009; Mani and Chakravorty 2007). The input parameters used for soil erosion modelling and watershed prioritization can easily be calculated using RS and GIS. RS and GIS technology are widely applied and have great potential for soil erosion assessment, inventory mapping by soil erosion modeling and erosion hazard assessment, and help for adaptation of best management practices. Kothyari and Jain (1997) estimated sediment yield using GIS, whereas Jasrotia et al. (2002) conducted rainfall-runoff and soil erosion modeling using RS and GIS techniques for the Tons watershed. Prioritization of watershed using morphologic analysis is very important for water resource modeler and flood management (Miller and Craig Kochel 2010; Youssef et al. 2011; Bali et al. 2012). These results are of utmost importance to conserve water and soil and can also be used for designing efficient water harvesting structure in a watershed. For soil erosion assessment from the watershed, there are several empirical models based on the geomorphological parameters developed in the past and are used to quantify the sediment yield (Misra et al. 1984; Pandey et al. 2006). Besides, several other methods such as sediment yield index (SYI) method proposed by Bali and Karale (1977) and universal soil loss equation (USLE) developed by Wischmeier and Smith (1978) are extensively being used for watershed prioritization. The USLE, a lumped approach has been widely applied for watershed prioritization at a watershed scale to catchment scale

(Griffin et al. 1988; Dickinson and Collins 1998; Jain et al. 2001; Jain and Kothyari 2000). The above-mentioned methodologies are very effective but require extensive spatial and temporal time series and watershed data.

The prioritization concept is helpful to understand the geomorphology of individual sub-watersheds (Haing et al. 2008; Javed et al. 2011; Brooks et al. 2006; Strahler 1957), whereas GIS technique integrated with other spatial data is useful in positioning the ideal site for soil water harvesting structures and soil conservation measures (Gupta et al. 1997; Chowdary et al. 2009; Kumar et al. 2008). Therefore, the present study is focused on prioritization of sub-watersheds based on erosion assessment of different sub-watersheds. Besides prioritization of watershed based on geomorphological parameters estimated using RS and GIS concept through geomorphological analysis, information of current land use, soil type and land use are also utilized to further propose the suitable soil and water conservation measures in the Limkheda agricultural watershed, situated in middle semi arid region of Gujarat state, India.

Study area

Limkheda agricultural watershed, situated in the middle region of Gujarat, India (Fig. 1) is undertaken in this study. It has a total area of 220.86 km^2 with the outlet of the watershed located at latitude 22°49′55″ N and longitude 73°59′15″ E . The whole watershed area fall under Survey of India Toposheet sheet Nos. F43I1, F43I2, F43H13 with a scale of 1:50,000. The study area attains maximum elevation of 490 m and a minimum of 196 m above mean sea level. As the watershed being situated in semi arid region and dominated with agriculture and forest land with high variation in altitude,
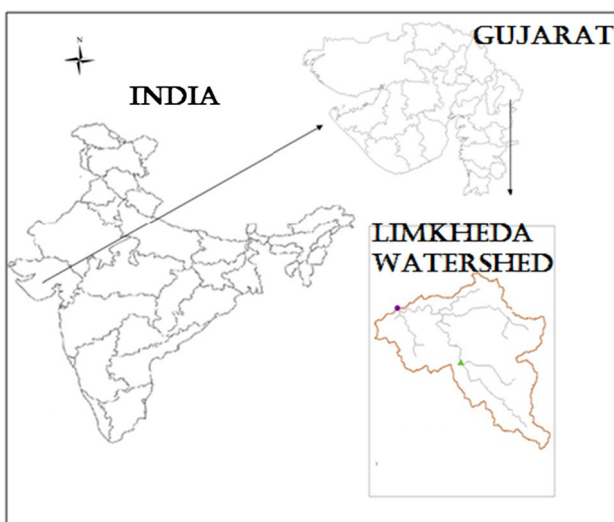
Fig. 1 Location map of Limkheda watershed

water availability and its conservation in the region is an important and critical issue. A majority of farm operators belong to marginal and small farmer categories cultivating less than 2 ha of land (Gujarat Agriculture XI PLAN Outcomes and Strategies 2009). In semi arid middle region of Gujarat comprising areas such as Panchmahals, Baroda, Anand, Balasinor, Borsad, Kapadvanj, Kheda, Matar, Ahmedabad, Nadiad, Petlad, Thasara, taluks of Kheda, etc., have rainfall ranging from 800 to 1000 mm. The agriculture is diversified in these locations with crops such as paddy, wheat, gram, soybean, perlmillets, pigeonpea, sorghum, maize, kodra, ragi, groundnut, sesamum, castor, cotton, sugarcane, potato, rapeseed and mustard grown in these areas. The soil type is deep black, medium black to loamy sand (Swain et al. 2012). One rainwater harvesting structure (Umaria reservoir) has been put in place over the past years located at 22°46′00″ N and longitude 74°04′12″ E and having an area of 72.52 km^2, having a bit success in improving the water availability for agricultural production. There is a huge scope of improving the potential of the watershed for increasing the availability of water for agriculture.

Materials and methodology

### Pre-processing of data set

Digital elevation model (DEM)

The DEM of the study area was downloaded from http://srtm.csi.cgiar.org/, where elevation data at 90 m resolution acquired through shuttle radar topographic mission (SRTM) is available for the globe. SRTM-DEM is used to delineate watershed and to extract stream network of the watersheds. The SRTM mission date was 11–22 February 2000, and during this time the shuttle had a flying attitude of 233 km, sending 1700 microwave impulses per second. Before the DEM is used, it is projected to Universal Transverse Mercator (UTM) under 43 zones applicable in the region. The DEM of the delineated watershed along with sub-watersheds is shown in Fig. 2. Limkheda watershed comprises of 19 sub-watersheds.

Land use map

For land use classification LISS-III remote sensing image with spatial resolution 23.5 m obtained from National Remote Sensing Centre (NRSC), Hyderabad, India for the year of 2012 is used in the study area to classify the watershed into different land use categories. Image is classified into prominent land use categories using ERDAS IMAGINE version 11 such as water bodies (WATR), agriculture (AGRC), pasture (PAST) built-up (URBN) and

Fig. 2 DEM with sub-watersheds of the study area
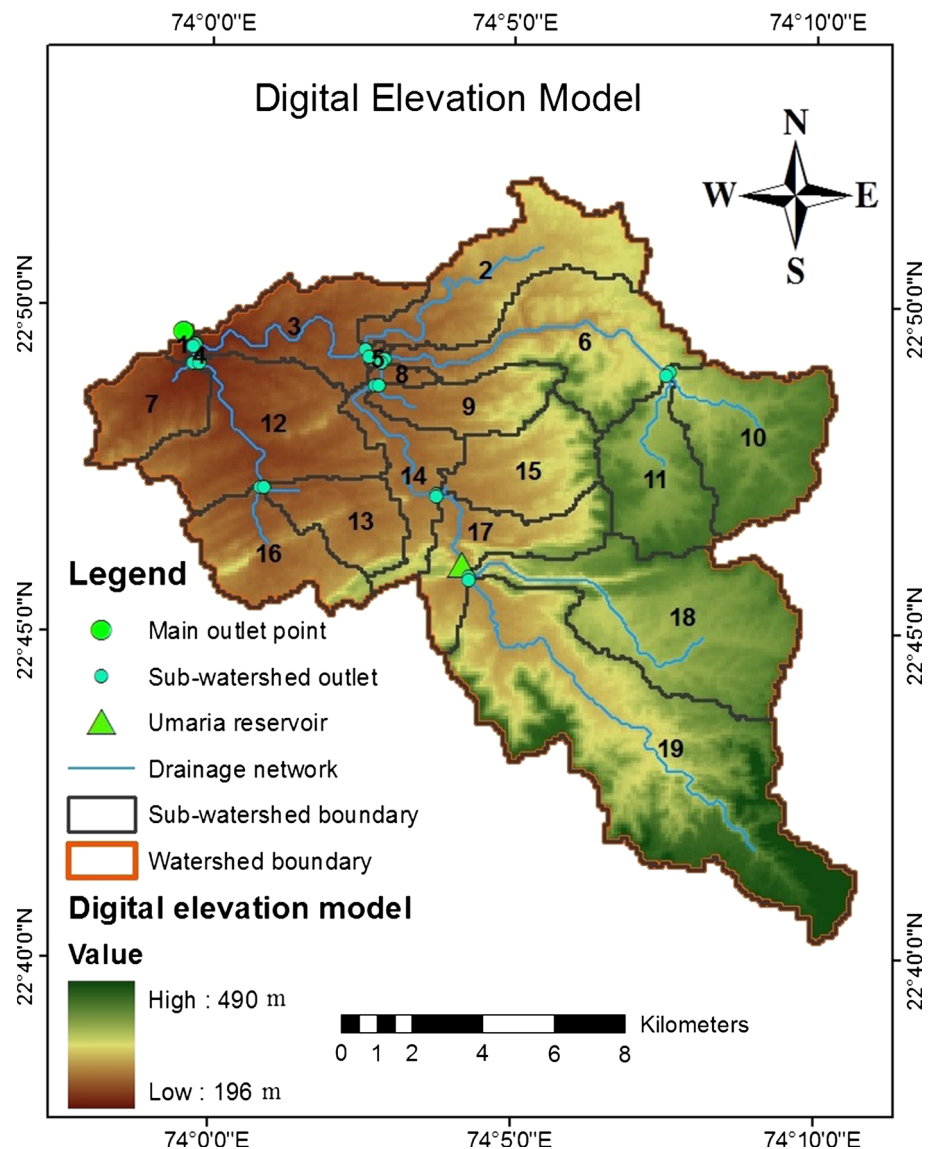
forest (FRST). The classified land use map of the water-shed is shown in Fig. 3.

Soil map

Soil series map at 1:250,000 scale for Gujarat state, published by National Bureau of Soil Survey & Land Use Planning (NBSS&LUP 2005), Nagpur is used as the source of soil database and soil grid. After pre-processing using GIS such as geo-referencing and UTM zone 43 projection assignment the soil texture obtained for the study area are clayey, loamy and fine as shown in Fig. 4.

Slope map

The slope map of the study area is prepared using the SRTM DEM as shown in Fig. 5. The slope in the watershed

ranges from 0–33 % with 6 slope ranges viz., 0–1, 1–3, 3–5, 5–10, 10–15, 51–35 % are applied to present the slope map for all the 19 sub-watersheds in the study area.

Geo-morphometric parameters

SRTM-DEM is used to extract different morphologic parameters in this study. Initially digitization of dendritic drainage pattern is carried out in SWAT model with GIS environment with stream ordering using the Horton's law. The fundamental parameters calculated in this study are namely stream length, area, perimeter, number of streams and basin length derived from the drainage layer using GIS environment. The morphometric parameters for all the delineated sub-watersheds areas are calculated based on the formula suggested by Horton (1945), Schumm (1956) and Miller (1953) as shown in Table 1.

Fig. 3 Land use map of study
area
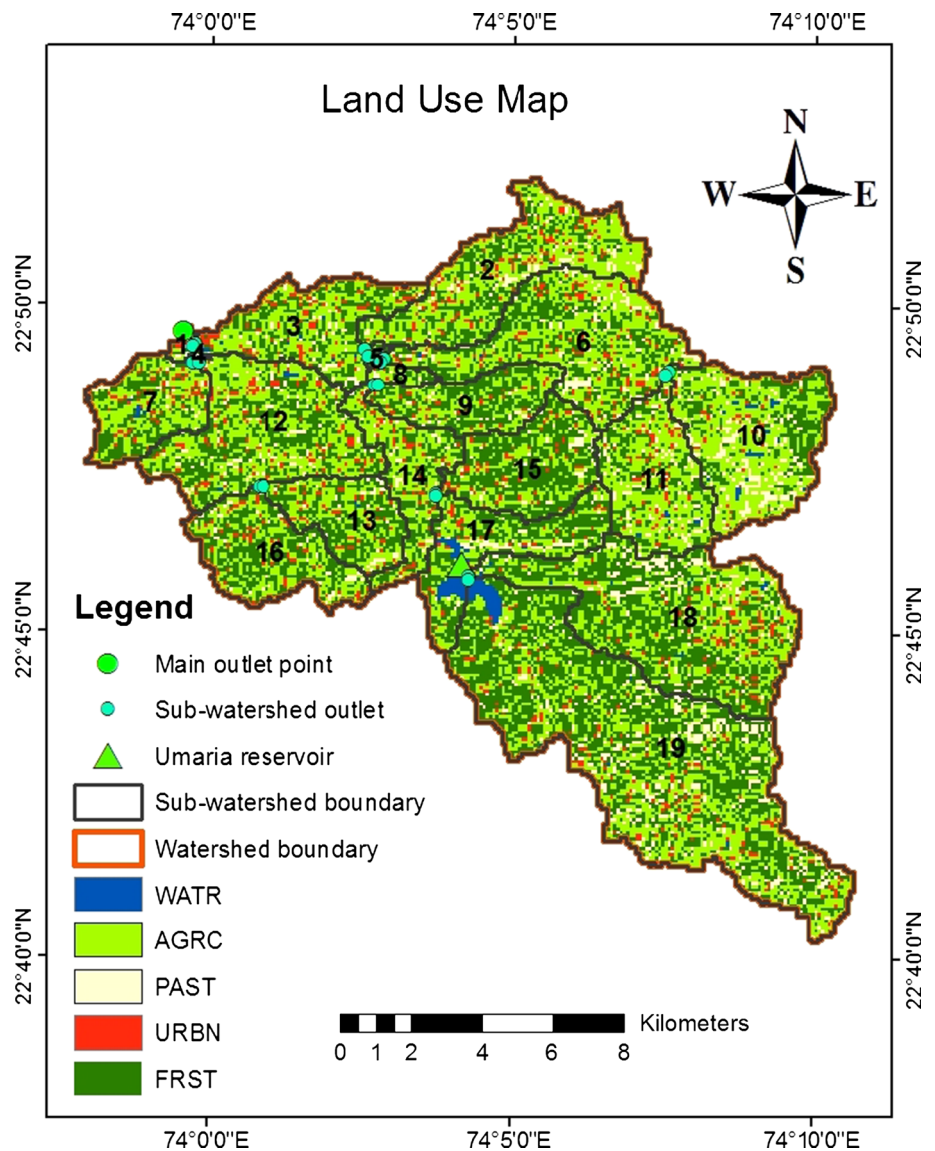
In this study seven important geomorphologic parameters, viz., elongation ratio, compactness coefficient, drainage density, form factor, circularity ratio, length of overland flow, and unity shape factor are considered for watershed prioritization. The linear parameters such as drainage density, length of overland flow have a direct relationship with erodibility, i.e. higher the linear parameters, more is the erodibility (Nookaratnam et al. 2005; Patel et al. 2013). Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, unity shape factor and form factor have an inverse relationship with erodibility (Nookaratnam et al. 2005; Javed et al. 2009), i.e. lower values of these shape parameters results in higher erodibility and vice versa. 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 are added up for each

of the nine sub-watersheds to arrive at compound parameter. 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.

Erdas Imagine 11.0 and ArcGIS 10.0 software were applied for image classification and geo-morphological analysis in this study.

Results and discussion

The different geomorphometric parameters for all the 19 sub-watersheds calculated using the equations shown in Table 1 are presented in Table 2. The detailed discussion of different linear and shape geo-morphological parameters as per their effect on the watershed prioritization is given below:

Fig. 4 Soil map of the study area
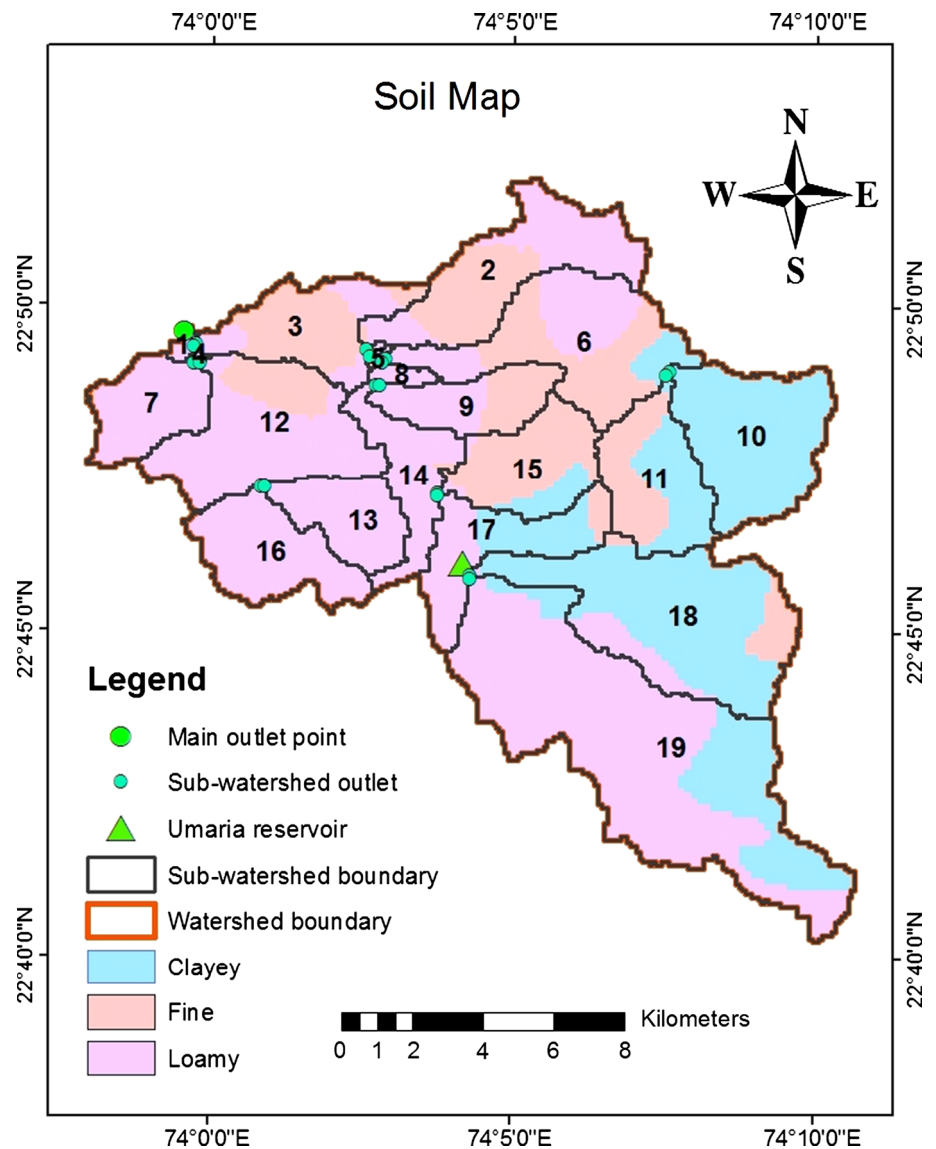
Drainage density (D_d)

Horton (1932) introduced the drainage density (D_d) as an important indicator of the linear scale of land-form elements in stream eroded topography, and is defined as the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of km/km^2. The drainage density is an indicator of the closeness of spacing of channels, and thus, providing a quantitative measure of the average length of stream channel for the entire basin. High drainage density is observed in weak or impermeable subsurface material with sparse vegetation and mountainous relief. It is suggested in previous studies that low drainage density indicates the basin is highly permeable subsoil and thick vegetative cover (Nag 1998). The drainage density (D_d) in this study varies from 0.049 to 3.149 km/km^2.

Length of overland flow (L_g)

It is the length of water over the ground before it gets concentrated into definite stream channels (Horton 1945). This factor is related inversely to the average slope of the channel and is synonymous with the length of sheet flow to a large degree. It is approximately equals to half of reciprocal of drainage density (Horton 1945). Table 2 reveals that the computed value of L_g for all sub-watersheds varies from 0.15 to 10.09. The higher value of L_g indicate low relief, whereas the lower values of L_g indicate high relief.

Fig. 5 Slope map of the study area
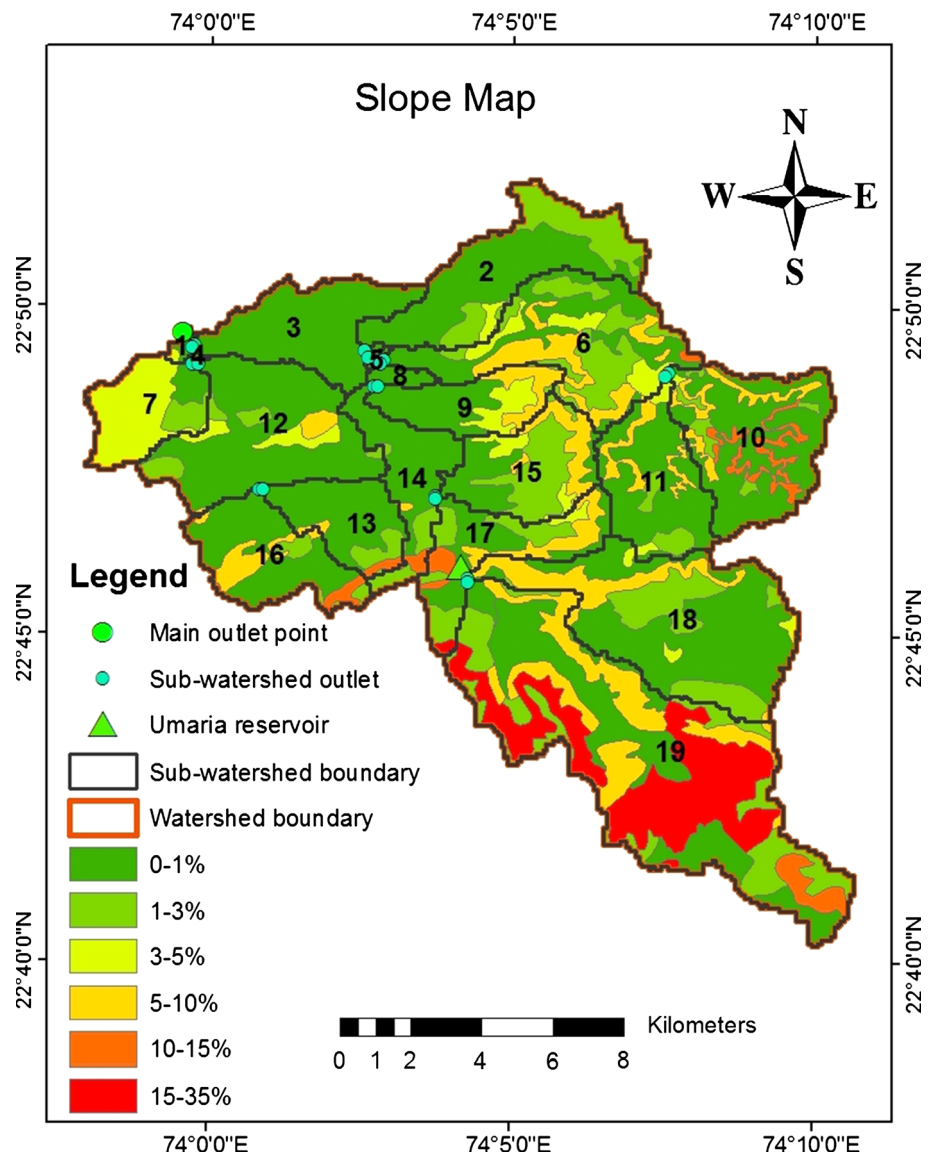
Table 1 Watershed morphometric parameters were estimated by using the following relationship

Sl. no.	Linear/shape parameters	Morphometric parameters	Formula	References
1	Linear	Drainage density (D_d)	$D_d = L_u/A$	Horton (1932)
2	Linear	Length of over land flow (L_g)	$L_g = 1/D_d \times 2$	Horton (1945)
3	Shape	Circularity ratio (R_c)	$R_c = 4 \times \pi \times A/P^2$	Miller (1953)
4	Shape	Elongation ratio (R_e)	$R_e = (2/L_b) \times (A/\pi)^{0.5}$	Schumm (1956)
5	Shape	Form factor (R_f)	$R_f = A/L_b^2$	Horton (1932)
6	Shape	Unity shape factor (R_u)	$R_u = L_b/A^{0.5}$	Horton (1945)
7	Shape	Compactness coefficient (C_c)	$C_c = 0.2821 \times P/A^{0.5}$	Strahler (1964)

A, area of basin (km^2), L_u, total stream length of all order (km), P, perimeter of basin (km)

Circulatory ratio (R_c)

It is ratio of the basin area to the area of circle having the same circumference as the perimeter of the basin (Miller 1953). In the present case R_c ranges from 0.16 to 0.439 indicating that it is elongated and all the sub-watersheds are characterized by low to moderate relief with limited structural control.

Table 2 Calculated sub-watersheds morphometric parameters

Sub-watershed no.	D_d (km/km^2)	L_g	R_c	R_e	R_f	R_u	C_c
1	1.131	0.442	0.434	0.912	0.653	1.237	1.517
2	0.541	0.925	0.206	0.538	0.227	2.098	2.205
3	0.718	0.696	0.217	0.544	0.232	2.076	2.148
4	3.150	0.159	0.353	0.774	0.470	1.458	1.683
5	2.386	0.210	0.331	0.723	0.411	1.561	1.738
6	0.539	0.928	0.241	0.533	0.223	2.119	2.036
7	0.127	3.949	0.439	0.754	0.446	1.497	1.509
8	0.719	0.696	0.350	0.616	0.298	1.832	1.691
9	0.234	2.141	0.341	0.638	0.319	1.769	1.713
10	0.238	2.101	0.398	0.851	0.568	1.327	1.584
11	0.316	1.581	0.389	0.699	0.383	1.616	1.604
12	0.272	1.836	0.321	0.774	0.470	1.458	1.765
13	0.168	2.983	0.401	0.560	0.246	2.016	1.580
14	0.724	0.691	0.161	0.522	0.214	2.162	2.494
15	0.050	10.092	0.366	0.721	0.409	1.564	1.654
16	0.188	2.664	0.291	0.829	0.540	1.361	1.853
17	0.330	1.515	0.216	0.693	0.377	1.628	2.151
18	0.359	1.392	0.273	0.603	0.285	1.873	1.916
19	0.309	1.621	0.232	0.533	0.223	2.119	2.075

Elongation ratio (R_e)

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. A circular watershed is more efficient in runoff discharge than an elongated basin (Singh and Singh 1997). The value of elongation ratio (R_e) generally varies from 0.52 to 0.91 associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief whereas that of 0.6–0.8 are associated with high relief and steep ground slope (Strahler 1964). These values can be grouped into three categories, namely circular (>0.9), oval (09–0.8) and elongated (<0.7).

Form factor (R_f)

It is defined as the ratio of basin area to square of the basin length (Horton 1932). The value of form factor for a perfectly circular basin would always be less than 0.7854. Smaller value of form factor indicates elongated basin. The basins with high form factors have high peak flows with shorter duration, whereas elongated watershed with low form factors have lower peak flow with longer duration. It is observed in study area that the R_f values vary from 0.21 to 0.65 indicating that they are to be elongated circular shape and suggesting flatter peak flow with longer duration. Flood flows of elongated circular watersheds are considered to be easier to manage than those of the circular watershed.

Unity shape factor (R_u)

The ratio of the basin length, L_b to the square root of the basin area, A in the study area varies from 1.23 to 2.16. The R_u values <2 of sub-watersheds indicates that have weaker flood discharge periods, whereas R_u value >2 indicates that have sharp peak flood discharge.

Compactness coefficient (C_c)

Compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. The C_c is independent of size of watershed and dependent only on the slope. It varies for 1.51–2.49 in the present study area.

Prioritization of sub-watersheds based on morphometric analysis

The compound parameter values of 19 sub-watersheds of Limkheda watershed are calculated and prioritization rating is given in Table 3. Sub-watersheds 6 and 14 with a compound parameter value of 8.7 receives the highest priorities with next in the priority list is sub-watershed 2 having the compound parameter value of 9.1. Highest priority indicates the greater degree of erosion potential associated in the particular sub-watershed and it becomes potential area for adaptation of

Table 3 Priorities of sub-watersheds and their ranks

Sub-watershed no.	D_d	L_g	R_c	R_e	R_f	R_u	C_c	Compound parameters	Final priority
1	3	17	18	19	19	1	2	11.3	19
2	7	13	2	4	4	16	18	9.1	3
3	6	14	4	5	5	15	16	9.3	5
4	1	19	13	15	15	4	7	10.6	14
5	2	18	10	13	13	7	10	10.4	13
6	8	12	6	2	2	17	14	8.7	1
7	18	2	19	14	14	6	1	10.6	15
8	5	15	12	8	8	12	8	9.7	8
9	15	5	11	9	9	11	9	9.9	9
10	14	6	16	18	18	2	4	11.1	18
11	11	9	15	11	11	9	5	10.1	11
12	13	7	9	16	16	5	11	11.0	16
13	17	3	17	6	6	14	3	9.4	6
14	4	16	1	1	1	19	19	8.7	2
15	19	1	14	12	12	8	6	10.3	12
16	16	4	8	17	17	3	12	11.0	17
17	10	10	3	10	10	10	17	10.0	10
18	9	11	7	7	7	13	13	9.6	7
19	12	8	5	3	3	18	15	9.1	4

Table 4 Land use and soil classes for 19 sub-watersheds

Sub-watershed no.	Land use class (km^2)					Soil class (km^2)		
	Water bodies	Agricultural land	Wasteland	Build-up	Forest	Clayey	Fine sand	Loamy
1	0.00	0.21	0.09	0.10	0.10	0.00	0.00	0.50
2	0.08	8.32	0.99	1.30	4.88	0.00	6.95	8.54
3	0.08	5.16	0.54	1.28	3.70	0.00	7.37	3.39
4	0.00	0.08	0.04	0.00	0.03	0.00	0.00	0.16
5	0.00	0.11	0.03	0.01	0.07	0.00	0.00	0.22
6	0.03	8.99	1.42	1.24	6.49	1.74	8.90	7.52
7	0.09	3.58	0.38	0.72	0.00	0.00	0.13	7.57
8	0.00	0.47	0.08	0.04	0.33	0.00	0.00	0.93
9	0.00	2.83	0.28	0.38	3.70	0.00	3.38	3.81
10	0.28	8.44	2.12	0.47	4.40	15.71	0.00	0.00
11	0.07	6.06	1.12	0.61	3.10	5.60	5.36	0.00
12	0.07	8.40	1.04	1.27	6.81	0.00	3.72	13.86
13	0.02	3.08	0.34	0.50	3.26	0.00	0.00	7.19
14	0.00	4.10	0.36	0.52	2.55	0.00	0.15	7.37
15	0.00	3.31	0.49	0.58	5.72	1.87	7.87	0.37
16	0.00	4.81	0.47	0.67	4.89	0.00	0.00	10.21
17	0.80	3.55	0.61	0.43	4.43	4.03	0.93	4.85
18	0.18	9.67	1.90	1.18	11.91	19.44	2.46	2.94
19	0.73	16.92	4.07	1.81	22.24	11.37	0.00	34.40

soil conservative measure. Thus, in first glance, soil conservation measures should first be applied to sub-watersheds area 6 and 14 then to the other sub-watersheds according to their ranking/priority.

Land use and soil analysis for sub watersheds

In this study besides prioritizing the sub-watershed using geomorphological analysis, effect of land use and soil

texture is also considered to propose appropriate soil conservation measures. Different type of land use and soil texture in all the 19 sub-watersheds in the Limkheda agricultural watersheds is presented in Table 4. It can be observed that all these sub-watersheds not only vary significantly in terms of size but also contain high variability in terms of different land use classes and soil texture categories.

Location of proposed soil conservation structures

The priority of the watersheds is assigned as per the different geo-morphologial parameters. Further in this study the information related to soil type, land use and slope is also utilised to propose suitable soil and water conservation structures. For example, it is found in this study that sub-watersheds 6, 14, 2 and 19 are highly vulnerable for erosion and have been assigned high priority for soil conservation measures. As presented in Table 4, it can be observed that sub-watersheds 6, 14 and 2 are dominated with sandy to loamy soil whereas sub-watershed 19 is dominated with clayey soil. Moreover, it can be observed that sub-watershed 19 is mostly hilly area with slope 5–35 %, and watershed 6 is also sloppy with substantial area having slope from 5 to 10 %. Therefore, in sub-watershed 19 terracing and bunding, and in watershed 6 level and contour bunding can be proposed as suitable soil and water conservation measures. Further, as sub-watersheds 6 and 19 are dominated with sloppy and forest land and as terracing and bunding are more suitable when agricultural crops are grown, and therefore in these watersheds, stop dams and check dams can be proposed for soil and water conservation. In watersheds 14 and 2, being dominated with agricultural land, different agricultural measures such as strip cropping, contour cropping, and bori bund can be proposed as suitable soil and water conservation measures.

Among watersheds 3, 13, 18 and 8, it can be observed that, except sub-watershed 18, watersheds are occupied with agricultural and forest lands and land slopes are less than 3 %. Therefore, in these watersheds more emphasis should be given on different agricultural practices such as different cropping patterns, strip cropping, level bunding as suitable soil and water conservation measures. In sub-watershed 18 being located in the upstream and covering a substantial area with sloppy lands, and the area is also covered with clayey soil having less infiltration capacity, some suitable check dams can be proposed at the upstream of the outlet of the sub-watershed with terracing and bunding in the sloppy area of the watershed.

Conclusion

Soil erosion is one of the dominant problems faced by the agricultural land and therefore prioritization of watershed is important to take appropriate agricultural and mechanical measures to prevent soil erosion. Therefore, in this study, a remote sensing and GIS integrated approach is adopted to prioritize all the sub-watersheds and then to propose appropriate soil conservation measures. Initially, prioritization of the sub-watersheds is carried out using geomorphologic analysis by considering different linear and shape parameters of the watershed. Then all the sub-watersheds are assigned a rank on the basis of priority for adopting soil conservation measures. Besides, land use and soil type, land slope are taken into consideration for proposing suitable soil and water conservation structures in the highly vulnerable sub-watersheds. The suitable soil conservation measures are proposed as per the adoptability in different type of land use such as agricultural, forest, pasture, etc., soil conditions such as fine, loamy and clayey and slope ranging from 0 to 35 %.

In this study, it is proposed that soil conservation measures should be adopted as per the priority assigned to reduce the adverse effect on the land and environment. Moreover, the priority assigned for the sub-watersheds should be analysed as per the prevailing land use, soil type and land slope. Previously, in several studies prioritization of watersheds are carried out on the basis of geo-morphological analysis, but in this study this analysis is coupled with land use, soil type and land slope to propose appropriate soil conservation measures. Overall, it is concluded that delineation of watersheds into sub-watersheds and prioritization of these sub-watersheds is very relevant and important in Limkheda watershed, located in semi-arid regions of middle Gujarat, India, where there is high diversity in agricultural practices and size of land holdings.

It is found in this study that SRTM DEM, LISS-III remote sensing image, soil map along with the GIS technique are very efficient tools in watershed delineation and geomorphological analysis and can provide promising results for watershed prioritization. Besides, it is also emphasised in this study that consideration of land use, soil type and land slope in the sub-watersheds can help to choose appropriate soil conservation measures.

As in the Limkheda watershed the major crops grown are maize, paddy, wheat, gram, soybean and pigeonpea, with most of the area and crops are under rainfed condition with limited availability of irrigation water through open wells. Further, most of the area being hilly and located in semi arid region, there is huge scope for adoption of suitable soil and conservation measures in the watershed.

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