



Water Harvesting Structure Positioning by Using Geo-Visualization Concept and Prioritization of Mini-Watersheds Through Morphometric Analysis in the Lower Tapi Basin

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Abstract Geo-visualization concept has been used for positioning water harvesting structures in Varekhadi watershed consisting of 26 mini watersheds, falling in Lower Tapi Basin (LTB), Surat district, Gujarat state. For prioritization of the mini watersheds, morphometric analysis was utilized by using the linear parameters such as bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_u), texture ratio (T), length of overland flow (L_o) and the shape

parameter such as form factor (R_f), shape factor (B_s), elongation ratio (R_e), compactness constant (C_c) and circularity ratio (R_c). The different prioritization ranks were assigned after evaluation of the compound factor. 3 Dimensional (3D) Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) and DEM from topo contour were analyzed in ArcScene 9.1 and the fly tool was utilized for the Geo-visualization of Varekhadi mini watersheds as per the priority ranks. Combining this with soil map and slope map, the best feasibility of positioning check dams in mini-watershed no. 1, 5 and 24 has been proposed, after validation of the sites.

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Introduction

A watershed is a natural hydrological entity which allows surface runoff to a defined channel, drain, stream or river at a particular point (Chopra et al. 2005). Hence, watershed is an ideal unit for management and sustainable development of its natural resources. Watershed management is the process of formulation carrying out a course of action that involves modification in the natural system of watershed to achieve specified objectives. It further implies appropriate use of land and water resources of a watershed for optimum production with minimum

hazard to natural resources. Water harvesting structure is one of the important components of watershed development to conserve soil and water.

GIS is an effective tool not only for collection, storage, management and retrieval of a multitude of spatial and non-spatial data, but also for spatial analysis and integration of these data to derive useful outputs and modeling (Gupta and Srivastava 2010; Srivastava et al. 2011). Remote Sensing (RS) coupled with Geographical Information System (GIS) techniques has proved to be an efficient tool in drainage delineation and their updation for morphometric analysis (Chopra et al. 2005; Patel and Dholakia 2010a, b). Nookaratnam et al. (2005) have carried out check dam positioning by prioritization of micro watersheds using Sediment Yield Index (SYI) and morphometric analysis. Prioritization of Mohr watershed, lying between Sabarkantha and Kheda district, Gujarat has been carried out by Thakkar and Dhiman (2007). By prioritization of watersheds, one can conclude which watershed can lead higher amount of discharge due to excessive amount of rainfall. Recently, Singh et al. (2009) have represented a case study to select suitable sites for water harvesting structures in Soankhand watershed, Punjab by overlaying of DEM, soil map and slope map using RS and GIS approach. Watershed visualization is an important component to understand, analyze or explain the distribution of phenomena on the surface of the earth, and will become increasingly important as volumes of digital spatial data become more unmanageable (Buttenfield and Mackaness 1991). Geo-visualization has been characterized as a kind of geo information use with emphasis on individuals using interactive visual tools in the search for unknowns (MacEachren 1994).

The present study is focused on the identification of suitable sites for positioning of water harvesting structure such as check dams in Varekhadi watershed, based on Geo-visualization concept with watershed prioritization using morphometric analysis. The prioritization concept is helpful to understand the morphology of individual watersheds, whereas the Geo-visualization concept is useful in positioning the ideal site for water harvesting structure. This study is an attempt to visualize a site and take the decisions for positioning an appropriate water harvesting structure remotely. In this way a lot of expenses and labour may be saved involved in costly field visits. These

structures directly check the excessive water coming from the watersheds and hence, lead the soil and water conservation. Thus, the study envisages suitability for water harvesting structure in watershed, which can help to increase water potential for irrigation and domestic purpose.

Study Area

The Varekhadi watershed, a part of the LTB of Surat district in Gujarat, covering an area of 1500 km² and is bounded by North latitudes 21° 00" to 21° 30" and East longitudes 73° 15" to 73° 45". The study area is located immediately downstream of the Ukai reservoir, the main reservoir on the LTB, and extends up to 65 km. The left bank canal of Ukai reservoir passes through Varekhadi watershed no. 7, 8, 9, 10, 17 and 18. At 25 km downstream of Ukai reservoir, Kakrapar weir is situated on river Tapi, which leads left bank and right bank canal and also passes through some watersheds (Fig. 1). The topography in LTB comprises narrow valley and gently sloping ground (Central Water Commission 2000–2001). The mean daily maximum temperature in study area rises up to 44.4°C in summer, while mean daily minimum temperature can be as low as 10°C in winter. In LTB, humidity varies from 40% to 80% and an average annual rainfall is 1376 mm. The main crops are sugarcane and cotton, mainly irrigated by Kakrapar left bank and right bank canal.

Methodology

Geo Referencing and Digitization

Toposheets of Varekhadi watershed, having 1:50,000 scales lies into no. 46 G/3, 4, 7, 8, 11 and 12 were collected from Survey of India (SOI), regional department, Ahmedabad. The topo map was then scanned with 400 dpi resolution. Scanned map was geo-referenced in Arc GIS 9.1 software, provided by BISAG, by taking four corners latitudes and longitudes. Later it was converted into GCS-WGS-1984 projection system. The shape files for contours and drainages are digitized from the registered toposheets. Human errors produced during digitization process such as over shoot/under shoot, dangling, overlapping

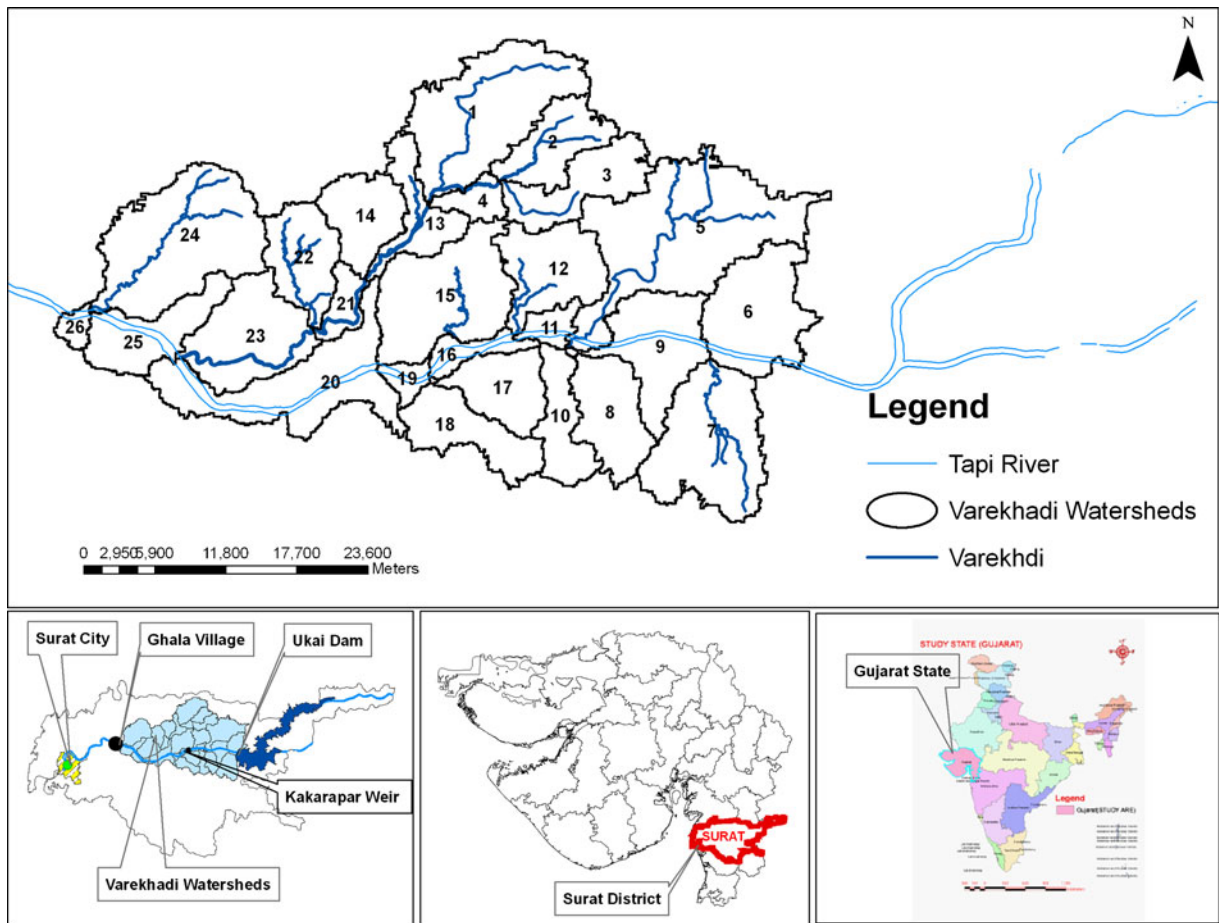


Fig. 1 Location map of the study area

and intersection were removed. The Shuttle Radar Topography Mission (SRTM) C band radar data was used to derive the digital elevation model and slope of the area. The accuracy evaluation of the SRTM has done by the digitized contour and slope map of the area. The accuracy of x, y and z obtained for this application are $x=90$ m, $y=90$ m and $z=\pm 16$ m. SRTM is a good choice for this study because of its free availability, easy processing in GIS environment and nearly equal or higher accuracy than ASTER (Dowman and Balan 2007; Hubbard et al. 2007; Fujita et al. 2008).

Thematic Maps

Drainage Map

The drainage map was prepared by digitizing drainage from SOI toposheets (Fig. 2). Using drainage

delineation tool and SRTM, drainages are delineated in the study area and are corrected by making comparison with SOI toposheets in GIS environment. Each stream has given order number by following the Horton’s (1945) stream ordering technique. The morphometric parameters for the delineated watershed area were calculated based on the formula suggested by Horton (1945), Miller (1953), Schumm (1956), Strahler (1964), Nookaratnam et al. (2005) and Thakkar and Dhiman (2007) and are given in Table 1.

Slope Map

The slope map was prepared from SRTM and contour map. 3D analyst tool is then used to convert digitized contours into Triangulated Irregular Network (TIN) model and then to DEM (Fig. 3). From this DEM, slope map was generated using this process: Arc GIS-

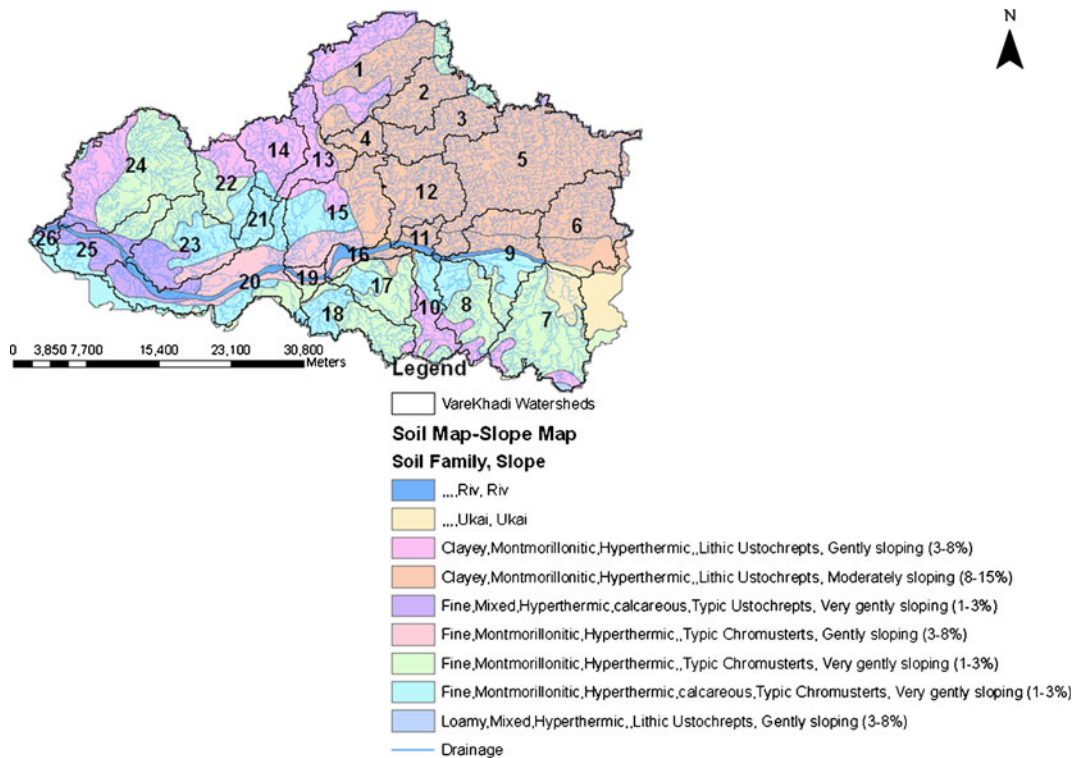


Fig. 2 Overlaid soil, slope and drainage map of the study area

3D Analyst tool- Surface analysis- Slope- Percentage function. Slopes were classified on the basis of the guidelines mentioned in Integrated Mission for Sustainable Development (IMSD) document, Department of Space, India, http://www.ncap.res.in/upload_files/workshop/. In the study area, slopes were categorized as: low slope (1–3%), moderate slope (3–8%) and high slope (8–15%). Slope map of the area suggested that most of the terrain in the North-East was characterized by a higher slope, may be responsible for a higher runoff in this region, while the South and West part of the terrain comes under lower slope category may be responsible for a higher water logging in this area. Most of the moderate slope category can be seen in North side of the area, responsible for intermediate rate of runoff in the watershed.

Soil Map

Soil map prepared by the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), NRIS (National (Natural) Resources Information

System), Technical Bulletin- Report on Reconnaissance Soil Survey of Surat District. (Department of Agriculture, Gujarat State, Ahmedabad-6) is used for the study. Here, soil series are Baldha, Bilimoda and Tadkeshwar-II. The soil units on the soil map are associations of sub- groups. In the sites, Lithic Ustochrepts, Typic Chromusterts, Typic Ustochrepts are subgroups (shown in Fig. 2, Table 2). The two major type of soil order found in the region are Inceptisol and Vertisol (Fig. 4). Inceptisols are soils just starting to show horizon development because the soil is quite young. Inceptisols are found in any type of environment and are commonly found forming in alluvium on floodplains and delta deposits. Vertisols are dark black soils rich in expandable clay minerals. Though found in every type of climate, they are often found in steppe and wet/dry tropical climates where the soil develops deep cracks as it dries (USDA soil classification <http://soils.usda.gov/technical/classification/>). Hydrological responses to rainfall strongly depend on local characteristics of soil, such as water storage capacity and infiltration rates (WMO 2007).

Table 1 Empirical formulas for computation of morphometric parameters

Morphometric parameters	Formula	Reference
Area of the Basin	$A = \text{Area of the Basin in km}^2$	Nookaratnam et al. (2005)
Perimeter of Basin	$P = \text{Perimeter in km.}$	Nookaratnam et al. (2005)
Total No of streams	$N = \text{No. of streams}$	Nookaratnam et al. (2005)
Total No of first order streams	$N_1 = \text{Total no. of first order streams}$	
Stream Order (u)	Hierarchical rank	Strahler (1964)
Basin Length (L_b)	$L_b = 1.312 \times A^{0.568}$ Where, $L_b = \text{Length of Basin (km)}$ $A = \text{Area of Basin (km}^2)$	Nookaratnam et al. (2005)
Stream Length (L)	Length of the stream	Horton (1945)
Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$ Where, $R_b = \text{Bifurcation Ratio}$ $N_u = \text{Total number of stream segment of order 'u'}$ $N_{u+1} = \text{Number of segment of next higher order}$	Schumn (1956)
Drainage Density (D_d)	$D_d = L_u / A$ Where, $D_d = \text{Drainage density}$ $L_u = \text{Total stream length of all order}$ $A = \text{Area of the basin}$	Horton (1945)
Stream Frequency (F_u)	$F_u = N_u / A$ Where, $F_u = \text{Total number of streams of all order}$ $A = \text{Area of the Basin (km}^2)$	Horton (1945)
Texture Ratio (T)	$T = N_u / P$ Where, $N_u = \text{Total number of streams of all orders}$ $P = \text{Perimeter (km)}$	Horton (1945)
Length of Overland Flow (L_o)	$L_o = 1/2 D_d$ Where, $L_o = \text{Length of the Overland Flow}$ $D = \text{Drainage density}$	Horton (1945)
Form Factor (R_f)	$R_f = A / L_b^2$ Where, $R_f = \text{Form Factor}$ $A = \text{Area of the basin (km}^2)$ $L_b^2 = \text{Square of the basin length}$	Horton (1945)
Shape Factor (B_s)	$R_f = L_b^2 / A$ Where, $B_s = \text{Shape Factor}$ $A = \text{Area of the basin (km}^2)$ $L_b^2 = \text{Square of the basin length}$	Nookaratnam et al. (2005)
Elongation Ratio (R_e)	$R_e = (2/L_b) \times (A/\pi)^{1/2}$ Where, $R_e = \text{Elongation Ratio}$ $L_b = \text{Length of basin (km)}$ $A = \text{Area of the basin (km}^2)$	Schumn (1956)
Compactness Constant (C_c)	$C_c = 0.2821P/A^{0.5}$ Where, $C_c = \text{Compactness Constant}$ $A = \text{Area of the basin (km}^2)$ $P = \text{Perimeter of the basin (km)}$	Horton (1945)
Circularity Ratio (R_c)	$R_c = 4\pi A / P^2$ Where, $R_c = \text{Circularity Ratio}$ $A = \text{Area of the basin (km}^2)$ $P = \text{Perimeter (km)}$	Miller (1953)

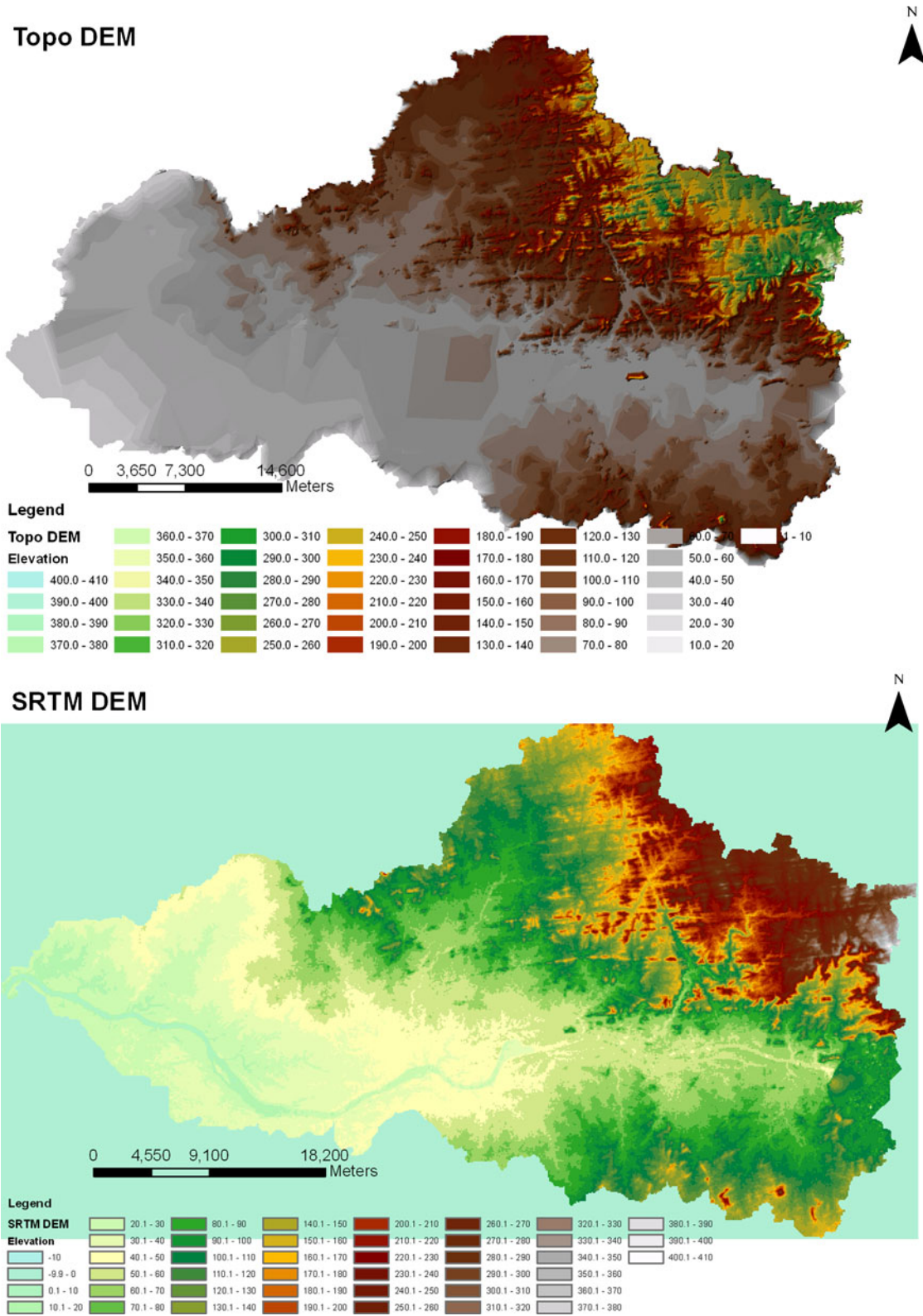


Fig. 3 Topo DEM and SRTM DEM of the Verakhadi watershed

Table 2 Soil classification of the study area

Sr. no	Soil series	Soil family	Order	Suborder	Great group	Subgroup
1	Baldha	Clayey, Montmorillonitic, Hyperthermic, Lithic Ustochrepts	Inceptisols	Ochrepts	Ustochrepts	Lithic Ustochrepts
	Bilimoda	Fine, Mixed, Hyperthermic, calcareous, Typic Ustochrepts				Typic Ustochrepts
2	Tadkeshwar-II	Fine, Montmorillonitic, Hyperthermic, calcareous, Typic Chromusterts	Vertisols	Usterts	Chromusterts	Typic Chromusterts

Morphometric Analysis

The information about basic morphometric parameters such as area (A), perimeter (P), length (L), number of streams (N) was obtained from mini watershed delineated layer and basin length (L_b) was calculated from stream length, while the bifurcation ratio (R_b) was calculated from the number of streams. Other morphometric parameters were calculated using the equations as described in Table 1. Linear parameters have a direct relationship with erodability by Nookaratnam et al. (2005), higher the value more is the erodability. The highest value of the linear parameter was ranked 1, the second highest value ranked 2 and so on. On the contrary, the shape parameters have an inverse relation with linear parameters, so that lower their value more is the erodability (Patel and Dholakia 2010a). Thus the lowest value of the shape parameter was rated as rank 1 and the second lowest as rank 2 and so on. Compound factor was then worked out by summing all the ranks of linear parameters as well as shape parameters and then dividing by number of parameters. From the group of these mini

watersheds, highest prioritized rank was assigned to the mini watershed having the lowest compound factor and so on.

Locating Suitable Sites for Water Harvesting Structure and Validation

To find suitable locations, site was visualized through fly tool of ArcScene 9.1 as per the priority assigned. It means higher ranked watersheds were visualized first and so on. Thus, we can visualize each mini watershed using morphometric analysis, and thus can find the best feasibility of positioning a water harvesting structure by overlaying of DEM, soil map and slope map along with guidelines of IMSD (Fig. 5). The proposed water harvesting structures has been validated with the data of previous water harvesting structures in the area.

Result and Discussion

Morphometric parameters were calculated using the formulas tabulated in Table 1 and the results are in Tables 3, 4 and 5.

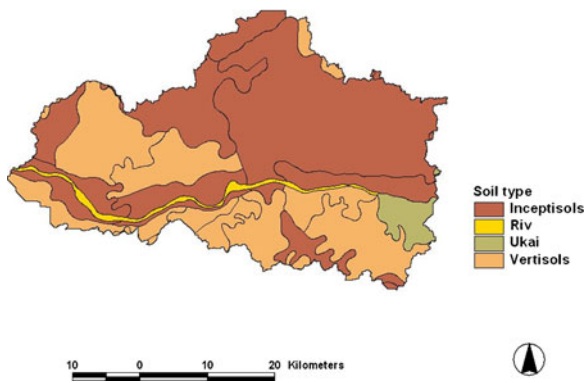


Fig. 4 Soil order map of the Verakhadi watershed

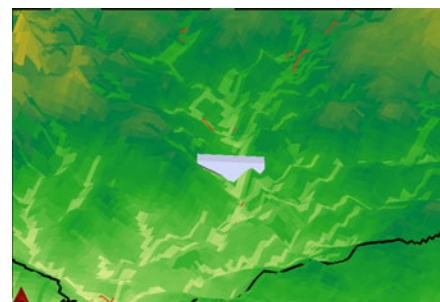


Fig. 5 A Positioned water harvesting structure by Geo-visualization concept

Table 3 Stream order of Varekhadi watersheds

Watershed no.	Stream orders							Total
	I	II	III	IV	V	VI	VII	
	I	II	III	IV	V	VI	VII	
1	405	108	37	25	9	2	0	586
2	95	56	25	9	0	0	0	185
3	215	62	22	6	11	0	0	316
4	44	10	4	0	2	0	0	60
5	673	220	130	36	29	26	0	1114
6	248	91	97	35	25	6	0	502
7	173	79	24	25	12	0	0	313
8	105	40	9	12	0	0	0	166
9	128	50	32	11	0	0	0	221
10	81	39	8	13	0	0	0	141
11	34	19	8	0	0	0	4	65
12	226	84	40	27	12	0	0	389
13	72	31	18	10	0	9	0	140
14	103	40	11	21	7	0	0	182
15	190	88	28	29	7	0	0	342
16	8	3	2	0	0	0	3	16
17	51	28	14	1	0	0	0	94
18	100	44	17	19	1	0	0	181
19	11	5	0	0	0	0	4	20
20	137	64	22	5	0	0	15	243
21	25	7	5	0	0	10	0	47
22	93	33	19	18	0	0	0	163
23	170	71	29	19	0	17	0	306
24	340	115	39	27	28	0	0	549
25	102	42	37	0	0	0	10	191
26	21	11	0	0	0	0	9	41
TOTAL	3850	1440	677	348	143	70	45	6573

Basic Parameters

Basic parameters include watershed area, perimeter, stream length, stream order and basin length (Table 4).

Area (A) and Perimeter (P)

The drainage area (A) is probably the single most important watershed characteristic for hydrologic design and reflects the volume of water that can be generated from rainfall. Present result shows that watershed no. 5 covers the maximum area of 156.92 km² while watershed no.26 has minimum area of 7.56 km². The basin perimeter (P) can be

represented as length of the line that defines the surface divide of the basin. Perimeters of watersheds are shown in Table 4; maximum and minimum values in watershed no. are same as the area parameter.

Total Length of Streams (L)

Addition of the lengths of all streams, in a particular order, defines total stream length. The numbers of streams of various orders in a mini watershed were counted and their lengths measured, shown in Table 4. These results help us to find the drainage density.

Stream Order (u)

The concept of stream order was introduced by Horton (1945) and Strahler (1964) to describe the basins in quantitative terms. This concept is applied with the linear dimension of the stream length. The first order stream has no tributary and its flow depends entirely on the surface overland flow to it. Likewise the second-order stream is formed by the junction of two first-order streams and as such has higher surface flow and the third-order stream receives flow from two second-order streams. This supplemented the study of stream order of the watershed. Among 26 watersheds, no. 1, 5, 6 and 24 are the watersheds having stream no. 586, 1114, 502 and 549 respectively as shown in Table 3. In watersheds no. 1 out of 586 streams, 405 are having stream order I, whereas none is having stream order VII. 26 streams in watersheds no. 5 are having stream order VI, whereas 15 streams are having stream order VII in watersheds no. 20.

Basin Length (L_b)

The basin length (L_b) is one of the watershed characteristics of interest and is important in hydrologic computations and increases as the drainages increases and vice versa. Basin length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. Since the channel does not extend to the basin-divide, it is necessary to extend a line from the end of the channel to the basin-divide following a path where the greatest volume of water would travel. Thus, the length is measured along the principal flow path. Basin length is the basic input parameter to count the

Table 4 Analyzed morphometric parameters

Watershed no.	Basic parameter					Linear parameter					Shape parameter					
	A km ²	P km	L km	N	N ₁	L _b km	R _b	D _d km/ km ²	F _u No/ km ²	T	L _o	R _f	B _s	R _c	C _c	R _c
1	111.15	80.23	373.57	586.00	405.00	19.06	3.09	3.36	5.27	5.05	1.68	0.31	3.27	0.62	2.15	0.22
2	42.85	52.36	147.87	185.00	95.00	11.09	2.24	3.45	4.32	1.81	1.73	0.35	2.87	0.67	2.26	0.20
3	49.26	61.42	178.11	316.00	215.00	12.00	2.62	3.62	6.41	3.50	1.81	0.34	2.92	0.66	2.47	0.16
4	14.91	26.10	42.75	60.00	44.00	6.09	2.97	2.87	4.02	1.69	1.43	0.40	2.49	0.72	1.91	0.28
5	156.92	118.76	555.90	1114.00	673.00	23.18	2.14	3.54	7.10	5.67	1.77	0.29	3.42	0.61	2.67	0.14
6	73.61	58.05	208.43	502.00	248.00	15.08	2.40	2.83	6.82	4.27	1.42	0.32	3.09	0.64	1.91	0.27
7	94.68	66.39	208.60	313.00	173.00	17.40	2.13	2.20	3.31	2.61	1.10	0.31	3.20	0.63	1.92	0.27
8	50.55	48.28	128.73	166.00	105.00	12.18	2.61	2.55	3.28	2.17	1.27	0.34	2.93	0.66	1.92	0.27
9	63.77	61.24	146.30	221.00	128.00	13.90	2.34	2.29	3.47	2.09	1.15	0.33	3.03	0.65	2.16	0.21
10	35.69	47.93	79.13	141.00	81.00	9.99	2.52	2.22	3.95	1.69	1.11	0.36	2.80	0.67	2.26	0.20
11	12.47	25.56	36.23	65.00	34.00	5.50	2.05	2.90	5.21	1.33	1.45	0.41	2.43	0.72	2.04	0.24
12	56.40	53.01	187.79	389.00	226.00	12.96	2.13	3.33	6.90	4.26	1.66	0.34	2.98	0.65	1.99	0.25
13	35.55	56.81	90.72	140.00	72.00	9.97	1.74	2.55	3.94	1.27	1.28	0.36	2.80	0.67	2.69	0.14
14	41.18	39.59	107.52	182.00	103.00	10.84	2.43	2.61	4.42	2.60	1.31	0.35	2.85	0.67	1.74	0.33
15	93.56	64.44	230.28	342.00	190.00	17.28	2.60	2.46	3.66	2.95	1.23	0.31	3.19	0.63	1.88	0.28
16	16.04	33.37	254.00	16.00	8.00	6.35	1.61	15.84	1.00	0.24	7.92	0.40	2.51	0.71	2.35	0.18
17	41.77	40.47	73.93	94.00	51.00	10.93	5.94	1.77	2.25	1.26	0.88	0.35	2.86	0.67	1.77	0.32
18	47.13	53.97	114.39	181.00	100.00	11.71	6.19	2.43	3.84	1.85	1.21	0.34	2.91	0.66	2.22	0.20
19	10.22	21.12	12.37	20.00	11.00	4.91	1.73	1.21	1.96	0.52	0.61	0.42	2.36	0.73	1.86	0.29
20	95.40	104.38	173.13	243.00	137.00	17.47	2.45	1.81	2.55	1.31	0.91	0.31	3.20	0.63	3.01	0.11
21	15.99	26.45	35.23	47.00	25.00	6.34	1.82	2.20	2.94	0.95	1.10	0.40	2.51	0.71	1.87	0.29
22	46.14	41.72	114.16	163.00	93.00	11.56	1.87	2.47	3.53	2.23	1.24	0.34	2.90	0.66	1.73	0.33
23	71.04	52.37	189.99	306.00	170.00	14.78	1.87	2.67	4.31	3.25	1.34	0.33	3.07	0.64	1.75	0.33
24	121.31	73.49	367.87	549.00	340.00	20.03	2.08	3.03	4.53	4.63	1.52	0.30	3.31	0.62	1.88	0.28
25	47.41	53.43	480.97	191.00	102.00	11.74	2.42	10.14	4.03	1.91	5.07	0.34	2.91	0.66	2.19	0.21
26	7.56	16.69	17.57	41.00	21.00	4.14	1.57	2.32	5.43	1.26	1.16	0.44	2.27	0.75	1.71	0.34

major shape parameters. In the result, basin length varies between 4.14 km and 23.18 km, shown in Table 4.

Linear Parameters

Linear parameters include bifurcation ratio, drainage density, stream frequency, texture ratio and length of overland flow.

Bifurcation Ration (R_b)

It is the ratio of the number of streams of a given order to the number of streams of the next higher order (Schumn 1956). Lower R_b values are the

characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag 1998). Table 4 shows that bifurcation ratios (R_b) of Varekhadi watersheds, watershed no. 26 has the least bifurcation ratio of 1.57 and no. 18 has maximum ratio of 6.19.

Drainage Density (D_d)

It is the ratio of the total length of streams within a watershed to the total area of the watershed; thus D_d has units of the reciprocal of length (1/L). A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response, values of D_d are as shown in Table 4.

Table 5 Calculation of Compound factor and prioritized ranks

Watershed No	R _b	D _d	F _u	T	L _o	R _f	B _s	R _c	C _c	R _c	Compound factor	Prioritized ranks
1	3	6	6	2	6	3	24	3	16	11	8	1
2	14	5	10	16	5	16	11	16	20	7	12	8
3	5	3	4	6	3	12	15	12	23	4	8.7	3
4	4	10	13	18	10	23	4	23	10	17	13.2	13
5	15	4	1	1	4	1	26	1	24	5	8.2	2
6	12	11	3	4	11	7	20	7	11	16	10.2	5
7	16	22	20	9	22	5	22	5	13	14	14.8	16
8	6	15	21	12	15	11	16	11	12	15	13.4	14
9	13	20	19	13	20	9	18	9	17	10	14.8	17
10	8	21	14	17	21	19	8	19	21	6	15.4	19
11	19	9	7	19	9	24	3	24	15	12	14.1	15
12	17	7	2	5	7	10	17	10	14	13	10.2	6
13	23	14	15	21	14	20	7	20	25	2	16.1	22
14	10	13	9	10	13	18	9	18	3	24	12.7	11
15	7	17	17	8	17	6	21	6	8	19	12.6	10
16	25	1	26	26	1	21	6	21	22	5	15.4	20
17	2	25	24	22	25	17	10	17	5	22	16.9	24
18	1	18	9	15	18	14	13	14	19	8	12.9	12
19	24	26	25	25	26	25	2	25	6	25	20.9	26
20	9	24	23	20	24	4	23	4	26	1	15.8	21
21	22	23	22	24	23	22	5	22	7	20	19	25
22	21	16	18	11	16	15	12	15	2	25	15.1	18
23	20	12	11	7	12	8	19	8	4	23	12.4	9
24	18	8	8	3	8	2	25	2	9	18	10.1	4
25	11	2	12	14	2	13	14	13	18	9	10.8	7
26	26	9	5	23	19	26	1	26	1	26	16.2	23

It is defined as the length of drainage per unit area. It is an inverse function of permeability and therefore is an important factor in runoff studies. The term was first introduced by Horton (1932) and is determined by dividing the total length of streams within a drainage basin by the drainage area. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrologic response to rainfall events, while a low drainage density means a poorly drained basin with a slow hydrologic response (Melton 1957; Gupta and Srivastava 2010). The drainage density can be defined as (Edet et al. 1998):

$$D_d = \frac{\sum_{i=1}^{i=n} S_i}{A}$$

where, $\sum_{i=1}^{i=n} S_i$ is the total length of drainage.

The drainage density indicated that only two watersheds are under high drainage density category, followed by rest of the watersheds (moderate drainage density category) with an average value of 2–4 km/km², except 17, 19 and 20 which was found under low drainage density category (0–2 km/km²). This analysis suggested that most of the watershed showed poorly drained basin with a slow hydrologic response. The two watersheds were found to be associated with a high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrologic response to rainfall events (Fig. 6).

Stream Frequency (F_w)

Stream frequency/channel frequency (F_w) is the total number of stream segments of all order per unit area (Horton 1932). Low value of stream frequency indicates low runoff value and increase in stream

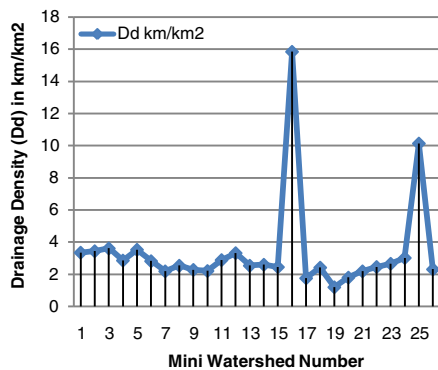


Fig. 6 Drainage density distribution of the study area

population with respect to drainage density. The value of stream frequency ranges from 1.0 to 7.10 for watershed no. 16 and 5, as shown in Table 4.

Texture Ratio (T)

The texture ratio can be defined as the ratio of total number of streams of first order to the perimeter of the basin. The value of the texture ratio ranges from 0.24 to 5.67 as shown in Table 4. These values of runoff show the moderate runoff.

Length of Overland Flow (L_o)

It is the length of water over the ground before it gets concentrated into definite stream channels and is equal to half of drainage density (Horton 1945). Length of overland flow relates inversely to the average channel slope. Table 4 reveals the length of overland flow for Varekhadi watersheds.

Shape Parameters

Shape parameters include form factor, shape factor, elongation ratio, compactness ratio and circulatory ratio.

Form Factor (R_f)

The form factor can be defined as the ratio of the area of the basin to square of the basin length (Horton 1945). The value of the form factor would always be less than 0.7854 (for a perfectly circular basin) (Chopra et al. 2005). Smaller the value of form factor, the basin will be more elongated. The

basin with high form factors have peak flow of shorter duration, whereas, elongated mini watershed with low form factors have lower peak flow with longer duration. In the present case the value of form factor is varied between 0.29, for watershed no. 5 and 0.44 for no. 26 as shown in Table 4. This value indicates the elongated shape of the basin and having flatter peak flow for longer duration, which helps to manage the flood easily than those of the circular basin.

Shape Factor (B_s)

The shape factor can be defined as the ratio of the square of the basin length to area of the basin (Horton 1945) and is in inverse proportion with form factor (R_f). Shape factor lies between 2.27 to 3.42 in present work, which indicates the elongated shapes of basin.

Elongation Ratio (R_e)

It is the ratio between the diameters of the circle of the same area as that of the drainage basin the maximum length of the basin. A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh 1997). The value of elongated ratio is varied between 0.6 and 1.0 are the typical regions of very low relief, whereas value ranged between 0.6 and 0.8 are associated with high relief and steep ground slope (Strahler 1964). The lower value of the elongation ratio indicates that particular mini watershed is more elongate than others. The elongation value can be grouped into three categories, namely circular basin ($R_e > 0.9$), Oval basin ($R_e: 0.9-0.8$), Less elongated basin ($R_e < 0.7$). In this study (Table 4), these values are less than 0.7 and hence the basins are elongated in shape.

Compactness Coefficient (C_c)

It can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and also known as the Gravelius Index (GI). This factor is indirectly related with the elongation of the basin area. Lower values of this parameter indicate the more elongation of the basin and less erosion, while higher values indicate the less elongation and high erosion. In this study, highest value is 3.01 while the lowest is 1.71 shown in Table 4.

Circularity Ratio (R_c)

It is a ratio of basin area (A) to the area of circle having the same circumference as the perimeter as basin (Miller 1953). It is affected by the length and frequency of the streams, geological structures, land use/land cover, climate, relief and slope of the basin. If the circularity in the main basin is minimum, it shows that the basin is less circular hence the discharge will be slow as compared to the others and so possibility of erosion will be less. In present study, maximum value is for watershed no. 26, which is 0.34 and minimum value is for watershed no. 20, which is 0.11.

Compound Factor and Ranking

Compound factor is calculated by summing all the ranks of linear parameters as well as shape parameters and then dividing by number of parameters. From the group of these mini watersheds, highest rank was assigned to the mini watershed having the lowest compound factor and so on. Depending upon the

value of compound factor, ranking to each mini watershed is assigned as shown in Fig. 7. For Varekhadi group of watersheds, watershed no. 1 is given rank 1 with least compound factor value at 8 and it is followed by watersheds no. 5 and 3, as second and third respectively. The values of compound factor and respective rank of all mini watersheds are shown in Table 5.

Positioning a Water Harvesting Structure and Validation

Watershed no. 20 and 23 are covered under Kakrapar right bank canal whereas left bank canal covers watershed no. 18 and 25. Ukai left bank canal covers watershed no. 7, 8, 9, 10, 17 and 18. As above watersheds are associated with canal network so that water harvesting structure is not feasible. It was found that the categorization of water harvesting structures by RS and GIS techniques was in close agreement with the available data. Total 8 points are suggested for the water harvesting structures, in which five coincides (Weirs numbers are 2, 3, 12, 13 and 15)

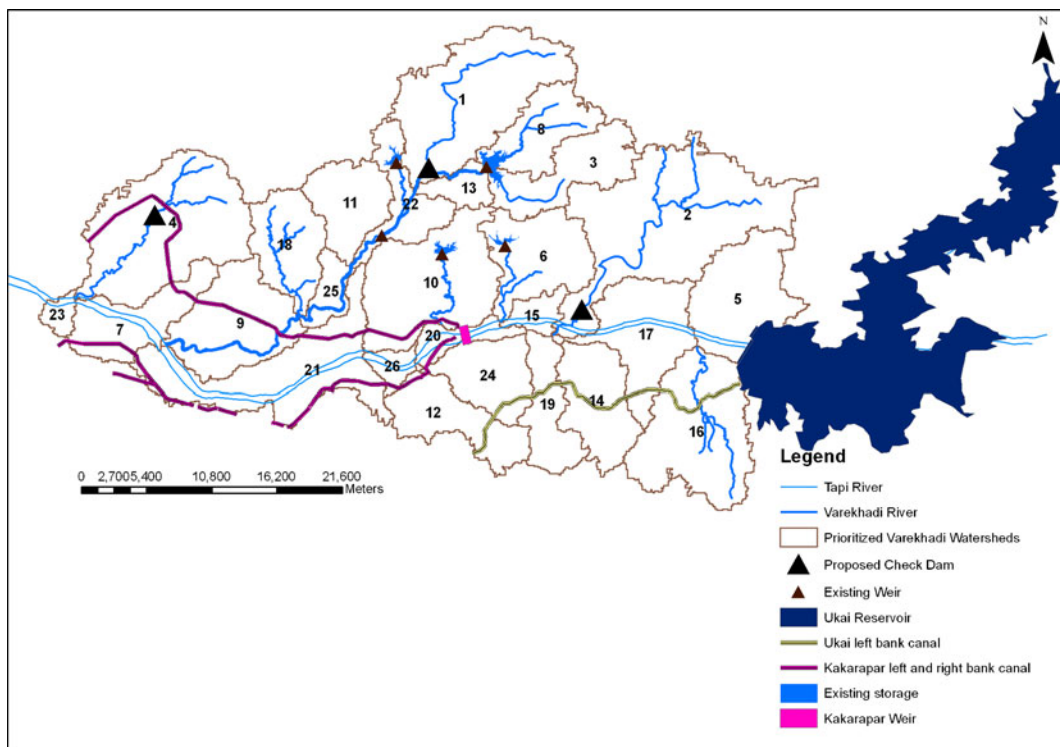


Fig. 7 Proposed water storage structures at Varekhadi mini watersheds

exactly with the structures made with Government of Gujarat. The others points where there is a need of these water harvesting structures are suggested in mini-watershed no. 1, 5 and 24 (Fig. 7). These analyses show that the priority based characterization is a promising approach for water harvesting structures allotment in the watersheds. Timely placement of these structures may reduce a number of losses and flood in the downstream area.

Summary and Conclusions

The study demonstrated SRTM and topographical map along with GIS technique be a highly efficient tool for delineating mini watersheds and drainage without RS data. Morphometric analysis is a very useful tool for prioritization of mini watersheds. The combination of morphometric analysis and Geo-visualization is helpful for positioning a water harvesting structure in Varekhadi mini watersheds. These structures directly check the excessive water coming from the Varekhadi mini watersheds. It leads the soil as well as water conservation and reduces the high run off and flood potential. Thus, for sustainable development of watersheds, soil and water conservation can be done by positioning suitable water harvesting structure in Varekhadi watersheds.

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