Morphometric analyses for prioritization of micro-watersheds in Ahad watershed around Udaipur city of Rajasthan state, India: Applications of geoinformatics

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Abstract: Udaipur city of Rajasthan state is a world famous tourist hub due to its scenic beauty, history for valor and chivalry and strategic location. But due to excessive industrialization, mining, influx of tourists and population sprawl, the area is undergoing an environmental stress. Ahad watershed, encircling Udaipur city, divides the drainage systems of the Bay of Bengal and the Arabian Sea and covers 88% of Udaipur and 12% area of Rajsamand district of Rajasthan state. Its morphometric analyses reveals development unto 7^{th} order, a mature and well developed watershed. To prioritize the work at a smallest workable unit, a micro-watershed in each sub- and its mini-watershed has been selected based on developmental criteria. Morphometric analyses carried out of micro-watershed in GIS environ supports the prioritization. Field verification confirms the findings. Study wraps up that drainage morphometric analyses supported with geographic, spatial and non-spatial parameters leads for precise prioritization for developmental plan at grass root level.

Keywords: Watershed, Geoinformatics, morphometry, prioritization, Ahad, Udaipur

1. Preamble

Morphometric studies in the field of hydrology were first initiated by Hortan (1945) for the measurement of shapes. Drainage watershed morphometry is a measurement, calculation and analyses for an ideal areal hydrologic unit, for the interpretation and analyses of its various parameters.

Watershed experiences an orderly growth, in terms of law of allometric growth, indicating dynamic nature of development; but tectonic, climatic and biotic factors introduce anomalies in its systematic natural growth.

A holistic approach towards comparing development of micro-watersheds with the drainage morphometry analyses of an area, in Natural Resource Management, is adopted by many Indian researchers viz. Hegde et al. (1991), Narendra and Rao (2006), Singh (2006) and many others.

This paper describes prioritization of micro-watersheds in a watershed using drainage morphometry analysis by applying Geoinformatics along with collaborative data, evidences and limited field work at cadastral level to prepare developmental plan for its effective utilization in the field.

2. Data used

Remote sensing data of IRS 1D AWiFS with 180m resolution, LISS-III temporal data with 23m resolution of October 2005, January and May 2006 have been used for reconnoiter studies. High resolution satellite data have been utilized for detail case studies. Survey of India sheets, surveyed during 1936-46 and 1967-72 are used. Collateral data, pertaining to the area, available with various governmental/non-governmental organizations have been used.

ENVI 4.0 and Arc GIS 9.2 software have been used for image processing and GIS in UTM projection and WGS 84 datum for generation of various thematic, non-thematic and derived layers and query system to analyze and retrieve information to achieve the goal.

3. Method adopted

- National water divide criteria based selection of watershed around Udaipur city from AISLUS (1990) Atlas.
- Reconnoiter survey using multi-satellite temporal remotely sensed data.
- Preparation of satellite data mosaic and clipping of watershed.
- Demarcation of drainages from SoI sheets and remotely sensed data as polyline in GIS environ as a single unit unto joining to next segment. Width is taken as a single line passing through centre of water bodies/drainage and continuity has been extrapolated over gaps.
- Calculation and analyses of various morphometric parameters of the watershed, to understand behavior of watershed.
- Division of watershed into sub-, mini- and micro-watershed to narrow down studies and assess morphometric parameters at smallest workable unit.
- Prioritization based on development and comparison with morphometric analyses.

4. Ahad watershed and its morphometry

Ahad watershed 2D2F7 is bounded by 73°30’ to 74°04’E longitude and 24°25’ to 24°55’N latitude and covers an area of 1,728 km^2. On its southwest a major surface water divide exists with water flowing about 1500 km east into the Bay of Bengal and 300 km south into the Arabian Sea. Geologically watershed comprises Archaean to Lower Proterozoic era rocks. To understand watershed's behavior, morphometric parameters are calculated and analyzed (Table 1).

4.1. Number and order of streams

There are total 4014 stream segments linked with 7th order stream. 1st order has highest 2915 number of segments which gradually reduces to 1 with 7th order segment through which whole water discharges (Figure 1). Throughout, the law of lower the order higher the number of streams is implied. Development unto 7th order is indicative of mature and well developed watershed.

4.2. Length of streams (l)

Total length of drainages is 3315.91 km. It varies within the watershed and the order e.g. the smallest stream measured for 1st order is 100 m on the westernmost side in hills while longest 1st order measured 5.2 km on the plain area in northeast.

Order length is indicative of chronological developments of the stream segments including interlude tectonic disturbances. Generally higher the order, longer the length of streams is observed in nature. But here 8.4 km 6th order stream is shorter than that of two 5th order streams i.e. 8.58 and 10.25 km, suggesting anomalous development. Also the 89.04 km total length of 6th order, more than 5th order of 61.16 km, again signifies anomaly.

4.3. Drainage density (Dd)

Characteristically Archaean rocks are hard, impermeable and resistant to erosion. But in time, as it underwent various tectonic upheavals, became prone to shear, joints and fissures. This resulted into higher drainage density on hard exposed elevated terrain in the western part leading to higher run off than the eastern soily plains. Poor drainage density on eastern side indicates higher ground water recharge reflected with intense well irrigation. Drainage density calculated for the watershed is 1.92 km/km^2.

4.4. Stream frequency (Sf)

Higher stream frequency in northwest and southwest portion of watershed suggests higher slope intensity, rainfall and forests; indicating growth of newer drainages and/or lengthening of the existing streams. Sf, expressed as number of all order streams/area, for watershed is 2.32 /km^2.

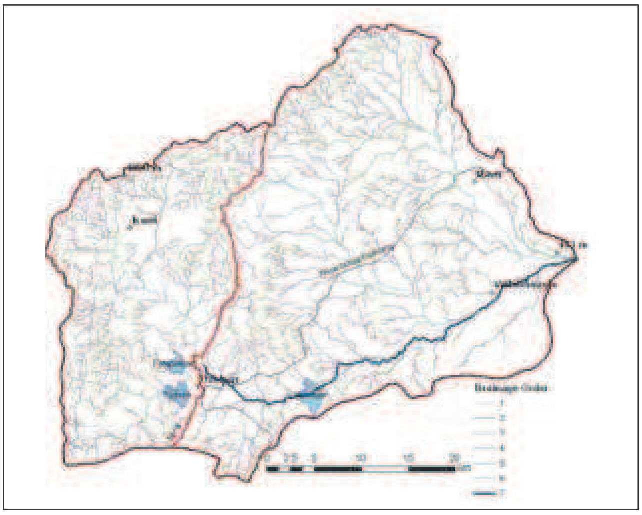

Figure 1: Drainage orders

4.5. Circulatory ratio (Rc)

Rc of the watershed is 0.56 which is a ratio of watershed area to the surface area of a circle holding the same perimeter of the watershed. Higher the Rc means more the circularity of watershed and quicker the discharge. Maximum value for circulatory ratio is 1.

4.6. Infiltration number (In)

It is influenced by the rock types, slope, subsoil texture and vegetation cover; causing obstruction to surface water flow and allow to infiltrate.

Infiltration number is a multiple functions of the drainage density and drainage frequency with maximum value of Dd/Sf = 1. In value of 0.k83 for this watershed indicates more percolation in the region.

5. Morphometry of sub-watersheds

To narrow down studies for further developmental strategy, watershed is subdivided into 12 sub-watersheds (Figure 2).

Table 1: Morphometric results of watershed

SN	Order	No of Streams	Length km	Area km^2	Perimeter(km)	Dd km/km^2	Sf km^2	Rb	Rc	In
1	1st	2915	1632.9					3.58		
2	2nd	815	713.97					3.74		
3	3rd	218	471.16					4.27		
4	4th	51	296.15	1727.95	197.55	1.92	2.32	5.1	0.56	0.83
5	5th	10	61.16					2.5		
6	6th	4	89.04					4		
7	7th	1	51.53					-		
Total		**4014**	**3315.91**	**1727.95**	**197.55**	**1.92**	**2.32**	**-**	**0.56**	**0.83**

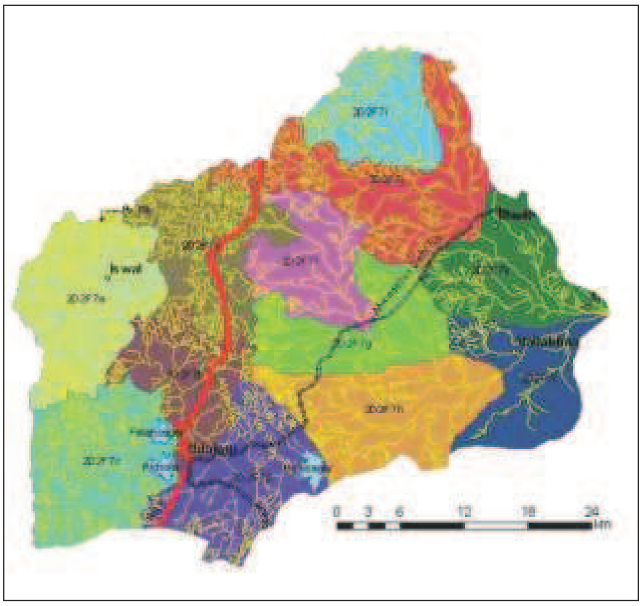

Figure 2: Sub watersheds with drainages

5.1. Analyses

Parameters of sub-watersheds were calculated as per the criteria of morphometric analyses. Based on all calculations and summing up, it is revealed that sub-watersheds 2D2F7a, 2D2F7g and 2D2F7l show better development in descending order to be opted accordingly for development (Table 2). Values in italics show parameters for developed and bold for undeveloped.

As a developmental strategy, morphometric analyses based selected sub-watersheds were further compared with their geographic, spatial and non-spatial attributes (Table 3).

Amongst selected sub-watersheds, 2D2F7a is least developed; geographically it is on higher altitude, steeper slope, massive rocky area with ridges and valleys, lower population density with higher scheduled tribe population. Spatially poor built up density and least irrigation, highly forested with more wastelands. Sub-watershed 2D2F7l is most developed; has lower altitude, gentle slope and higher population density with lower scheduled tribe population. Spatially more built up density and maximum irrigation, no forests with fewer wastelands. Sub-watershed 2D2F7g has an intermediate developmental stage.

This way least developed sub-watershed 2D2F7a is to be selected on priority basis for its development which is also supported by prioritization through morphometric analyses.

6. Developmental planning

These three prioritized sub-watersheds fall in upper, middle and lower part of the Ahad watershed respectively and vary in their characteristics. To assess an effective impact of various developmental programs at grass roots level in the watershed, sub-watersheds have been divided into their respective mini- and micro-watersheds ranging between 1-20 km^2 sizes (Figure 3). 2D2F7a has been subdivided into 5 mini- and 28 micro-; 2D2F7g into 4 mini- and 14 micro- and 2D2F7l into 3 mini- and 14 micro-watersheds.

Figure 3: Location of prioritized sub-watersheds

A single micro-watershed from each sub-watershed has been selected based on:

- Rugged topography with high gradient
- Type and coverage of wastelands with convertibility into arable land
- Least irrigation and more rain-fed areas
- Degraded forests cover
- Higher percentage of backward class population
- Poor infrastructure facilities

Each micro-watershed was registered on high resolution satellite data under GIS environment, studied and compared in alliance with secondary data.

Morphometric analyses of micro-watersheds and its comparison with geographic, spatial and non-spatial attributes on above line displays that micro-watersheds 2D2F7a4g, 2D2F7g1b and 2D2F7l1a (Figure 4) as the least developed in descending order in their respective sub-watershed.

Village layer was overlaid and micro-watershed was ascertained village boundaries.

A pre-field Landuse/Landcover (LU/LC) plan is generated by employing expertise gained in R S & GIS subject and field knowledge. Taking smallest visible unit into consideration, all land use classes viz. agriculture, forests, wastelands, water bodies, built-up areas, mining areas etc. were demarcated.

Table 2: Morphometric parameters of sub-watersheds

SN	Sub -watershed No.	Order	No. of Streams	Length-km	Area km^2	Perimeter km	Dd	Sf	Rc	In
1	2D2F7a	6^{th}	582	498.05	177	68.92	7.22	3.29	0.47	*2.19*
2	2D2F7b	7^{th}	257	239.91	114.4	62.16	2.1	2.25	0.37	0.93
3	2D2F7c	6^{th}	543	540.21	173.1	60.38	3.12	3.14	0.60	0.99
4	2D2F7d	7^{th}	363	294.06	154	61.38	1.91	2.36	0.51	0.81
5	2D2F7e	6^{th}	485	424.44	148.7	83.69	2.85	3.26	0.27	0.87
6	2D2F7f	6^{th}	*168*	157.42	105.1	61.81	1.5	1.6	0.35	0.94
7	2D2F7g	6^{th}	248	294.46	124.9	67.84	2.36	1.99	0.34	1.86
8	2D2F7h	7^{th}	292	376.33	175.2	65.69	2.14	1.67	0.51	1.28
9	2D2F7i	5^{th}	317	294.51	107	106.99	2.75	2.96	*0.12*	0.93
10	2D2F7j	6^{th}	518	447.65	196.2	106.99	2.28	2.64	0.22	0.86
11	2D2F7k	7^{th}	169	189.27	131.9	55.52	1.43	1.28	0.54	1.12
12	2D2F7l	7^{th}	*85*	*107.04*	120.7	60.85	*0.89*	*0.7*	0.41	1.27

Developed **Undeveloped**

Table 3: Comparison of 2D2F7a, 2D2F7g & 2D2F7l sub-watersheds

Details			Parameters		
Geographical	Sub-watershed no.		**2D2F7a**	**2D2F7g**	**2D2F7l**
	Location in WS		NW	Middle	SE
	Altitude-m		1040-700	820-520	520-480
	Slope & Direction		Steep, SE	Gentle, WE	Gentler, NE
	Average Rainfalls		596-608mm	602-607mm	605-608mm
	Rainwater/yr		$151Mm^3$	$74.91Mm^3$	$109.8Mm^3$
	Geology		Granite Gneiss, Meta siltstone, Dolomitic Marble, Phyllite chlorite mica schist, Garnetiferous mica schist	Migmatite Gneiss & felspathoid, Quart-zite with interbands of phyllite	Granite, Granodiorite & Ionalitic Gneiss, Carbo-natite, Migmatite Gneiss & felspathoid schist
	Lineaments		Many	Few	Few
	Geomorphology		Ridges & valleys	Pediplains	Pediplains
	G W level	Pre	13-15m	11-14m	13-15m
		Post	5-6m	3-5m	6-7m
	G W quality	Pre	1000ppm	1000-1500ppm	1500ppm
		Post	1000ppm	1500ppm	1500-2000ppm
Spatial	Area-km^2		251	125	183
	Built up density		Poor	Higher	Medium
	Forests-km^2		27	11	3
	Irrigated Area		14	19	34
	Unirrigated Area-km^2		36	78	59
	Culturable waste- km^2		104	85	49
	Unculturable waste-km^2		71	54	39
Non-spatial	No. of villages		47	46	38
	Total Population		48815	67126	45383
	Population density km^2		194	538	247
	SC Population		3431	5854	4221
	ST Population		19958	16906	7301
	SC/ST density		93	187	63
Morpho-metric	No. of Streams		582	248	85
	Length of Streams-km		498.05	294.46	107.04
	Drainage density		7.22	2.36	0.89
	Stream frequency		3.29	1.99	0.7
	Circulatory		0.47	0.34	0.41
	Infiltration Ratio		2.19	1.86	1.27

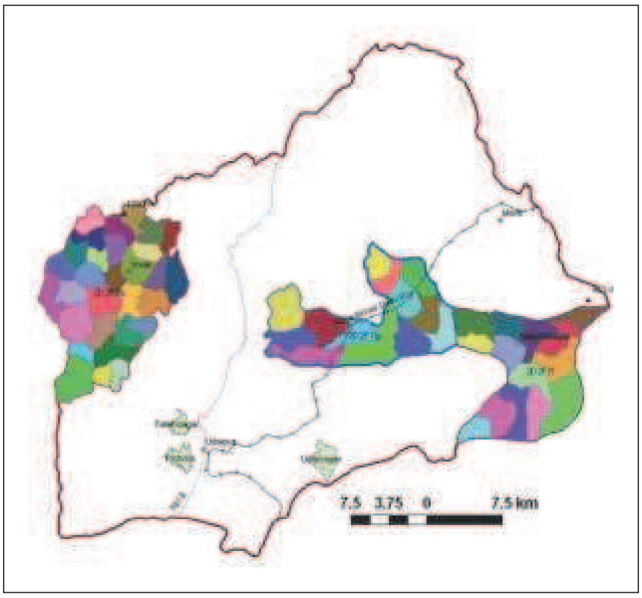

Figure 4: Prioritized micro-watersheds

Limited field check was made to ascertain the findings which supported the results. A land and water resource action plan (Figure 5) is generated to show the way of development in the region.

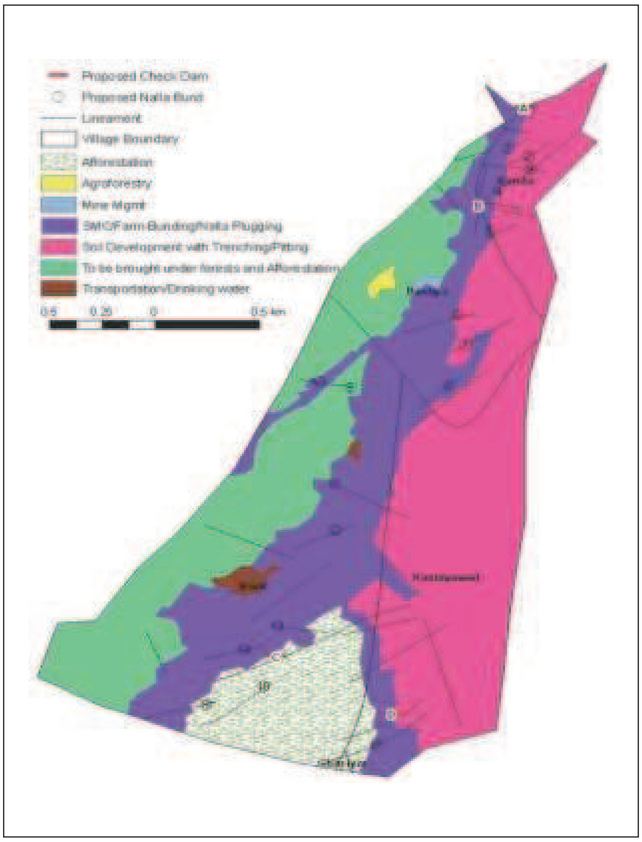

Figure 5: Land and water resource action plan for 2D2F7a4g micro-watershed

Conclusions

Sub-watersheds 2D2F7a, 2D2F7g and 2D2F7l of Ahad watershed could be prioritized on its developmental stage on the basis of its morphometric analyses. Its geographic, spatial and non-spatial parameters studied through Geoinformatics also supported.

Study reveals that classification of sub-watersheds into mini- and micro-watersheds and its criteria based selection with morphometric analyses supported with geographic, spatial and non-spatial parameters lead for better prioritization for developmental action plan at grass root level.

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