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Morphometric Analysis of Baltira Watershed Using QGIS Platform

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Abstract*: In India due to rising in the population, resources like land and water goes on decreasing. So, it is absolutely necessary to conserve these natural resources and exertion of the resources in an effective way. From the administrative point of view, the watersheds act as the basic units for conservation of resources. For detail characterization of landforms and properties, the morphometric analysis of basins is of great help in understanding by interpreting the information available from dimensionless analysis which helps to find out the linear and aerial aspects. Morphometric analysis is the most acceptable method to be considered for reservoir basin. For developing the topographic and geomorphologic conditions, it is necessary to understand various parameters of diverse basins. In this study, a detailed morphometric assessment is done by QGIS for Baltira watershed which covers an area of 273 km^2. Baltira is one of the tributaries of Man River. The result of morphometric analysis reveals that watershed of Baltira in which geology is reasonably homogeneous, having high relief and steep ground slope. For this study, ASTER-DEM is utilized for watershed delineation and drainage parameter calculation by the hydrological module of QGIS software.

Index Terms: **ASTER, Baltira, Morphometry, QGIS**

I. INTRODUCTION

The constant growth in urbanization and population causes overutilization of the natural resources and also the climate changes [1]-[4]. Due to this, proper storage and management plan for water becomes complicated [5]. Thus, there is an instant demand for the water resources assessment as it is vital for achieving sustainability and has been in focus all over the globe [6]. Morphometry is referred to as measuring and mathematically analyzing the surface configuration, including the dimension and shape of the landforms, physical properties, interrelationship of morphological characteristics and hydrological behavior [7].

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The most important information of any watershed can be estimated using Morphometric analysis, which accounts for the hydro morphological processes of the basin and describes the crucial drainage system quantitatively [8]. Ground water is the cheapest source of drinking water and knowledge about its quality is essential for efficient utilization.

Under natural condition composition of groundwater depends upon rainwater, soil and aquifer material [9]. Regarding earth's water balance components, a vast majority (97.2%) is saline water whereas the remaining portion is fresh water. Over one-fifth of this available freshwater is constituted by groundwater, which is regarded as the most reliable source of clean water and also fulfils the industrial, agricultural and domestic needs of mankind [10]. Nevertheless, the anthropogenic activities like land use changes, discharge of effluents and the resultant disturbances in geology have remarkable negative effects on the quality of groundwater. Assessment of morphometric parameters requires the examination of different drainage parameters, for example, basin relief, bifurcation ratio, stream order, stream frequency drainage density, drainage length, basin perimeter and area etc. The primary goal of this examination is to figure out different drainage parameters in order to develop of a better understanding of the drainage basin. Further, the topography of the watershed can also be depicted precisely, which helps in minimizing the risks involved in watershed planning and management. Ultimately, the various land use practices can also be monitored in a better way if the morphometric assessment is taken into account [11]. This work aims to perform quantitative analysis of various hydro-morphological parameters over Baltira watershed, Maharashtra, India. Maharashtra has been prone to the water availability problems very frequently across its several parts. Therefore, this case study is carried out at a very finer spatial unit (273 km^2) so as to better analyze the key factors, which can help the policymakers to make efficient management plans.

II. STUDY AREA

The study area is situated about 90 km North Eastern part of Sangli city. The study area lies between North Latitudes 17^o 18' to 17^o 28' and East longitudes 74^o 42' and 75^o 0'. The entire study area is delineated from survey of India topographic map numbers 47 K/11 and 47 K/15. The minimum elevation is 540 m and maximum elevation is 834 m. Drought in the semi-arid regions is quite common due to the low rainfall rate and insufficient irrigation during dry periods. Furthermore, the availability of surface water resources is also scanty.

Thus, the groundwater resources in this area are under a rising demand [12]. Therefore, failure of open dug well and tube well is common feature in the hard rock regions of the Deccan trap area. This issue, in general, gets aggravated due to lack of exact water potential areas or improper utilization of water (e.g. excessive pumping from wells). The study area and its location details are represented in Figure 1.

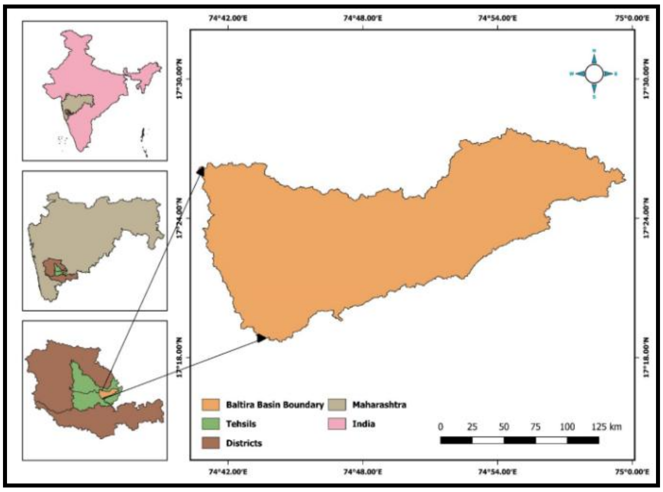

Fig. 1. Location Map of Baltira Watershed (Maharashtra, India)

Man River is a tributary of Bhima River, which originates from severe drought prone region of Satara district of Maharashtra. Baltira is one of the tributaries of Man River and its watershed consists of the catchment areas of mainly Atpadi and Sangola tehsils of Sangli and Sholapur districts respectively. Atpadi is a big settlement in eastern part of Sangli district and is also tehsil headquarter of Sangli district. The study area of Baltira basin consists of number of tributaries such as Shukra Nala, Dhandar Nala, Dabucha Nala and Khavni Nala. The watershed of Baltira consists of Atpadi city at centre and parts of Deshmukhnagar, Pandharevadi, Ambiwadi, Pujariwadi, Atpadi, Nangremala, Maptemala, Bhingevadi, Mitkiwadi, Kamath, Jambhulni, Ghanand, Chinchale, Kharsundi, Thoratwadi, Valvan, Ghamki, Pedhalkarwadi, and Jalki Taraswadi from East to West direction along the channel of different tributaries of the river. These surrounding villages are mainly covered by agriculture, forest, revenue and residential areas. It is a unique watershed with village boundary coinciding with the watershed boundary of its greatest extent. This area from Atpadi Taluka of Maharashtra is prone to severe and chronic droughts. Hence, the research work of not only watershed management and water budgeting of this region but also the new watershed design would help for soil and water conservation, groundwater recharge, agricultural growth and development, increase in food production, improvement in livelihoods, environmental protection etc. Hence, investigation for water budgeting and watershed designing of this region is proposed, for the present work.

III. METHODOLOGY

The satellite remote sensors give dependable and exact data regarding natural resources, which is prerequisite for proper planning and management of the watershed. The GIS procedures integrated with remote sensing gives dependable, exact and updated database.

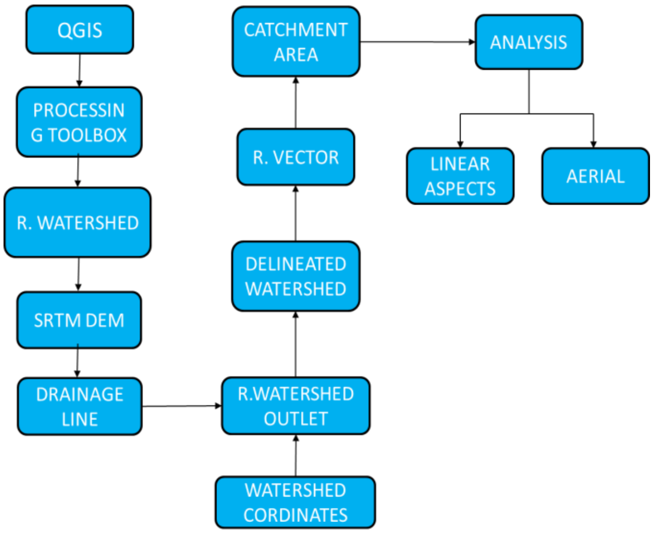

Fig. 2. Flowchart representing the detailed methodology

A digital elevation model (DEM) is the three-dimensional representation of the earth's topography and is formed from elevation data of terrain. ASTER GDEM is a satellite-based DEM available at a resolution of 30m. 'GDEM' stands for Global Digital Elevation Model, whereas 'ASTER' stands for Advanced Space borne Thermal Emission and Reflection Radiometer. This is used in several studies of morphometric assessments as well as in hydrological modeling studies due to its reliable resolution. Figure 2 shows the detailed methodology of the morphometric analysis carried out in this work.

IV. RESULTS AND DISCUSSIONS

The results of the morphometric analysis are presented in Table 1. The Baltira watershed is divided into ten sub-watersheds and the morphological parameters for each of these watersheds are computed. The detailed assessment of the parameters are as follows.

Linear Aspects - The topologic characteristics are assessed in terms of linear aspects of the basin which includes the channels along with open links of the networks or streams [13]. A particular river helps to study in graphic terms and the drainage network which consist of all the stream segments, where in stream junctions are taken as points while the streams are taken as the lines. All the stream segments (Nu) are counted their hierarchical orders are determined, the lengths of the stream segments are measured and various inter relationships are analyzed for this purpose.

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Table 1. The results of morphometric analysis over Baltira watershed

Sub Watershed		SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8	SW9	SW10	Whole Basin
Stream Number	1	19	29	44	37	12	49	49	22	47	35	330
	2	6	6	11	9	3	9	11	5	9	8	73
	3	1	3	2	3	1	2	3	2	3	1	14
	4		1	2	1		1	1		1	1	3
	5			1			1					1
Stream Length	1	17.96	18.54	32.27	24.72	9.79	28.02	32.67	12.8	25.2	19.8	221.71
	2	6.69	4.85	10.44	10.73	5.05	7.18	9.57	11.3	11.7	9.77	87.23
	3	5.77	5.2	2.1	8.53	2.89	3.69	3.71	3.53	4.36	9.61	45.69
	4		4.3	9.06	1.51		11.72	12.95		13.8	0.83	30.3
	5			0.69			0.6					28.32
Stream Length Ratio	II/I	0.37	0.26	0.32	0.43	0.52	0.26	0.29	0.88	0.46	0.49	0.39
	III/II	0.86	1.07	0.20	0.79	0.57	0.51	0.39	0.31	0.37	0.98	0.52
	IV/III		0.83	4.31	0.18		3.18	3.49		3.16	0.09	0.66
	V/IV			0.08			0.01					0.93
Bifurcation Ratio	I/II	2.68	3.82	3.09	2.30	1.94	3.90	3.41	1.13	2.16	2.02	2.54
	II/III	1.16	0.93	4.97	1.26	1.75	1.95	2.58	3.20	2.67	1.02	1.91
	III/IV		1.21	0.23	5.65		0.31	0.29		0.32	11.58	1.51
	IV/V			13.13			19.53					1.07
Area (Km2)		21.07	22.41	35.78	29.09	12.82	35.25	40.54	19.1	43.6	28.1	287.81
Perimeter		29.30	33.11	44.82	37.62	29.53	51.00	49.43	32.67	72.11	39.34	136.63
Mean Bifurcation Ratio		1.92	1.99	5.36	3.07	1.84	50.37	2.09	2.17	1.72	4.87	1.76
Mean Stream Length Ratio		1.17	0.84	0.91	0.91	1.11	0.82	0.92	0.95	0.92	0.89	0.98
Basin Length (Km)		7.50	7.80	10.28	10.27	8.00	13.35	13.20	9.40	12.73	11.17	103.70
Drainage Density Dd (Km/Km²)		1.54	1.47	1.52	1.56	1.38	1.44	1.46	1.45	1.26	1.42	1.44
Stream Frequency (Fs)		1.23	1.74	1.68	1.72	1.25	1.76	1.58	1.52	1.37	1.60	1.46
Form Factor (Rf)		0.57	0.37	0.34	0.53	0.20	0.20	0.23	0.22	0.52	0.23	0.03
Circulatory Ratio (Rc)		0.31	0.26	0.22	0.26	0.18	0.17	0.21	0.22	0.11	0.23	0.19
Elongation Ratio (Re)		0.69	0.68	0.66	0.59	0.50	0.50	0.54	0.52	0.59	0.54	0.18
Relief Ratio (Rr)		19.73	11.15	13.91	16.36	22.50	6.97	6.82	10.85	6.99	5.46	2.89
Channel Gradient		16.33	12.88	131.92	70.82	39.65	986.63	4.42	18.39	4.11	46.78	6.74
Basin Shape (Bs)		0.3	0.37	0.47	0.32	0.29	0.52	0.36	0.38	0.35	0.57	0.393

Stream Order - The Baltira River is fifth order stream covering an area of 273 Km^2. The stream order is a natural number representing the extent of branching or furcating in the drainage system of a river and has common usage in hydro- morphology. This order is used to identify and classify the types of streams based on their numbers of tributaries. It is to be mentioned that the intersection of two links of different orders does not result in an increase in order. In the present study, the segment of the drainage basin has been ranked according to **Strachler's (1964)** stream ordering system [14]. The stream orders of Baltira watershed are shown in Figure 3.

Stream Number – For each sub-watershed, the streams of first order to the highest order are numbered from starting of each segment of the stream. After numbering, the order numbers of the drainage system are allotted. For each order, the number of stream segments in that particular order are summed up to obtain the stream number (N_u) corresponding to 'u' order [15]. The study area has 421 numbers of streams on total.

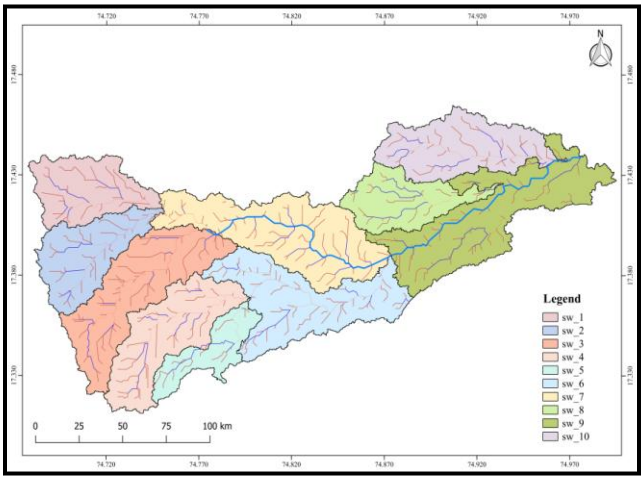

Fig. 3. Number of Stream Orders in Baltira Watershed

Stream Length - The stream length is calculated by Horton's Law [16] for all the sub-catchments. Normally, the overall stream length is highest for 1st order and declines with increase in order of streams. But, for sub-watersheds SW2, SW4 and SW8, the stream lengths of different orders exhibit deviation from said condition. This change may be due to lithological variations or flow of streams from high elevation along steep gradients.

Form Factor (R_f) – The area of a basin (A) with respect to the square of the highest length of the basin (L_b) is regarded as Form factor, which ranges from zero to one [16]. Low form factor indicates elongated basin. Basins with low form factor have flatter peak flow for longer duration while the basins with high form factor have higher peak flows for a shorter duration. If the form factor of a basin is high, the larger peak flows persist for lesser time. In contrast, the duration of lower peaks are longer, given the form factor is low. The R_f has ranged between 0.20 (for SW6) to 0.37 (for SW1 and SW2).

Stream Length Ratio - The stream length ratio can estimated as the average stream length of a particular order with respect to the stream length of the just relegated order (lowered by unity) [17]. Study area shows change in basin with the stream of different order. This represents the late youth stage of hydromorphic development in the streams of Baltira watershed, which may be due to topographic variations.

Aerial Aspects - The basin area is a remarkable parameter, which has influence over distribution of numerous morphometric parameters with respect to space [18]. The parameters viz., drainage density, drainage texture, stream frequency, slopes, dissection index, circularity ratio, etc are also affected by the drainage area of the basin. The DEM of Baltira watershed is shown in Figure 4.

Elongation Ratio (R_e) – If a circle is formed with same area as that of basin, then the ratio of the aforementioned circle's diameter with maximal length of the basin is regarded as the elongation ratio (R_e). Whenever R_e gets close to 1, it represents low relief. But $0.6 < R_e < 0.8$ indicates high relief and steep gradients. Typically, R_e ranges between 0.5 to 0.69 ver diverse geologic and climatic features. Regarding categorization of shape from R_e, basins may be called oval ($0.8 < R_e < 0.9$), circular ($R_e > 0.9$) or less elongated ($R_e < 0.7$).

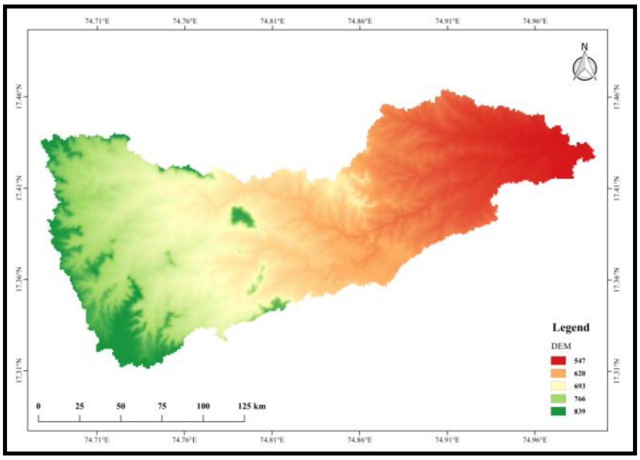

Fig. 4. DEM map of Baltira river basin

Circulatory Ratio (R_c) – If a circle has same perimeter as that of the basin, then the ratio of the drainage area of the basin with respect to the circle's area will be called as the circulatory ratio. The slope, relief, climate, land use/land cover, geological structure, frequency as well as length of stream, influence the R_c [19]. It is more likely to have circular shape of basin at the higher value of circulatory ratio and vice-versa. The R_c of sub-watersheds ranged between 0.20 (SW9) to 0.57 (SW1). $R_c < 0.5$ represents the sub-watersheds to be elongated whereas, $R_c > 0.5$ infers for their near circular shapes. For a circular shaped basin, the system of drainage is controlled structurally and the relief varies from moderate to high. $R_c > 0.5$ is found for the sub-watersheds SW1, SW4 and SW9 whereas, for the remaining 7 sub-watersheds, $R_c < 0.5$, representing an elongated condition.

Stream Frequency (F_s) - Stream frequency is expressed as the total number of streams (all orders) per 1 km^2 area of the basin. The stream frequency possesses direct variation to relief and inverse variation to permeability of sub-surface material [19]. Thus, higher the stream frequency, higher will be the runoff. Stream frequency values of the sub-watersheds vary from 1.23 (for SW1) to 1.76 (for SW6). For all the sub-watersheds, it exhibits positive relation with drainage density. Thus, stream population rises in accordance with the drainage density. High stream frequency in SW2 and SW6 produces more runoff in comparison to others.

Drainage Density (D_d) - The total length of streams of all orders per drainage area is called drainage density [20]. D_d ranged from 1.26 to 1.56 Km/Km^2 in all the sub-watersheds of Baltira watershed. The highest value of drainage density is recorded in SW 1 and SW4 which is 1.54 and 1.56 respectively, whereas the lowest is found in SW9 (D_d = 1.26). The main causes for high drainage density may be steep relief, sparse vegetation and poor subsurface materials.

V. CONCLUSIONS

The remote sensing capabilities integrated with GIS have been efficient for watershed delineation and hydromorphological applications. The objective of the study was to perform morphometric analysis for Baltira watershed, Maharashtra, India.

From the results, it can be observed that the SW5 and SW10 are having the highest and lowest relief respectively amongst all the sub-watersheds. The highest value of drainage density is recorded in SW1 and SW4 which is 1.54 and 1.56 respectively, while lowest for SW9 i.e. 1.26. High drainage density is found in SW1 and SW4, which suggests a higher runoff yield. The circulatory ratio of sub-watersheds SW1, SW4 and SW9 are greater than 0.5, representing their near circular shape. For the remaining 7 sub-watersheds, circulatory ratio is less than 0.5 representing their elongated condition. The form factor over the study area varied from 0.20 (for SW6) to 0.37 (for SW1 and SW2). The elongation ratio values of all watersheds vary from 0.5 to 0.69. The results will be helpful to the policy-makers for better planning and management over the study area. The results can also be applied over several regions of Maharashtra with similar morphological characteristics.

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