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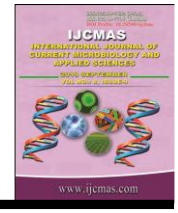

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Quantitative Analysis of Geomorphometric Parameters of Ozat River Basin Using Remote Sensing and GIS

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A B S T R A C T

The present investigation intends to examinations the morphometric attributes of Ozat River basin to comprehend the hydrogeological behavior and influence on hydrology of the basin. The basic and derived morphometric parameters (linear, areal and relief aspects of drainage network) for the basin were determined using ASTER DEM (30 m resolution),remotely sensed images of Linear Imaging Self Scanner III (LISS III) and Geographic Information System (GIS). The maps for the topic of land use/land cover, soil, drainage, slope and contour were prepared and investigation was made for the said subjects utilizing the ArcMap V10.1. The drainage area of the basin was found to be 3176.24 km^2 and shows sub-dendritic to dendritic drainage pattern. The study area designated as 7^{th}order basin with the drainage density value being as 1.46 km/km^2. The slope of the basin varies from 10% to 50%. The mean bifurcation ratio was 3.96 represent geological heterogeneity, high permeability and less structural control. The results of the morphometric analysis reveal that Ozat River Basin is elongated with high erosion and peak flow. It has a strong relief and steep ground caused severe erosion and down cutting activity in the past and it is still susceptible to surface erosion at present. The morphometric properties determined for this basin as entire and for every watershed will be valuable for the sound planning of water harvesting and groundwater recharge projects on watershed base.

Introduction

River basin or watershed is a natural hydrological entity which allows surface run-off to a defined channel, drainage, stream or river at a particular point (Chopra *et al.,* 005). The River basin is used as an ideal areal unit for geomorphometric analysis because it has inherent limited, convenient and usually clearly defined and unambiguous topographic unit (Martinez-Casasnovas *et al.,* 1998). The close relationship between hydrology and geomorphology play an important role in the drainage morphometric analysis (Horton, 1932). A technique was introduced earlier by Horton (1932 and 1945) and elaborated by Smith (1950), Strahler (1952a and 1957), Miller (1953) and Schumm (1956) those who later established the quantitative fluvial geomorphic research (Thakkar *et al.,* 2007; Patel *et al.,* 2012 and 2013; Dhruvesh *et al.,* 2011; Wandre and Rank, 2013).

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal 1998; Obi Reddy *et al.,* 2002). Morphometric analysis is a quantitative description and analysis of landforms as practiced in geomorphology that applied to a particular kind of landform or to drainage basins. The main characteristics which are often analyzed are: area, altitude, volume, slope, profile and texture of the land, and other different aspects of drainage basins (Clark, 1966).

A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton 1945; Leopold and Maddock 1953; Abrahams 1984). Since the mid-1980s, the development of geospatial analytical techniques (GIS and RS) and other software designed specifically to quantify and calculate linear, areal, shape and relief morphometric parameters (Prasannakumar *et al.,* 2013 and Markose *et al.,* 2014). Along with increasing availability of digital elevation data, have enhanced the process of quantitative description of drainage networks, morphometric thematic mapping, and the applicability of geomorphometric analysis in different fields of research. Remote sensing (RS) and Geographic Information System (GIS) has proved to be an efficient tool in delineation of watershed, drainage pattern and water resources management and its planning. Conventional geomorphometric studies were carried out to explore the relationship between morphometric properties of drainage networks and climate, relief, lithology and structure in order to interpret the morphometric parameters (Nageswara *et al.,* 2010 and Thomas *et al.,* 012). Conventional maps are static, with fixed projection, scale and coordinate systems; it is difficult to combine multiple map sheets and overlays are restricted. GIS provides easy way to update and analyzed the spatial data (Clark, J.1966).Comparison and evaluation of morphometric data derived through conventional, manual methods, and automated geospatial techniques, indicate that modern technology provides powerful and cost-effective tools for managing and processing data and creating maps for different applications (Saeedrashed *et al.,* 2013).

Many researchers concluded that RS and GIS technology are efficient tools for measuring and calculating precise drainage basin morphometric parameters. Other advantages are the capabilities of managing and processing spatial information in large amounts accurately and in a timesaving manner (Franklin, 1987; Apaydin *et al.,* 2006; Ozdemir *et al.,* 2009; Singh *et al.,* 013). Pioneering work on the drainage basin morphometry has been carried out by Horton (1932 and 1945), Smith (1950), Miller (1953), Strahler (1964) and others. In India, some of the recent studies on morphometric analysis using remote sensing technique were carried out by Srivastava (1997), Nag (1998), Rudraiah (2008), Patel *et al.,* (2011 and 2013), Wandre *et al.,* 2013), Biswas (2014), Meshram and Khadse (2015). The present study aims to assess the morphometric characteristics of Ozat River basin for planning of soil and water conservation schemes, watershed and natural resources management.

Study area

The Ozat River basin is extended between latitude of 21° N to 22° N and longitude of 70° E to 71° E (Fig. 1), covering an catchment area of 3176.24 km^2. Eight major reservoirs were constructed across the Ozat river basin namely Amipura, Dhrafad, Jhanjesri, Madhuvanti, Magharadi, Magharadi, Pasawala, Uben. The Holy Girnar, a circular hill massif made up of intrusive rocks rises to impressive heights, the highest peak, attains a height of 1046 m above mean sea level. Terrain elevation varies from 1046 m as maximum to 1 m as minimum (above mean sea level of India). The large difference in the contour value is due to the Girnar Mountain situated in middle of the basin. The Ozat River originates from near Merwada village of the Bhesantaluka. After flowing through the district for a distance of 125.27 km, it drains into the Arabian sea.

The important tributaries of the Ozat river are Ambajal, Popatdi, Uben, Utavali, Bhandukia, Jhanjheshri, Fulsar and Lol, in which Abajal and Popatdi are right bank tributaries while Uben and Utavali are left bank tributaries of this river. These rivers originate in the central plateau region of Saurashtra and meanders in a radial pattern through the plains to meet the Arabian Sea.

The study area located in topo sheets No. 41G10, 14, 15, 41K02, 03, 06, 07, 10, 11, 14 and 15 prepared by Survey of India. The climate of the project area can be classified as tropical and sub-tropical. The types of soil are fine, clay, loamy and rock found in the basin. Soil depth is varies between 25cm to 150cm throughout the entire river basin.

Materials and Methods

Geomorphometric analysis of Ozat river basin was carried out using topographic maps with scale 1:50,000 (20m counter Interval). The data used for assessments are mentioned in Table 1. The basin was divided into four subbasins 5G1C2 to 5G1C5 (Fig. 3). The drainage networks of main basin and sub basins were generated using ASTER DEM (30m resolution) (Fig. 2) as wells as from satellite image of IRS P6 LISS III having resolution of 23.5 m × 23.5 m to meet the maximum accurate results, then digitized using Arc GIS V10.1 software package(Pareta and Pareta, 2011). Various thematic maps such as land cover/land use, soil, slope, drainage and watershed etc. were prepared using geo-coded IRS P6, LISS III digital image data on 1:50,000 scale. The data extraction and data analysis, stream lengths and basin areas are measured with GIS software Arc GIS 10.1. The images from Google Earth Pro were also used for reference purpose only. A Field check was carried out to verify the features identified on the satellite data. Adequate ground truth information on agriculture and related aspects was surveyed for preparing GIS database.An assessment of the morphometric parameters for each drainage network was executed at sub basin level. The derived parameters were classified into threeclass (Arulbalaji and Gurugnanam, 2017) such as linear, areal and relief aspects of the basin.

A total of 4 watersheds were identified within this basin. Digitization work has been carried out for entire analysis of basin morphometry using GIS software (ArcGIS 10.1). The order was given to each stream according to the system proposed by Strahler (1952 and 1964) stream ordering technique. The attributes were assigned to create the digital data base for drainage layer of the river basin. The drainage pattern in the study was prepared with help of

ArcMap V10.1. The methods adopted for computing linear, areal and relief aspects of the basin are described in Table 2. Based on the stream order, the Ozat River basin is classified as 7th order basin to interpret the morphodynamic parameters as listed in Table 1 (Gravelius 1714; Horton 1932, 1945; Melton 1957 and 1958; Smith 1950; Schumm 1956; Hadley and Schumm 1961; Strahler1957, 1964; Sreedevi *et al.,* 2005; Mesa 2006; Wentworth 1930). Morphometric analysis of a watershed provides a quantitative description of the drainage system which is an important aspect of the characterization of watersheds (Strahler, 1964). Significant Geomorphometric parameters such as relative relief, basin relief and dissection index have been quantified and calculated from the Digital Elevation Model (DEM). The morphometric analysis for individual sub basins has been achieved through measurements of linear, areal and relief aspect of the basin and slope contribution (Nag and Chakraborty, 2003) were determined using GIS.

Results and Discussion

Morphometric analysis

Quantitative analysis of Ozat River basin and four sub-basins was performed to assess the characteristics and properties of the drainage network. Approx. twenty ninemorphometric parameters which represent linear, area land relief aspects of the watershed were considered for analysis in order to characterize the catchment, and to improve our understanding of: geomorphic history, erosional stage of landforms, rejuvenation phases and geomorphic processes operating across the basin or watershed (Horton, 1945 and Strahler, 1964).

The drainage pattern of the basin clearly reflects the structure and lithology of the basin; these patterns are indicative of prominent structural control and lithological information of catchment. The naming of stream order is the first step in morphometric analysis of drainage basin, in the present investigation, stream ordering for the watershed and sub-watersheds has been ranked according to Strahler's technique of the hierarchical ranking system (Strahler, 1952a). It is apparent that the total number of streams gradually decreases as the stream order increases (Table 3 and 4). Each length of stream is identified by its order (i.e. first-order, second-order, etc.) In the present study Ozat Basinbasinhas maximum seventh order stream, so that it was considered as seventh order river basin. The morphometric characterization in the form of linear, areal and relief aspects for the Ozat river basin and delineated sub basin was calculated as given in Table 2, 3 and 4. The variation existing in the stream order is attributed largely to structural and morphological characteristics of the watershed. The total number and total length of stream order change according to the size of the sub-basins. However, the total number of streams at various orders, and their lengths from mouth to drainage divide for Ozat river basin (including the sub-basins) were derived from the DEM and measured with the help of ArcGISV10.1 software package. Their number and lengths are higher and more precise compared with those measured manually from topographic maps of scale 1:50,000 (Farhan, 1971).

The morphometric parameters of Ozat River basin and its four sub basins namely 5G1C2, 5G1C3, 5G1C4 and 5G1C5 have been calculated as per adopted described methods and results are given in the Table 3, 4 and 5. The drainage area of four sub basin 5G1C2, 5G1C3, 5G1C4 and 5G1C5 was 521.14 km^2, 998.58 km^2, 587.62 km^2 and 1068.9 km^2 respectively from which the Ozat River basin was formed and makes total basin drainage area of 3176.24 km^2. The drainage pattern was dendritic in nature and it is influenced by the general topography, geology and rainfall condition of the area. Slope, aspect and contour maps were prepared fromASTER (DEM).

Linear parameter /liner aspects

The parameters such as basin length, stream order, number of streams, stream length, mean stream length, stream length ratio, length of overland flow, bifurcation ratio, mean bifurcation ratio, and RHO coefficient are taken into account for the present study and the results have been tabulated in the Table 3 as a whole basin and Table 4 and 5 as sub basins.

Stream number (Nu)

As per Horton's law (1945) of stream numbers, 'The number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio'. The total number of streams in Ozat River basin is 4676. The details of total number of streams are represented in Table 3. It reveals that the study area has relatively greater percentage of first order streams (75.49%) and there is possibility of unpredicted flood heavy rainfall in lower reach of the basin (Chitra el al., 2011).During calculation it is identified that the number of streams gradually decreases as the stream order increases; the variation in stream order and size of tributary basins is largely depends on physiographical, geomorphological and geological condition of the region. Using the GIS, application the total number of streams of each order was computed.

Stream order (U)

The stream orders are classified up to seventh order, Ozat River basin and it's watersheds could be designated as a 7thorder stream because the seventh order streams is originated from upper most sub basin 5G1C5 (Fig. 2). Details of stream order of several tributaries of Ozat River basin and their sub-basin area are shown in the Figure 3 and Table 2 and 3. Total no. of 4676 stream line including Ozat River basin is recognized in the whole basin, out of which 75.49 % (3532) is 1st order, 18.51 % (866) 2nd order, 4.32 % (202) 3rd order, 1.20 % (56) 4th order, 0.30 % (14) 5th order, 0.11 % (5) 6th order and 0.09 % comprises 7th order stream (1). The maximum stream order frequency is observed in case of first-order streams and then for second order. Hence, it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa. The higher amount stream order indicates lesser permeability and infiltration in these sub basins. The most of the first order stream is observed in highly elevated region of the study area, which indicates the terrain density, compressed nature of basic lithology and still basin is suffering from erosion while less number indicates developed topology (Pande and Moharir, 2015).

Stream length (Lu)

The result of order-wise stream length in Ozat River basin with its four sub basinsare shown in Table 3 and 4. The total length of the 1st order streams is highest i.e. 2398.57 km, and that of 2nd order is 989.16 km, 3rd order is 612.55 km, 4th order is 374.68 km, 5th order is 164.35 km, 6th order is 54.88 km and the lowest is of 7th order of 91.80 km respectively. Generally higher the order, longer the length of stream is noticed in the nature. Longer length of stream is advantages over the shorter length, in that the former collects water from wider area and greater option for construction a bund along the length. Lower stream lengths are likely to have lower runoff (Chitra *et al.,* 2011). It was clearly identified that the cumulative stream length was higher in first-order streams and decreases as the stream order increases. The highest stream order was 7th, i.e., for Ozat River basin has a length of 91.7 km.

Mean stream length (Lsm)

It has been computed by dividing the total stream length of order 'u' by the number of stream segments in the order (Table 4). The Lsm values for the Ozat River basin range from 0.68 to 91.11 km (Table 4) with a mean Lsm value of 8.17 km. It is noted that Lsm value of any stream order is greater than that of the lower order and less than that of its next higher order in the basin. The Lsm values differ with respect to different basins, as it is directly proportional to the size and topography of the basin. Strahler (1964) indicated that the Lsm is a characteristic property related to the size of drainage network and its associated surfaces. The mean stream length is directly related to mean annual runoff; therefore, the highest mean stream length has relatively high has relatively high mean annual rainfall runoff and relatively low mean annual rainfall runoff in less mean stream length. In the present study, mean stream length was indicating the high mean annual rainfall runoff. Mean stream length (km) of sub basins of Ozat river basin based on stream order is shown in the Table 4.

Stream length ratio (RL)

The stream length ratio of Ozat river basin showed an increasing trend. The RL values are presented in Table 5. The value of stream length ratio ranges widely varies from 0.41 to 1.67 which shows the early stage of maturity of the basin. The stream length ratio between the streams of different orders of the Ozat river basin shows a change in each sub basins (Table 5). This change might be attributed to variation in slope and topography, indicating the late youth stage of geomorphic development in the streams of the Ozat river basin (Singh and Singh 1997; Vittala *et al.*, 2004). The higher values were noticed in the fifth stream orders and lower values noticed in the first stream order.

Length of overland flow (Lg)

The Length of overland flow for basin 0.338 km and for subbasins ranges from 0.2432 - 0.6845 km as shown in Table 4. The watershed5G1C5 is having lower values of length of overland flow comes under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff. For basin it is greater than 0.25 km it comes under very less structural disturbance, less runoff conditions, long flow path, more infiltration and having higher overland flow (Sethupathi *et al.*, 2011). If the Lg value is between 0.2-0.3 km indicates the presence of moderate ground slope, moderate infiltration associated with moderate runoff. Other three remaining watersheds (i.e., 5G1C2, 5G1C3 and 5G1C4) having length of overland flow greater than 0.25 km are under very less structural disturbance, moderate runoff conditions and havingmoderate overland flow.

Bifurcation ratio (Rb)

It is observed that Rb is not same from one order to its next order as these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1952). The Rb for the Ozat river basin varies from 2.80 to 5.0 (Table 2, 3 and 4). The analysis of bifurcation value shows that the basin and its watersheds possesses well developed drainage network as the bifurcation ratio ranges between 2.0 to 6.0(i.e. low value). The theoretical minimum possible value of 2.0 rarely approached under natural condition. In the Ozat river basin, the higher values of Rb6.00 for watershed 5G1C3 indicate a strong structural control in the drainage pattern whereas the lower values (< 6.0) indicate that the geologic structures do not distort the drainage pattern (Strahler 1964; Vittala *et al.,* 2004; Chopra *et al.,* 2005).

The mean bifurcation ratio (Rbm)

Using Strahler's (1957) method of taking into consideration of actual number of streams that are involved in the ratio, Mean Bifurcation Ratio of different sub-basins was calculated. The mean bifurcation ratio varied from 3.49 to 3.82. The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all order (Table 3) and it was3.96 in case of Ozat River basin. High figures indicate that drainage development in the main basin including the sub-basins was influenced crucially by structural disturbances represented by the tectonic activity and rejuvenation phases at the middle part of the basin.

RHO coefficient (RHO)

The mean RHO coefficient of the Ozat River Basin is 0.16 while the mean RHO of the sub-basins varies from 0.13 to 0.15 as shown in Table 4. RHO coefficient value signifies the storage capacity of a basin; higher values of RHO have higher water storage during flood periods and as such attenuate the erosion effect during elevated discharge and vice versa for lower RHO coefficient value (Mesa, 2006).

Areal parameter

The areal aspect is the two dimensional properties of a basin. It is possible to delineate the area of the basin which contributes water to each stream segment. The watershed can be traced from where the stream has its confluence with the higher order stream along hillcrests to pass upslope of the source and return to the junction. This line separates slopes which feed water towards the streams from those which drain in to other streams. The information of hydrologic importance on fluvial morphometry is derived by the relationship of stream discharge to the area of watershed. The planimetric parameters directly affect the size of the storm hydrograph and magnitudes of peak and mean runoff of the basin area. The maximum flood discharge per unit area is inversely related to the size of the basin (More, 1967).

Area (A) and Perimeter (P)

Area of the basin is calculated as total area projected upon a horizontal plane contributing to accumulate of all order of basins. Perimeter is the length of the basin boundary (Ahmed *et al.,* 2010). The drainage area of four sub basin 5G1C2, 5G1C3, 5G1C4 and 5G1C5 was 521.14 km^2, 998.58 km^2, 587.62 km^2 and 1068.9 km^2 respectively and while considered above four sub basins as single basin (Ozat River basin) then it has drainage area of 3176.24 km^2. The perimeter of four sub basins 5G1C2, 5G1C3, 5G1C4 and 5G1C5 is 122.57 km, 168.23 km, 160.29 km and 148.69 km respectively, while Ozat River basin is formed by perimeter of 350.13 km.

Form factor (Ff)

It is defined as the ratio of basin area to square of the basin length ($F_f = A/L_b^2$) (Horton, 1932). The value of form factor would always be less than 0.7854 (for a perfectly circular basin). The value of form factor is in between 0.1-0.8. Smaller the value of form factor, more elongated will be the basin have lower peak flow of longer duration and the basin with high form factor 0.8, have high peak flows of short duration. F_f parameter has been developed to predict the intensity of a basin of a defined area. For a perfectly circular basin, the F_f value is always <0.754 (Chopra *et al.*, 2005).

Form factor is the numerical index (Horton, 1932) commonly used to represent different basin shapes. The F_f value for Ozat river basin is 0.19, and the values range from 0.22to 0.25 for the sub basins, which indicates that the Ozat river basin was under the shape criteria of an elongated basin. Thus, low peak flows of long duration are expected (Mangesh *et al.*, 2011).

Compactness coefficient (Cc)

Lower values of this parameter indicate the more elongation of the basin and less erosion and vice-versa. The compactness coefficient for basin ranges from 1.28 to 1.87 and for basin is 1.75 (Table 3 and 4). They have elongated shape so they have enough time for discharge.

Basin Shape

The main indices used to analyze basin shape and relief is the elongation and relief ratios. The value of Shape factor was varies from 4.03 to 4.44 in sub basins, which indicate elongated shape of the basins. The value of basin supports the result of sub basin as 5.15 indicate basin was strongly elongated in shape. Due to elongated shape, basin is not efficient in runoff discharge as compared to circular basin.

Circularity ratio (Rc)

The circularity ratio is mainly concerned with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Low, medium and high values of Rc indicate the young, mature, and old stages of the life cycle of the tributary watershed (John Wilson *et al.*, 2012). Rc value of Ozatbas in as whole was 0.33and Rc value of different sub basins was ranging from 0.29 to 0.61 (Table 3 and 4).Drainage basins with a range of circularity ratios of 0.4 to 0.5, were described by Miller (1953), indicating they are they are strongly elongated, highly permeable, with homogeneous geological materials. Low, medium and high values of Rc indicate the young, mature, and old stage of the geomorphic cycle of the watershed (Magesh, 2011). The Rc value of Ozatbasin was 0.33 which indicates that the basin was elongated in shape with low runoff and high permeability of the subsoil. The circularity ratios of the sub basins vary from 0.4 to around 0.6, which supports the result of the basin.

Elongation ratio (Re)

Based on Re values, watersheds were grouped into five categories, i.e. circular (0.9 - 1.0); oval (0.8 - 0.9), less elongated (0.7 - 0.8); elongated (0.5 - 0.7), and more elongated (<0.5). The elongation ratio for Ozat basinwas0.50, while the values for the sub-basins 5G1C2 to 5G1C5 are: 0.56, 0.54, 0.56, and 0.54 respectively. All these values are indicative of elongated shape, and associated with high relief and steep slopes. They also imply that the hydrograph of these basin and sub-basins might be smoother (i.e. the crest segment of the hydrograph will be flatter and the slope of the rising and recession limbs will be low) (Thomas, 2012).

Drainage density (Dd)

The poorly drained basins have a drainage density of 2.74 Km/Km^2, while the well-drained one has a density of 0.73 Km/Km^2, or one fourth as great (Horton, 1945). In the present study, drainage density for Ozat basin was 1.48 km/km^2. It is indicates low drainage density in the basin. Therefore, the values for drainage density from Table 3 and 4 indicates that Ozat river basin and sub basins 0.73 to 2.06Km/Km^2 indicated that the sub basins has moderate to high density or of moderate permeable subsoil, and a thick vegetative cover and moderate relief.

Drainage texture (T)

According to Smith (1950), drainage texture is classified into five categories: very coarse (< 2), coarse (T = 2-4), moderate (T = 4 - 10), fine (T value is above 10), and ultra-fine or badlands topography (T value is >15).

Drainage Texture (T) is an expression of the relative spacing of drainage lines in a fluvially dissected terrain. It is obvious from such classification, that the drainage texture of the Ozat basin (T = 13.36) was fine drainage texture, one of the sub basin falls under very coarse drainage texture with the values of 1.86, two sub basin falls under moderate drainage texture with the values 5.96 and 5.15, while last sub basin 5G1C5 was falls under ultrafine drainage texture class with the value of 17.63.

More is the texture more will be dissection and leads more erosion. High drainage texture value of sub basin 5G1C5 indicate the presence of soft rock with low resistance against erosion while coarse drainage texture of sub basins 5G1C2, 5G1C3 and 5G1C4indicates presence of hard rock and high resistance against erosion.

Texture ratio (Tr)

Texture ratio is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain (Schumm, 1956). The Tr is expressed as the ratio between the first order streams and perimeter of the basin. The Tr of the Ozat River basin was computed as 10.09 and for sub basins of Ozat basin is: 1.35, 4.48, 3.88, and 13.39 respectively, which categorized as high to moderate textured basins in nature.

Constant channel maintenance (Cm)

Constant of channel maintenance for Ozat basinwas0.68 and varied from 0.49 to 1.37 throughout its four sub basins. Higher value of constant channel maintenance for sub basin 5G1C2 reveals strong control of lithology with a surface of high permeability than other sub basins, while lower value for sub basins 5G1C3, 5G1C4 and 5G1C5 indicates inverse result (i.e., weak control of lithology with a surface of low permeability) Schumn (1956).

Stream Frequency (Fs)

Stream Frequency (Fs) represents the ratio of the total number of streams (Nu) in a basin to the basin area (A), and is defined as the number of streams per unit of area (Horton 1932). The value of stream frequency ranges from 3.91 to 9.99.

The Fs value depends mainly on the lithology of the basin and, reflects the texture of the drainage network. The Fs value for Ozat basinwas1.47 km/km^2, and for sub basins 5G1C2 to 5G1C5 are; 0.44, 1.0, 1.41, and 2.47 respectively. Fs values are relatively low to high for Ozat river basin and the sub basins which indicated that more surface water infiltrates down through permeable rocks to subsurface strata (Chitra *et al.,* 2011). The distribution suggests that topographically, the Ozat river basin is in its late mature to old stage of the basin.

Infiltration Number (If)

The infiltration number has been defined as the product of drainage density and drainage frequency, which gives an idea about the rate of infiltration and reveals impermeable bedrock and high relief areas in the watershed (Umrikar, 2016). In the present study, infiltration number was computed as2.17. Therefore, the runoff is relatively moderate in case of entire basin, while the value of infiltration number for four sub basins are; 0.32, 1.23, 2.11 and 5.04 respectively. Higher values of sub basin 5G1C5 indicated that lower will be the infiltration and the higher run-off for that sub basin, this leads to the development of higher drainage density. It gives an idea about the infiltration characteristics of the basin reveals impermeable lithology and higher relief. While lower values of other three sub basins namely 51C2, 5G1C3 and 5G1C4 indicated that higher will be the infiltration and the lower runoff than sub basin 5G1C5.

The Lemniscate Ratio (k)

The Lemniscate Ratio (k) was elaborated by Chorely *et al.,* (1957) as a measure to describe how closely the actual drainage basin shape approaches the loop of a lemniscates. They concluded that for describing the drainage basin shape accurately, it is essential to determine the lemniscates shape which the basin most nearly approaches.

The lemniscate (k) value for the Ozat river basin was1.29 which shows that the basin is mostly elongated in shape and flow for a longer duration, for the same values of k for the the sub-basins are 1.01 for 5G1C2, 1.01 for 5G1C3, 1.02 for 5G1C4 and 1.11 for 5G1C5which supports results of another shape parameter the Ozatbasin value as basin is elongated in shape.

Relief aspects

Linear and areal features have been considered as the two dimensional aspect lie on a plan. The third dimension introduces the concept of relief. By measuring the vertical fall from the head of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average vertical fall.

Relief aspects is an indicator of flow direction of water as it is an important factor in understanding the extent of denundational process that have undergone within watershed.

Basin relief (Bh)

Basin Relief (Bh) or "total relief" of the basin, is defined as the difference in elevation between the highest and lowest points on the basin (Schumm, 1956). Generally, relief measures are indicative of the potential energy of a drainage system present by virtue of elevation above a given datum (Strahler, 1964).

In the present study, lower relief 1m and higher relief 1045 m are noticed. Therefore, relief of the watershed was 1044 m. It indicated that the erosional forces and the mean denudational rates are higher in the study area. While the sub basin values varied between 47m to 1035m. High value indicates a high potential erosional energy of the drainage system while low relief value 47m for sub basin 5G1C2 indicated a low potential erosional energy of the drainage system. Due to thatsoil erosion is prominent active geomorphic processes across the basin.

Relief ratio (Rr)

Relief Ratio (Rr) is the ration between the total relief (or basin reliefBh) of a basin and the longest basin length parallel to the principal drainage line. Relief ratio allows comparison of the relative relief of any basin regardless of differences in scale of topography (Schumm, 1956). The higher values of relief ratio indicates steep slope and high relief while the lower values indicates the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope (Mahadevaswamy *et al.,* 2011).

Table 1 Data used and sources

Sr. No.	Data Layer / Maps	Source
1	Topographical Map	Topographical Map, Survey of India (1:50,000)
2	Remote Sensing Data	• IRS-P6(ResourceSAT-1) LISS-III Satellite Imagery of Year 2012 with 23.5 m Spatial Resolution • ASTER DEM of 30 m spatial resolution
3	Geological Map and Geomorphology Map	Geological Map of Study area prepared by GSI is updated through IRS-P6 LISS-III Satellite Remote Sensing Data with Limited Field Checks.
4	Morphometric Analysis	Landforms/geomorphological map prepared using remote sensing data, ASTER(DEM) & limited field checks.
5	Slope Map	Quantitative analysis has been done based on Survey of India (SOI) toposheets and ASTER (DEM) data.
6	Drainage Map	Drainage network generated in GIS environment using ASTER (DEM) data.

Table 2 Methodology adopted for computation of morphometric parameters

Sr. No.	Parameters	Formulae / Definition	References
Liner Aspects			
1	Basin Length (L_b)	$L_b = 1.312 \times A^{0.568}$	Sreedevi *et al.*, 2005)
2	Stream Order (U)	The smallest permanent streams are called “first order”. Two first order streams join to form a larger, second order stream; and so on.	Strahler (1964)
3	Stream Length(L_u)	The average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio.	Horton (1945)
4	Mean Stream Length (L_{sm})	$L_{sm} = L_u/N_u$, Where, L_{sm}= mean stream length L_u = total stream length of all orders N_u = total no. of streams segment of order “u”	Strahler (1964)
5	Stream Length Ratio (RL)	RL= L_u/L_{u-1}, Where, L_{u-1} = the total stream length of its next lower order	Horton (1945)
7	Length of Overland Flow (L_g)	(Lg) = $1/2D_d$ Dd = Drainage density	Horton (1945)
8	Bifurcation Ratio (Rb)	Rb = N_u/N_{u+1}, Where, Nu+1 = no. segment of the next higher order	Horton (1932)
9	Mean Bifurcation	Rbm = Average of bifurcation	Strahler (1964)

	Ratio (Rbm)	ratio of all Orders	
10	RHO Co-efficient (RHO)	RHO = R_l/R_b The ratio between the stream length ratio and the Bifurcation ratio.	Mesa (2006)
Areal aspects			
1	Area (A)	Area of the basin in (km^2)	Horton (1945 and 1932)
2	Basin Perimeter (P)	Perimeter of the basin (km)	
3	Form Factor (Ff)	$Ff = A/L_u^2$	
4	Compactness Coefficient (Cc)	Cc = P/Circumference of the circle of the same area	Gravelius (1914) Hidore (1964)
5	Basin Shape (Bs)	$Bs = L_b^2/ A$, Where, $\pi = 3.14$, A = area of the basin (km^2), L_b^2 = square of the basin length	Horton (1945)
6	Circularity Ratio (Rc)	$Rc = 4\pi A/P^2$, Where, $\pi = 3.14$, A = area of the basin (km^2), P= Perimeter of the basin (km)	Miller (1953) and Strahler (1964)
7	Elongation Ratio (Re)	$Re = (2/L_b) \times (A/\pi)^{0.5}$, Where, L_b= basin length (km), A = area of the basin (km^2)	Schumm (1956)
8	Drainage Density (Dd)	$Dd = \Sigma Lu/A$, Where, Lu = total no. of stream segments of order 'u'', A = area of the basin (km^2),	Horton (1945)
9	Drainage Texture (Dt)	$Dt = \Sigma Nu/P$, Where, N_u = total no. of streams segment of order "u", P = Perimeter of the basin	
10	Texture Ratio (Tr)	$Tr = \Sigma N_1 / P$, Where, N_u = total no. of streams segment of order "1", P = Perimeter of the basin (km).	Schumm (1956)
11	Constant Channel Maintenance (Cm)	$C_m = 1 / Dd$	
12	Stream frequency(Fs)	$Fs = \Sigma Nu/A$, Where, Nu = total no. of stream segments of order 'u'', A = area of the basin (km^2)	Horton (1945)
13	Infiltration Number (If)	If = Fs (Dd)	Faniran (1968)
14	Lemniscate's (k)	$k = Lb^2 \pi/ (4A)$	Chorely et al. (1957)
Relief aspects			
1	Basin Relief (R)	R = H – h	Schumm(1956); Hadley and Schumm (1961)

2	Relief Ratio (R_f)	$R_f = H/L_b$	Schumm (1963)
3	Ruggedness number (Rn)	Rn = Dd *(H /1000)	Strahler (1964)
4	Dissection Index (D_{is})	D_{is} = Bh/Ra, where, Ra = absolute relief Bh = basin relief or total relief	Singh and Dubey (1994)

Table 3 Morphometric parameters of Ozat River basin

Sr. No.	Parameters	Results			
Liner Aspects					
1	Basin Length (L_b)	127.97km			
2	Stream Order (U)	7^{th}			
3	Stream Length in each order (L_u)	I	II	III	IV
		2398.56	989.15	612.54	374.67
		V	VI	VII	
		164.34	54.87	91.77	
	Total no. of streams in all orders	4676			
4	Mean Stream Length (L_{sm})	I	II	III	IV
		0.68	1.14	3.03	6.69
		V	VI	VII	
		11.74	10.98	91.77	
5	Stream Length Ratio (RL)	II/I	III/II	IV/III	V/IV
		0.41	0.62	0.61	0.44
		VI/V	VII/VI		
		0.33	1.67		
7	Length of Overland Flow (L_g)	0.34			
8	Bifurcation Ratio (Rb)	I/II	II/III	III/IV	IV/V
		4.08	4.29	3.61	4.0
		V/VI	VI/VII		
		2.80	5.0		
9	Mean Bifurcation Ratio (Rbm)	3.96			
10	RHO Co-efficient (RHO)	I/II	II/III	III/IV	IV/V
		0.10	0.14	0.17	0.11
		V/VI	VI/VII		
		0.12	0.33		
Areal aspects					
1	Area (A)	3176.24 km^2			
2	Basin Perimeter (P)	350.13 km			
3	Form Factor (Ff)	0.194			
4	Compactness Coefficient (Cc)	1.75			
5	Basin Shape (Bs)	5.15			
6	Circularity Ratio (Rc)	0.33 km			

7	Elongation Ratio (Re)	0.50 km
8	Drainage Density (Dd)	1.48 km^2
9	Drainage Texture (Dt)	2.17 km
10	Texture Ratio (Tr)	13.36
11	Constant Channel Maintenance (Cm)	0.68
12	Stream frequency(Fs)	1.47
13	Infiltration Number (If)	1.0
14	Lemniscate's (k)	4.05
Relief aspects		
1	Relief (R)	1044 m
2	Relief Ratio (Rf)	8.17
3	Ruggedness number (Rn)	1.54
4	Dissection Index (Dis)	1.00

Table 4 Areal and Relief aspects of sub basins

Sr. No.	**Parameters**	**Results**			
		Sub Basin			
		5G1C2	**5G1C3**	**5G1C4**	**5G1C5**
Areal aspects					
1	Area (A) (km^2)	521.14	998.58	587.62	1068.90
2	Basin Perimeter (P) (km)	122.57	168.23	160.29	148.69
3	Form Factor (Ff)	0.248	0.227	0.244	0.225
4	Compactness Coefficient (Cc)	1.51	1.50	1.87	1.28
5	Basin Shape (Bs)	4.03	4.40	4.10	4.44
6	Circularity Ratio (Rc)	0.44	0.44	0.29	0.61
7	Elongation Ratio (Re)	0.56	0.54	0.56	0.54
8	Drainage Density (Dd)	0.73	1.23	1.50	2.06
9	Drainage Texture (Dt)	1.86	5.96	5.15	17.63
10	Texture Ratio (Tr)	1.35	4.48	3.88	13.39
11	Constant Channel Maintenance (Cm)	1.37	0.82	0.66	0.68
12	Stream frequency(Fs)	0.44	1.00	1.41	2.45
13	Infiltration Number (If)	0.32	1.23	2.11	5.04
14	Lemniscate's (k)	3.17	3.46	3.22	3.49
Relief aspects					
1	Relief (R)	47 m	1035 m	948 m	708 m
2	Relief Ratio (Rf)	0.68	8.53	8.22	8.21
3	Ruggedness number (Rn)	0.04	1.28	1.44	1.54
4	Dissection Index (Di)	0.98	0.99	0.99	0.94

Table.5 Liner aspects of sub basins

Parameters	Sub Basin															
	5G1C2				5G1C3				5G1C4				5G1C5			
Basin Length (L_b)	45.83 km				66.31 km				49.07 km				68.92 km			
Stream Order (U)	7^{th}				7^{th}				7^{th}				7^{th}			
Stream Length in each order (L_u)	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
	170.63	83.86	61.00	25.00	643.65	247.34	150.38	109.71	438.65	187.38	106.00	80.77	1145.64	470.57	295.17	158.30
	V	VI	VII		V	VI	VII		V	VI	VII		V	VI	VII	
	-	-	39.26		46.95	24.93	1.52		30.33	-	40.56		87.07	30.35	10.43	
Total no. of streams in all orders	228				1003				826				2622			
Mean Stream Length (Lsm)	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
	1.03	1.78	5.55	6.48	0.85	1.33	3.20	9.14	0.71	1.21	3.03	8.08	0.58	0.98	2.71	5.28
	V	VI	VII		V	VI	VII		V	VI	VII		V	VI	VII	
	-	-	39.26		23.48	24.53	1.52		10.11	-	40.56		9.67	7.59	10.43	
Stream Length Ratio (RL)	II/I	III/II	IV/III	V/IV	II/I	III/II	IV/III	V/IV	II/I	III/II	IV/III	V/IV	II/I	III/II	IV/III	V/IV
	0.49	0.73	0.42	-	0.38	0.61	0.73	0.43	0.43	0.57	0.76	0.38	0.41	0.63	0.54	0.55
	VI/V	VII/VI			VI/V	VII/VI			VI/V	VII/VI			VI/V	VII/VI		
	-	-			0.52	0.06			-	-			0.35	0.34		
Length of Overland Flow (L_g)	0.68				0.41				0.33				0.24			
Bifurcation Ratio (Rb)	I/II	II/III	III/IV	IV/V	I/II	II/III	III/IV	IV/V	I/II	II/III	III/IV	IV/V	I/II	II/III	III/IV	IV/V
	3.51	4.27	2.75	-	4.05	3.96	3.92	6.0	4.01	4.43	3.50	3.33	4.16	4.39	3.63	3.33
	V/VI	VI/VII			V/VI	VI/VII			V/VI	VI/VII			V/VI	VI/VII		
	-	-			2.0	1.0			-	-			2.25	4.0		
Mean Bifurcation Ratio (Rbm)	3.51				3.49				3.82				3.63			
RHO Co-efficient (RHO)	I/II	II/III	III/IV	IV/V	I/II	II/III	III/IV	IV/V	I/II	II/III	III/IV	IV/V	I/II	II/III	III/IV	IV/V
	0.14	0.17	0.15	-	0.09	0.15	0.19	0.07	0.11	0.13	0.22	0.11	0.10	0.14	0.15	0.17
	V/VI	VI/VII			V/VI	VI/VII			V/VI	VI/VII			V/VI	VI/VII		
	-	-			0.26	0.06			-	-			0.15	0.09		

Run-off is generally faster in steeper basins, producing more peaked basin discharges and greater erosive power. It was found that value of relief ratio for Ozat basin was8.16 while for four sub basins are 1.04, 15.57, 19.48 and 10.90, among which the trend of low to high value indicated that the sediment loss per unit area is likely to be low to high in sub basins.

Relative relief

Relative relief is a one of the most significant geomorphic variable which is used for overall assessment of morphological characteristics of a terrain and for assessing the degree of dissection of a terrain (Singh 2001 and Suresh, 2002). It is also termed as relative altitude, topographic relief, and amplitude of available relief, local relief. The values of relative relief are influenced by lithology, structure, slope, climatic parameters, geomorphic process and vegetal cover etc. It helps in finding out the terrain characteristics and their significance with the controlling factors. In general it is the difference of elevation between highest and lowest points in a unit area (i.e., It is the ratio of relief to the perimeter of basin). The relative relief for sub basins varied from 0.38 to 6.15and for Ozatbasin it was 2.98. The watersheds having higher relative relief have higher runoff potential than others. Therefore, the watershed 5G1C2 and 5G1C4are having the lowest and highest runoff potential respectively.

Ruggedness number (Rn)

Ruggedness Number (Rn) is dimensionless parameter which represents the product of basin relief (Bh) and drainage density and it usually combines slope steepness with its length (Strahler, 1952a and 1964). An observed value of ruggedness number, morphology was possible to classify based on Rn values into five categories: <0.1 subdued morphology; 0.1 - 0.4 slight morphology; 0.4 - 0.7 moderate morphology; 0.7 - 1.0 sharp morphology; >1.0 extreme morphological expression, an extreme high value of ruggedness number occurs when both variables are large and slope is steep (Umrikar 2016). In the present study, the value of ruggedness number was 1.54 for Ozat basin. It is indicated that peak discharges are likely to be relatively higher. The Rn values for sub basins varied between 0.04 and 1.54. The lowest value of Rn was 0.04 for sub-basin5G1C2 and the highest value ofRnwas1.54 for sub basin 5G1C5. Sub basin 5G1C5 is located in the upper most area of the basin, while sub basins 5G1C3 and 5G1C4 are located in the middle basin where extreme morphological characteristics found, and sub basin 5G1C2 is part of the lower basin where subdued morphology is characteristic found.

Dissection index (Di)

Dissection Index (Di) is a parameter referring to the degree of dissection or vertical erosion, and the stage of landforms development in any given watershed (Singh, S. and Dubey, 1994). Di is the ratio between the total relief (relative relief) and absolute relief of the basin which always varies between 0.0 in case of complete absence of dissection and hence the dominance of flat topography and 1 for infrequent cases such as vertical cliff topography at the sea shore, or vertical escarpment of hill-slope. Accordingly, watersheds can be grouped into five categories: a) flat-undulating (<0.1), b) rolling (0.1 - 0.4), c) moderately dissected (0.4 - 0.7), d) highly dissected (0.7 - 1.0), e) extremely dissected (>1.0). Thus, the relative relief for a given basin was occasionally higher than maximum (absolute). Here, the total relief of the catchment was found 1.044 km, while the absolute relief of the basin is about 1.045 meters (above mean sea level). Therefore, the

Di value of basin was 1.0 and four sub basins are 0.99, 0.99, 0.99 and 0.94 respectively, which clearly indicated that the basin was in highly dissected stage.

In conclusion, the purpose of fluvial Morphometry is to derive information in quantitative form about the geometry of the fluvial system that can be correlated with hydrologic information. Usually, morphometric analysis of drainage system is a prerequisite to any hydrological study. The quantitative and qualitative analysis of geomorphometric parameters for the Ozat river basin and four sub-basins justifies the utilization of DEM and GIS tools for geomorphic evaluation of a drainage basin. The drainage network of Ozat River basin has been significantly influenced by geomorphic, lithologic, and structural factors. Morphometric analysis illustrates how these factors affected hydrogeological behavior and influence on hydrology of the basin. The study has shown that this basin is in conformity with the Horton's law of stream numbers and stream lengths. The drainage density (Dd) value for the basin is 2.06, and the Dd values for the sub-basins are below 3 which indicates that the fissured and jointed rock strata are relatively permeable, a characteristic feature of coarse drainage. The stream length ratio varies for both the Ozat river basin and the sub-basins as a result of local variation in morphology (changes and breaks of slope), slope steepness, relief and the stage of geomorphic evolution of landforms. High values of bifurcation ratios (6.0) for sub basin 5G1C3 indicated strong structural control in the drainage pattern while in low values in other sub basins indicated less structural control pattern. Low values of stream frequency denote that a significant proportion of surface water infiltrates to the subsurface strata, and thus the relatively high groundwater potential zone identified in the study area. The high value of drainage density indicative of region is composed of impermeable sub-surface materials, sparse vegetation and high mountainous relief causing higher surface run off, and a higher level of degree of dissection and low to moderate relief while low value indicates low runoff vice –versa. The Rb values characterize highly dissected mountainous basin with mature topography and higher drainage integration. The high relief ratio is an indicator of active erosion processes or steep slopes especially in the middle and lower reaches of the catchment, while low relief ratio is an indicate that no further erosion process going on in the basin area. Morphometric indices demonstrate a high dissected index (Di = 1.0) and a high ruggedness number (Rn = 1.24) as a result of extreme morphological expression including undulating topography. The development of stream segments in the basin area is more or less affected by rainfall. The present study demonstrates the usefulness of GIS for morphometric analysis of the Ozat river basin, Gujarat. Thus the morphometric properties determined for this basin as whole and for each sub basins will be aimed to help decision makers in planning efficient soil and water conservation schemes, watershed and natural resources management for future sustainable development on the sub basin level.

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