Asian Journal of Applied Science and Technology (AJAST)
(Open Access Quarterly International Journal) Volume 1, Issue 9, Pages 347-360, 2017

Morphometric Analysis of Trap Covered Suki River Basin, Maharashtra for Water Resource Management Using Geo-Spatial Tools

G.Shailaja[1], G.Gupta[1], S.T.Padmane[2] and S.N.Patil[3]

[1]*Indian Institute of Geomagnetism, New Panvel, Navi Mumbai 410218, India.*
[2]*Groundwater Surveys and Development Agency, Nagpur, Maharashtra 444602, India.*
[3]*School of Environment and Earth Sciences, North Maharashtra University, Jalgaon 425001, India.*

Article Received: 15 August 2017 *Article Accepted: 30 September 2017* *Article Published: 30 November 2017*

ABSTRACT

The Suki River basin of Raver sub-division in Jalgaon district, Maharashtra occurs at the threshold of two important stratigraphic unit's viz. the Quaternary alluvium and the Deccan traps and therefore is hydrogeologically interesting. This basin is located in the northern bank of river Tapi extending between the North Latitudes 21o04' to 21o23' and East Longitudes 75o43' to 76o03'. The area is divided into four geomorphic unit's viz. Upper Plateau, Piedmont zone, Older Alluvium and Flood Plains deposits. In order to enumerate the hydrological characteristics of the river basin, measurement of various morphometric parameters has been carried out. It is revealed that the basin has 6th order river network with a predominantly dendritic to sub-dendritic nature. The values obtained for bifurcation ratio (Rb), relief ratio (Rh), drainage density (D), stream frequency (Fs), drainage texture (Rt), circulatory ratio (Rc), elongation ratio (Re) etc have been correlated with each other to understand their underlying relationship and control over the basin hydrogeomorphology. The average bifurcation ratio is 4.17 and average drainage density of the area is 7.233 km/km2, suggesting coarse texture. It is observed that the watershed show relatively high correlation between drainage density and stream frequency. They are moderately well drained streams having relatively high run off. The correlation between drainage density and drainage texture suggest that the watershed show coarse to very coarse texture that supports suitability for water conservation structures. These results will be of vast utility for a comprehensive water resource management at watershed level.

Keywords: Suki River Basin, Morphometry, Hydrological Characteristics, Deccan Trap and Maharashtra.

1. INTRODUCTION

Groundwater resource occupies a key place in the irrigation sector in India because of its role in stabilizing Indian agriculture. With more than 700 million people sustaining their livelihood through agriculture in India, dependence on groundwater has recently increased due to introduction of high-yielding varieties of crops and adoption of multi-cropping pattern, both of which require a timely assured water supply. This reliability on groundwater as the most dependable source for irrigation has led to over exploitation in many parts of the country, both in hard rock terrain and alluvial areas (Naik and Awasthi, 2003). The cash crop irrigation has also created excessive pressure on the groundwater resource of these areas, to such an extent that, during past three decades, groundwater aquifer is being continuously over exploited. Further, progressive decline of groundwater levels and reduction in well yield are the chronic problems of such areas (Vijesh, 2013).

The Geographical Information System (GIS) technique has emerged as a very effective and reliable tool in the groundwater management studies (Reddy et al., 1996). This technique provides an authentic source of information for surveying, identifying, classifying, mapping and monitoring of natural resources in general and water resource in particular. The groundwater regime of any area is largely controlled by parameters like lithology, structures, geomorphology, slope, and land use/land pattern, which are inter-related and imperative for understanding the hydrological set-up of any area (Prakasam, 2010). The relevant baseline information on such features can be generated and analyzed as an individual thematic layer in the GIS environment (Gupta, 2003).

Morphometry is the measurement and mathematical analysis of the formation of earth's surface and of the shape and dimensions of its landforms (Clarke, 1966). Morphometric analysis of topographical features has long been applied in the structure and tectonic studies because their manifestations are usually well documented in the landform features of a region (Keller and Pinter 1996).

Quantitative measurements on drainages and relief features for morphometric studies have been done using the techniques of remote sensing and GIS in different drainage basins by many workers including Krishnamurthy and Srinivas (1995); Obi Reddy et al., (2004); Umrikar (2016) etc. The analysis of drainage basin has a particular relevance to geomorphology, taken either as a single unit or as a group of basins, which comprises a distinct morphological region. Thus, by analyzing the development of each drainage basin, greater understanding of the landscape as a whole can be achieved.

Keeping in view the relevance of the problem, the Suki River basin of Raver sub-division in Jalgaon district of Maharashtra has been studied to find answers to the water problems with respect to accessing groundwater potential and effective management of water in the basin. Hydrologically, the area is located on the threshold of two stratigraphic units of India i.e. Deccan Trap and Alluvium.

1.1 Geology and Hydrogeology of the area

Jalgaon district is located in north western part of Maharashtra state (Fig. 1). The area under investigation, Suki River basin in Raver sub-division, is situated to the northeast of Jalgaon district at a distance of about 55 km from Jalgaon. The area is included in Survey of India toposheet nos. 46 O/16, 46 O/15 and 55C/4 and bounded by latitude 21o04' to 21o23' and longitudes 75o43' to 76o03'.

The total area under study is 328.57 km2. The Suki River flows towards south having length of about 35.63 km. The local watercourses are the tributaries of Suki River. Further Suki River meets Tapi towards south near Mangalwadi village at right bank. The basin shows undulating topography. The northern part of the area has rugged topography due to east-west trending Satpuda ranges.

The average elevation is about 784 m. The southern part shows hill ranges covered with alluvial plain. The minimum elevation towards south is about 200 m. The drainage pattern is parallel to sub-parallel and flows towards south, while the pattern is dendritic along hilly area.

The general geomorphologic map of the Suki River basin is shown in Fig. 2. The upper plateau unit predominantly covers the northern part of the area. It consists of Deccan Traps covering 187.47 km2, which is about 57% of the area under study. The chances of occurrence of groundwater are scanty because of its nature. However these areas are suitable for extraction of groundwater through deep bore wells.

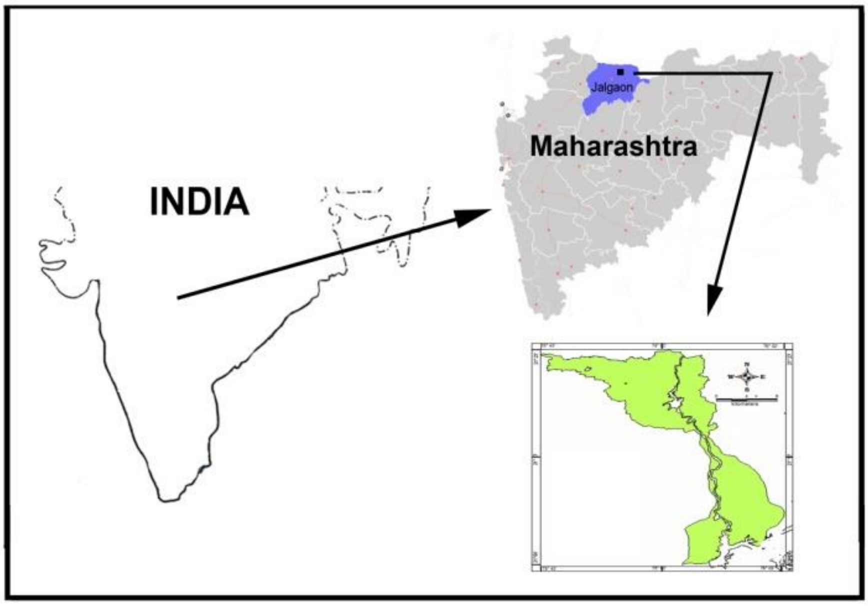

Fig. 1. Location map of Suki River basin, Jalgaon district, Maharashtra

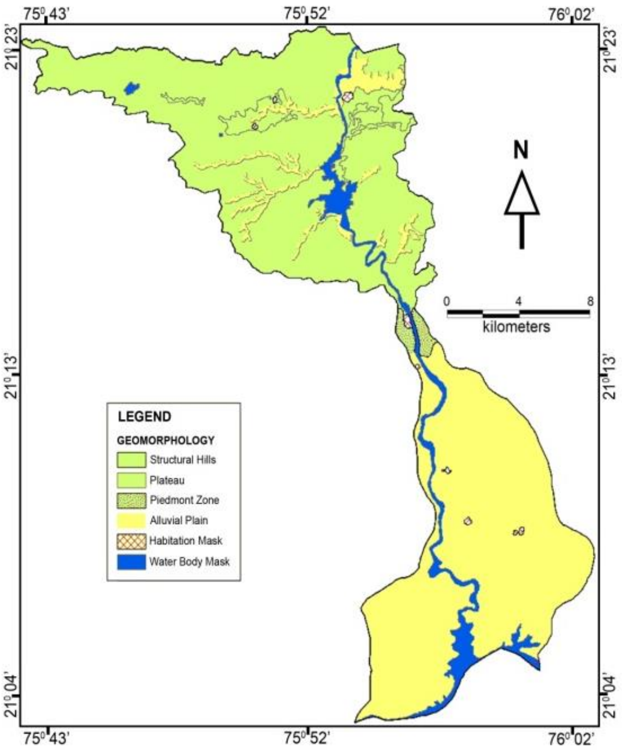

Fig. 2. Distribution of different geomorphologic units of Suki River basin

The piedmont zone is spread all along the Satpuda foothills of the study area (Fig. 2) and occupies nearly 1.4% of the total area. This zone consists of unconsolidated sediments like pebbles, cobbles, gravels and sand along with loose sand material and can be considered as good groundwater potential zone. The older alluvium, consisting of sandy-silt and clay, is observed in the southern part of piedmont zone (Fig. 2). It comprises of nearly 142.73 km^2, which is 43.44% of the area under investigation. The groundwater of the area is over-exploited due to banana and sugarcane plantation resulting in considerable depletion of water level especially in central part of the area. The floodplains (younger alluvium) are exposed along the bank of river Tapi and along the southern part of the area (Fig. 2). This area comprises mainly of sands, silts and clay and act as good aquifers. Thickness of alluvium is nearly 65 to 90 m and is characterized by badland topography with high percentages of clay.

2. MORPHOMETRIC ELEMENTS AND PARAMETERS

Systematic description of the geometry of a drainage basin and its stream channel system requires measurements of linear aspects of the drainage network, areal aspects of the drainage basin, relief (gradient) aspects of channel network and contributing ground slopes. The linear aspect deals with the hierarchical orders of stream numbers and lengths of stream segments, various relationships among them and related morphometric laws, e.g. laws of stream numbers and stream lengths. The areal aspect includes the analysis of basin perimeters, basin shape, basin area, stream frequency, drainage density and drainage texture. The relief aspect incorporates the study of absolute, relative relief, relief ratios, and average slope.

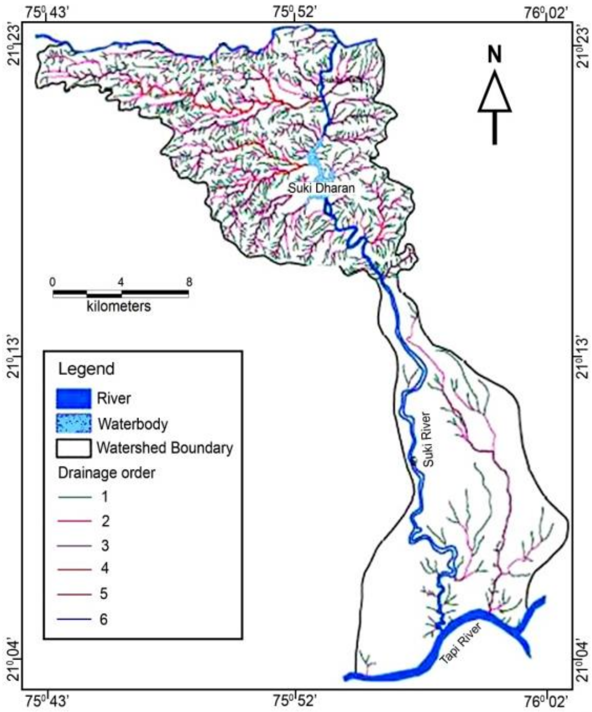

Fig. 3. Drainage map of Suki River basin showing streams of different orders

The morphometric parameters were computed using the formulae of different workers. For digitization, computation and output generation, GIS software like Arc GIS 9.5 version is used. Out of the various approaches of morphometric analysis, the analysis of drainage basin is performed with the help of 1: 50,000 scale topo sheet for the present study.

The basin is studied in linear aspect, areal aspect and relief aspect. Morphometric parameters of drainage basins are more in number which gives a clear picture of the evolutionary trend. The drainage basin is defined as the area drained by given stream and its tributaries delineated the Suki watersheds (Fig. 3). The basin demarcation is followed by ordering and ranking of streams. Although, various ways of stream ordering have been suggested, the method proposed by Horton (1945) and modified by Strahler (1952) is adopted in the present study.

3. RESULTS AND DISCUSSION

3.1 Linear aspects

Linear aspects of the basin are related to the channel patterns of drainage network wherein topological characteristics of the stream segments in terms of open links of the network system (streams) are analyzed. The following linear aspects of Suki River are studied using methods suggested by Horton (1945); Strahler (1952, 1964); Mueller (1968); Chorley (1969).

Stream Order (U)

The first step of drainage basin analysis includes designation of stream orders, following a system introduced by Horton (1945) and slightly modified by Strahler (1964). Stream order (U) states the relative magnitude of a segment of a stream channel and is determined by arrangement of tributaries with respect to the main trunk in the system of channel ordering. The smallest fingertip tributaries are designated as order 1; where two first order channels join, a channel segment of order 2 is formed; where two of order 2 join, a segment of order 3 is formed, and so forth. The trunk stream through which all discharge of water and sediments passes is therefore the stream segment of highest order. Table 1 gives an account of the number of streams of different orders in Suki River drainage basin.

Stream Number (Nu)

Following the ordering of the drainage network, all the segments of order U are counted to yield the number (Nu) of the stream segments in the basin. It is observed that the number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order (Table 1). According to Horton's law of stream numbers (Horton, 1945), the number of stream segments decreases with the number of increasing order in each case as well as in total.

Fig. 4. The relationship between stream orders (*U*) and number of streams (*Nu*) in the studied basin

The relationship between stream orders and logarithm of stream numbers (Figure 4) reveals that these two parameters are inversely proportion; i.e. with the increase of stream orders, the number of streams decreases. It can be observed from figure 4 that most of the points are located on or in vicinity of the straight line, whereas, the points that deviates from this line indicates that the study area is characterized by some regional upliftment (Ndatuwong and Yadav, 2014).

Stream Length (Lu)

Stream length is an important parameter as it reveals the attributes of surface runoff of a basin. Smaller stream lengths are characteristics of areas with greater slopes as well as fine textures, while longer stream lengths suggest flatter gradients. In general, the total length of stream segments decreases with increasing stream order, according to Horton's principle of stream length (Horton, 1932). The measurement of length of different orders of streams of the basin is tabulated in Table 1. The Suki River basin is of 6th order and the drainage pattern is predominantly dendritic to sub-dendritic in nature. Figure 5 shows the linear trend of logarithmic of stream length against stream order. The near linear pattern of the graph indicates that the homogenous rock was subjected to weathering-erosion characteristics of the study area. Here, the deviation from its general trend (Fig. 5) suggests that the basin is characterized by variation in lithology and topography.

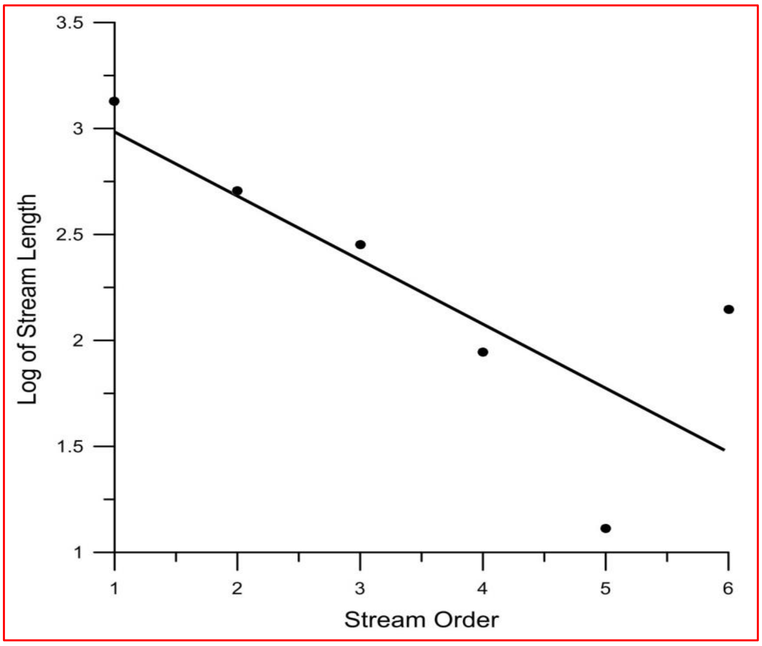

Fig. 5. The relationship between stream orders (*U*) and stream length (*Lu*) in the studied basin

Stream length ratio (RL)

Stream length ratio (RL) is defined as the ratio of average length of streams of a given order to that of streams of the next lower order. It has an important relation with the surface flow discharge and erosional stage of the basin (Horton, 1945). The values of RL range from 0.44-21.35 over the entire basin (Table 1). It is revealed that the stream length ratio between successive stream orders of Suki River basin varies drastically indicating differences in slope and topographic conditions (Sreedevi et al., 2005).

Table 1: Linear aspects of Suki River basin

Stream order (U)	Number of streams	Bifurcation ratio (Rb)	Total length of streams (Lu) (Km)	Stream Length ratio (RL)
1	843		1343.75	
		4.3		1.61
2	196		508	
		4.9		2.73
3	40		283.40	
		6.66		2.07
4	6		87.98	
		3		0.44
5	2		13.15	
		2		21.35
6	1		140.28	
Total/Mean	1088	4.17	2376.6	5.64

Bifurcation ratio (Rb)

Horton (1945) established a geometrical relationship of stream length and stream number to stream order, which states that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric series in which the first term is unity and the ratio is the bifurcation ratio. The ratio of number of segments of a given order (Nu) to the number of segments of the higher order (Nu+1), is termed as bifurcation ratio (Rb) (Strahler, 1964). The bifurcation ratio will precisely not be the same for all orders because of variation in watershed geometry but will tend to be a constant throughout the series. It characteristically ranges between 3.0 to 5.0 (Chow, 1964) for watershed in which the geology and structure do not distort the drainage pattern. The bifurcation ratio fall between 2 to 6.66 representing the universal range of maturely dissected drainage basins (Table 1). If the Rb value is less than 5 then it indicates geomorphological control, while if Rb is greater than 5, it indicates structural control on the development of the drainage pattern (Anantha Rama, 2014). For the V/VI order streams (3.0) and IV/V order streams (2.0), the Rb values are low, while the Rb for I/II (4.3) and II/III (4.9) are moderately high, while that for III/IV it is comparatively high (6.66), suggesting some structural control for the dissection of the streams in the central part of the basin.

3.2 Areal aspects

The areal aspects such as the drainage density (Dd), stream frequency (Sf), drainage texture (Rt), elongation ratio (Re), circularity ratio (Rc), drainage intensity (Id) and infiltration number (If) of the drainage basin were evaluated and the results are given in Table 2.

Drainage density

Drainage density (Dd) is the ratio of the total length of channel of all orders in a basin to the area of the basin (Horton, 1945). The influence of climate, vegetative cover, lithology, relief, infiltration capacity, surface roughness and run-off index also affects the drainage density (Ndatuwong and Yadav, 2014). In addition the amount and type of precipitation influences directly the quantity and quality of surface run-off. Thus an area with high precipitation results in more surface drainage channels. It is reported that low drainage density usually occurs in regions of highly resistant rocks and permeable sub-surface materials, thick vegetation and low relief, while high drainage density reveals weak and impermeable sub-surface materials, thin vegetation and showing high relief (Jadhav and Babar, 2013). This suggests that low drainage density reveals coarse drainage texture while high drainage density shows fine drainage texture.

Table 2: Areal aspects of Suki River basin

Sr. No.	Morphometric parameters	Suki River basin
1	Area of the basin (Sq. Km.)	328.57
2	Perimeter (Km)	90.44
3	Length of the basin (Km)	69.8
4	Width of the basin (Km)	19.06
5	Drainage density (Km/Sq. Km)	7.233
6	Stream frequency (Km^{-2})	3.31
7	Drainage texture (km^{-1})	12.03
8	Elongation ratio (Re)	1.49
9	Circularity ratio (Rc)	0.504
10	Drainage intensity (Id)	0.46
11	Infiltration number (If)	23.94

High drainage density (7.233 km/km2) is observed in Suki River basin (Table 2), which is indicative of weak and impermeable sub-surface material, sparse vegetative cover and moderate to high relief. The topography in combination with the nature of soil and sediments is largely responsible for the high surface run-off, poor infiltration and its impact on consequent scarcity of ground/surface water resources.

Stream frequency

Stream frequency (Fs) is a supplementary measure of fitness of the texture of topography. It is defined as the ratio of the total number of channel segments of all orders to the area of the basin (Horton, 1945). This parameter is useful in determining the number of streams per unit area. The stream frequency number increases on steep slopes whereas it decreases when the river flows in a flatter surface. This is also related to the total amount of rainfall or discharge against the texture and composition of the land cover. The Suki River basin reveals a stream frequency value of 3.31/km2 (Table 2). The stream frequency, which is on a higher side, shows a positive correlation with the drainage density thus indicating higher run-off rate.

Drainage texture

Drainage texture (Rt) is an important parameter in morphometric analysis which signifies relative spacing of drainage lines (Horton, 1945). This parameter also depends on several natural factors like precipitation, type of weather, vegetative cover, infiltration capacity, rock and soil type, and relief aspect of the terrain. Ndatuwong and Yadav (2014) reported that low drainage density suggests coarse drainage texture whereas high drainage density shows fine drainage texture. The drainage texture values in Suki River basin are 9.32 (1st order streams), 2.17 (2nd order streams), 0.44 (3rd order streams), 0.07 (4th order streams), 0.02 (5th order streams) and 0.01 (6th order stream). Thus the Suki River basin falls under fine to moderately coarse texture category, suggesting weak and impermeable sub-surface material which is largely responsible for the high surface run-off, poor infiltration and insignificant recharge of groundwater, except for the 3rd, 4th, 5th and 6th order streams.

Elongation ratio (Re)

Elongation ratio (Re) is defined as the ratio of diameter of a circle of the same area as the basin to the maximum length of the basin (Schumm, 1963), which gives an idea about the hydrological characteristics of a drainage basin. Value of Re about 1 indicates regions of very low relief, while the values ranging from 0.6-0.8 suggests high relief and steep ground slope (Strahler, 1964). The Suki River basin exhibits a high elongation ratio of 1.49 (Table 2), indicating multi-phase nature of the basin. The northern part of the basin is more of circular in nature whereas, the central and southern part is more elongated in nature.

Circulatory ratio (Rc)

The circulatory ratio (Rc) measures the degree to which a basin approximates a circle in planimetric outline. The shape of the basin changes with order and with increasing size of the drainage area. Strahler (1964) defined Rc as the ratio of the basin area to the area of the circle having the same perimeter as the basin. Along with the shape of the basin, this ratio also reveals the stage of development of a drainage basin. Furthermore, the circulatory ratio is influenced by the lithological character of the basin. The Rc value nearing unity suggests that the shape of the basin is circular and hence uniform infiltration is possible. This scenario also indicates that excess water will take a longer time to reach the basin outlet, depending on the local geology, slope and vegetative cover. The Rc value of the entire Suki River basin is 0.5 (Table 2). The high elongation ratio and comparatively low circulatory ratio indicates that the basin is fairly compact and more elongated.

Drainage Intensity (Id)

Faniran (1968) defines the Id as the ratio of the stream frequency to the drainage density. Drainage intensity measures the ability of the basin to discharge its water. This study shows a low drainage intensity of 0.74 for the basin (Table 2). According to Faniran (1968), the low value of Id implies that Dd and Fs have little effect on the extent to which the surface has been eroded by the agents of soil erosion.

Infiltration number (If)

The infiltration number of a drainage basin is defined as the product of drainage density and stream frequency. This parameter reveals about the infiltration characteristics of a watershed. The higher the infiltration number, the lower will be the infiltration and higher run-off. The infiltration number in Suki River basin is calculated to be 23.94 (Table 2), which is high and thus suggests poor infiltration and high surface run-off.

3.3 Relief aspects

The relief aspects of drainage basins are important to understand the flow direction of water and the extent of denudational process that have undergone within the basin. The relief parameters are useful to study the features involving area, volume and height of landforms to examine different geohydrological characteristics. Some important relief parameters are basin relief, relief ratio and basin slope.

Basin relief (H)

It is a measure of the general steepness of a basin, measured by the difference between the height of highest point on the watershed and the height of the mouth of the basin. In Suki River basin, the basin relief is evaluated to be 584 m (Table 3). It is an important parameter for understanding the geomorphological processes and landform characteristics of a watershed.

Table 3: Relief aspects of Suki River basin

Sr. No.	Morphometric parameters	Suki River basin
1	Elevation in meters Max “Z” Min “z”	 784 200
2	Total basin relief (H)	584
3	Relief ratio	8.37
4	Basin slope	1-50º

Relief ratio (Rh)

The relief ratio is a dimensionless parameter defined as the ratio of maximum basin relief to the horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1963). This parameter is an indicator of the extent of erosional processes operating on slopes of the watershed. It also specifies the relief characteristics of a basin and acts as a guiding factor for the flow of streams. The relief ratio of Suki River basin is 8.37 (Table 3). It has been generally noticed that higher values of relief ratio reveals steep slope, high drainage frequency and high stream frequency. In the present study, the high relief ratio value indicates the mature and elongated nature of the basin.

Asian Journal of Applied Science and Technology (AJAST)
(Open Access Quarterly International Journal) Volume 1, Issue 9, Pages 347-360, 2017

Slope analysis

Slope analysis is a significant factor in geomorphic studies, which are controlled by the climate-morphogenic processes in the area having rocks of varying resistance (Mesa, 2006). The perception of slope distribution is critical as a slope map provides data for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures, morpho-conservation practices etc. (Sreedevi et al. 2005). The general slope of the basin (Fig. 6) varies greatly. Towards south it is almost plane and adultery, while the northern area is characterized by hilly tract depicting all types of slope category, viz. crust and scrab slope, debris slope followed by pediment zone. The average slope towards south of the area is 0-3%, whereas large area of the northern part reveals a slope of 15-35%. High degree of slopes of 35-50 % is seen in other parts in northern part of the study area.

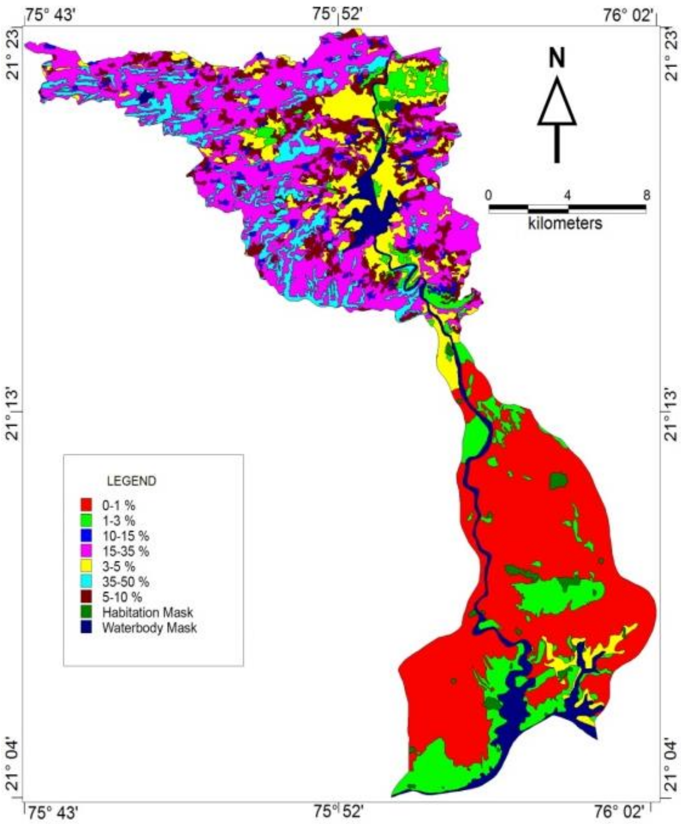

Fig. 6. Slope variation map of Suki River basin

4. CONCLUSIONS

On the basis of morphometric studies supported by the topographic evidences, it is revealed that the highest stream is of 6th order in Suki River basin. The total number of streams in the area are 1088, out of which 843 are of 1st order, 196 are of 2nd order, 40 are of 3rd order, 6 are of 4th order, 2 are of 5th order and 1 is of 6th order. The average bifurcation ratio of the area is 4.17 indicating a high gradient of the basin. It also indicates slightly hilly and well dissected drainage basin with high gradient in the initial stages of the river development. The number of streams against the orders shows a nearly perfect linear relationship. The mean length and order of stream also show a straight line relationship with some deviation.

The value of the circularity ratio (0.5) shows moderately elongated nature of the basin. The drainage density in the study area is 7.233 km/km2 and indicates coarse to fine texture of the basin. The stream frequency of Suki River basin is 3.31 which is because of the hilly terrain and steep gradient of the area. The textural ratio is 12.03 which reveals that the southern part of the area is having coarse to fine texture while the northern, north-western, and north eastern area has coarse to medium texture. High basin relief value is revealed (584 m) in the study area. Relief ratio is 8.39 and suggests a high relief of this basin, indicating the mature nature of the basin. It is evident that the relief ratio is high in the north, while it is comparatively low in the southern part of the area. It has been observed that the water of watershed shows relatively high correlation between drainage density and drainage frequency. It is important to look into the hydrogeological configuration of a watershed so that recharge measures are put in the right perspective at the planning stage itself. Hydrogeological mapping and morphometric drainage analysis should be integrated fruitfully to effectively plan the location of such facilities. These will in turn lead to better understanding of the groundwater scenario for societal development.

ACKNOWLEDGEMENTS

The authors are obliged to Director, IIG for the keen interest and support during the course of the work and allowing publishing the same. The first author (GS) is grateful to IIG for research fellowship. The authors are thankful to Shri B.I. Panchal for drafting the diagrams.

REFERENCES

[1] Anantha Rama, V., (2014), “Drainage basin analysis for characterization of 3rd order watersheds using Geographic Information System (GIS) and ASTER data”, Journal of Geomatics, 8(2), pp. 200-210.

[2] Chorley, R.J., (1969), “Introduction to Physical Hydrology”, Suffolk, Methues and Co. Ltd.

[3] Chow, V.T., (1964), “Handbook of applied hydrology”. McGraw Hill Book Company, Inc., New York.

[4] Clarke, J.I., (1966), “Morphometry from maps, Essays in geomorphology”, Elsevier Publ. Co., New York, pp. 235-274.

[5] Faniran, A., (1968), “The index of drainage intensity -a provisional new drainage factor”, Australian Journal of Science, 31, pp. 328– 330.

[6] Gupta, R.P., (2003), “Remote Sensing Geology”, Springer Verlag Berlin Heidelberg, Germany, (2nd Edition), pp. 1- 11.

[7] Horton, R.E., (1932), "Drainage basin characteristics", Transactions American Geophysical Union, 13, pp. 350-361.

[8] Horton, R.E., (1945), "Erosional development of streams and their drainage basins hydrophysical approach to quantitative morphology", Bulletin Geological Society of America, 56, pp. 275-370.

[9] Jadhav, S.I. and Babar, Md., (2013), "Morphometric analysis with reference to hydrogeological repercussion on Domri river sub-basin of Sindphana river basin, Maharashtra, India", Journal of Geosciences and Geomatics, 1(1), pp. 29-35.

[10] Keller, E.A. and Pinter, N., (1996), "Active tectonics", Prentice Hall, Upper Saddle River, New Jersey, 338p.

[11] Krishnamurthy, J. and Srinivas, G., (1995), "Role of geological and geo-morphological factors in groundwater exploration: A study using IRS LISS data", International Journal of Remote Sensing, 16, pp. 2595–2618.

[12] Mesa, L.M., (2006), "Morphometric analysis of a subtropical Andean basin (Tucumam, Argentina)", Environental Geology, 50(8), pp. 1235-1242.

[13] Mueller, J.E., (1968), "An introduction to the hydraulic and topographic sinuosity indexes", Annals of the Association of American Geographers, 58, pp. 371-385.

[14] Nag, S.K. and Chakraborty, S., (2003), "Influence of rock types and structures in the development of drainage network in hard rock area", Journal Indian Society of Remote Sensing, 31(1), pp. 25-35.

[15] Naik, P.K. and Awasthi, A.K., (2003), "Groundwater resources assessment of the Koyna river basin, India", Hydrogeology, 11, pp. 582-594.

[16] Ndatuwong, L.G. and Yadav, G.S., (2014), "Morphometric Analysis to Infer the Hydrogeological Behaviour in Part of Sonebhadra District, Uttar Pradesh, India, Using Remote Sensing and GIS Technique", International Journal of Remote Sensing and GIS, 3(1), pp. 1-7.

[17] Obi Reddy, G.P., Maji, A.K., Chary, G.R., Srinivas, C.V., Tiwary, P. and Gajbhiye, K.S., (2004), "GIS and remote sensing applications in prioritization of river sub basins using morphometric and USLE parameters- a case study", Asian Journal of Geoinformatics, 4(4), pp. 35-48.

[18] Prakasam, C., (2010), "Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal taluk, Tamil Nadu", International Journal of Geomatics and Geosciences, 1(2), pp. 103-113.

[19] Reddy, P. R., Vinod Kumar, K. and Seshadri, K., (1996), "Use of IRS-1C data in groundwater studies", Current Science, 70(7), pp. 600-605.

[20] Schumm, S.A., (1963), "Sinuosity of alluvial rivers on the Great Plains", Bulletin of Geological Society of America, 74, pp. 1089-1100.

[21] Sreedevi, P.D., Subrahmanyam, K. and Shakeel, A., (2005), "The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain", Environmental Geology, 47(3), pp. 412-420.

[22] Strahler, A.N., (1952), "Dynamic basis of geomorphology", Bulletin of Geological Society of America, 63, pp. 923-938.

[23] Strahler, A.N., (1964), "Quantitative geomorphology of drainage basins and channel networks", In: V. T. Chow (Ed.), Handbook of Applied Hydrogeology, McGraw Hill Book Co., New York, pp. 4-76.

[24] Umrikar, B.N., (2016), "Morphometric analysis of Andhale watershed, Taluka Mulshi, District Pune, India". Applied Water Science, DOI 10.1007/s13201-016-0390-7.

[25] Vijesh, V.K., (2013), "Groundwater information, Jalgaon district, Maharashtra", Technical Report 1788/DBR/2013, Central Ground Water Board.