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Morphometric Analysis of Abdan Basin, Almahfid Basement Rock, Yemen: using Remote Sensing and GIS

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Abstract To achieve the morphometric analysis of Abdan basin, Survey of Yemen Geological Survey and Mineral Resources Board (YGSMRB) topomaps in 1:100000 scales are procured and the boundary line has been extracted by joining the ridge points. The drainage map is prepared with the help of GIS tool and morphometric parameters such as linear, aerial and relief aspects of the basin have been determined. For detailed study we used SRTM data for preparing DEM, elevation and slope map. GIS was used to estimate the linear, aerial and relief aspects of morphometric parameters. The result indicate that the drainage area is 922.933 km^2, perimeter 163.115 km, basin length 54.156 km, drainage texture 1.974, constant of channel maintenance 1.145, the stream frequency 0.349, drainage density 0.873, length over flow 0.572. Mean bifurcation ratio 4.355 so the drainage pattern has not been disturbed by structural disturbance. Form factor 0.315 and circulatory ratio 0.436 indicate that the basin is sub-circular to elongate in shape.

Keywords *Abdan Basin; Almahfid Basement; Geographic Information System; Morphometry*

1. Introduction

Drainage basins are the fundamental units to understand geometric characteristics of fluvial landscape, such as topology of stream networks, and quantitative description of drainage texture, pattern, shape and relief characteristics (Obi Reddy et al., 2004; Subba Rao, 2009). Morphometric analysis is an important technique to evaluate and understand the behaviour of hydrological system. Morphometric analysis of a river basin offers a quantitative description of the drainage system, which is an important aspect of the characterization of basins (Strahler, 1964). According to Clarke (1996), geomorphometry is the measurement and mathematical analysis of the configuration of the Earth's surface, shape and dimensions of its landforms.

The morphometric analysis is performed through measurement of linear, aerial, relief, gradient of channel network and contributing ground slope of the basin (Ali, 1988; Nautiyal, 1994; Nag and Chakraborty, 2003; Magesh et al., 2012b). Morphometric analysis of a river basin comprises of discrete morphologic region and has special relevance to drainage pattern and geomorphology (Strahler, 1957; Dornkamp and King, 1971).

Remote sensing and GIS utility provides useful source for the preparation of various thematic layers for morphometric analysis. Morphometric and other characteristics (elevation, slope etc.) of landscape can be evaluated to any extent using Digital Elevation model. SRTM data has been used in spatial environment (GIS) to assess the morphometric behaviour with ease, accuracy and cost effective way. Remote sensing and GIS technology has been used for morphometric analysis of river basins carried out using (Ali et al., 2013; Ali & Ali, 2014)

In the present study, evaluation of various morphometric parameters is described using ArcGIS10.2 software for Abdan Basin, YEMEN. The mathematical calculation of linear, aerial and relief aspects were done to decipher the various geomorphometric parameters for planning and development of Abdan Basin.

2. Materials and Methods

2.1. Study Area

The Abdan basin covers an area of 922.933 km^2 with basin length of 54.156 kms. The greater portion of Abdan basin is located in Nisab and Hatib districts, Shabwah governorate, and a small part is located in Jayshan district, Abyan governorate, Republic of Yemen. This basin lies between longitudes 46^o 10' to 46^o 40' and latitudes 14^o 00' to 14^o 40' (Figure 1). The climate of the study area is tropic-arid. It is essentially affected by the monsoon winds of the Indian Ocean. The climate is moderate in summer and cold in winter. The vegetation in some parts of the surface is limited either in terms of quantity or type and it is almost exclusively in certain types of grasses and small plants that abound during the rainy seasons as well as some old trees scattered near the valleys and mountain passes and the most important of these trees are lotus, acacia tortilis and acacia nilotica and some trees of acacia gummifera, tamarisk and boxthorn.

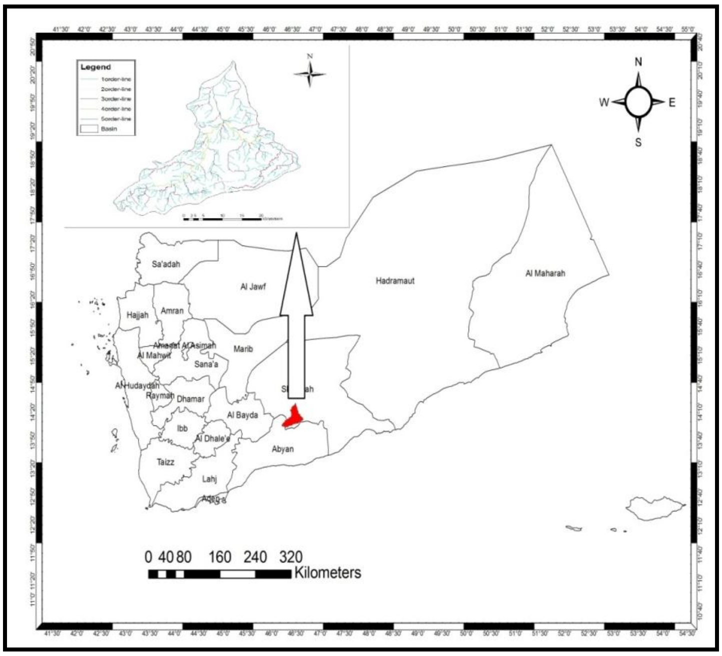

Figure 1: *Location Map of Abdan Basin*

2.2. Geology of Study Area

Abdan basin is part of Almafid zone which is in this basin consist of Barak subzone which is lower Proterozoic and Hatib subzone which is higher Proterozoic. The Barak group comprises Biotite-

Plagioclase Schist, Biotite-Amphibole Gneisses, a part of which is granitized. The Hatib group complete sequence is subdivided into the Hogl, Wasr, Medwa, Ayan and Samaq formation.

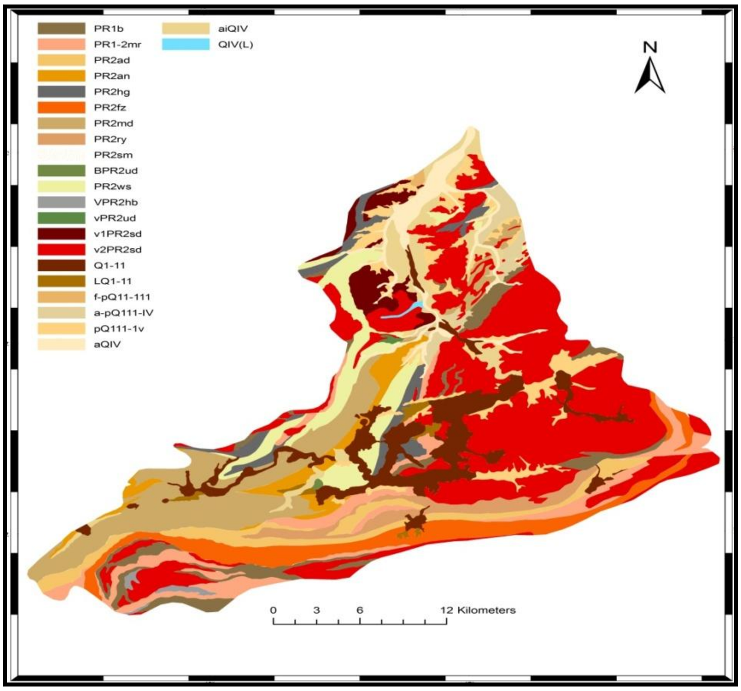

Figure 3: *Geological Map of Study Area*

2.3. Methodology and Data Source

The study of Abdan basin is based on Yemen Geological Survey Board (YGSMRB) toposheet maps on a 1:100000 scale. The toposheet maps (D-38-57, D-38-58, D-38-69 and D-38-70) and also an SRTM data were used. The SRTM was an 11 day space shuttle mission in February 2000 (Figure 7 & 8). The drainage network (Figure 3) and morphometric analysis was carried out at the basin in Arc GIS 9.3. The morphometric parameters were divided into three categories: linear, areal and relief aspects of the basin.

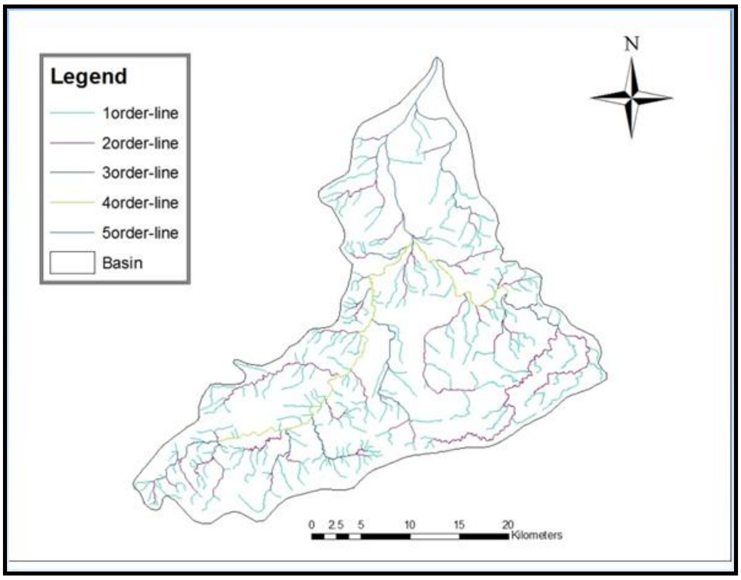

Figure 2*: Drainage Map of Abdan Basin*

Table 1: *Description Geological Map of Study Area*

S/O	Symbol	Description	Period
I	PR1b	Biotite-Plagioclase Schist, Biotite-Amphibole Gneisses, a part of which is granitized. Barak Group	Lower Proterozoic
II	PR1-2mr	Mash'ar formation	Lower Proterozoic
III	PR2ad	'Ads formation. Fahman Group.	Upper Proterozoic
IV	PR2an	Ayan formation. Hatib Group.	Upper Proterozoic
V	PR2hg	Hogl formation. Hatib Group.	Upper Proterozoic
VI	PR2fz	Fayzum formation. Fahman Group.	Upper Proterozoic
VII	PR2md	Medwa formation. Hatib Group.	Upper Proterozoic
VIII	PR2ry	Ray formation. Fahman Group	Upper Proterozoic
IX	PR2sm	Samaq formation. Hatib Group.	Upper Proterozoic
X	BPR2ud	Metadiabase. Uddamar Magmatic Complex.	Upper Proterozoic
XI	PR2ws	Wasr Formation. Hatib Group.	Upper Proterozoic
XII	VPR2hb	Metagabbro, Gabbro-Amphibolite. Hatib Group.	Upper Proterozoic
XIII	vPR2ud	Metagabbro. Uddamar Magmatic Complex	Upper Proterozoic
XIV	v1PR2sd	Older Granite. Sa'id Magmatic Complex.	Upper Proterozoic
XV	v2PR2sd	Younger Granite, Mainly Syenogranite. Sa'id Magmatic Complex	Upper Proterozoic
XVI	Q1-11	Lower-Middle Quaternary Basaltic Rocks	Quaternary Volcanites
XVII	LQ1-11	Lacustrine Loam, Sand, Gravel And Gruss. Lower-Middle Quaternary	Quaternary Volcanites
XVIII	f-pQ11-I11	Fluvial-Proluvial Pebble Gravel, Boulders, Conglomerate. Middle-Upper Quaternary	Quaternary
XIX	a-pQ111-IV	Alluvial-Proluvial Pebble Gravel, Boulders, Conglomerate. Upper Quaternary-Recent.	Quaternary
XX	pQ111-1V	Proluvial Rubble, Pebble Gravel. Upper Quaternary-Recent	Quaternary
XXI	aQIV	Alluvial Pebble Gravel, Gravel And Sand.	Quaternary
XXII	aiQIV	Agro-Irrigation Loesslike Loam. Recen	Quaternary
XXIII	QIV(L)	Basalt. Recent	Quaternary

3. Results and Discussion

The Morphometric characteristics of study area are examined with reference to linear, aerial and relief aspects.

Table 2: *Formulae Adopted for Computation of Morphometric Parameters*

S. No.	Morphometric Parameters	Formula	Reference
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length (L.u)	Length of the stream	Horton (1945)
3	Mean stream Length (L. sm)	L.sm = L.u / Nu where L.sm = Mean stream length L.sm = Total stream length of order 'u' N.u = Total no. of stream segment of order 'u'	Strahler (1964)
4	Stream length Ratio (R.L)	R.L. = L.u / Lu-1 Where R.L = Stream length Ratio L.u = The Total stream length of order 'u' L.u.1 =The total stream length of its next lower order	Horton (1945)
5	Bifurcation Ratio (Rb)	Rb. = Nu/Nu + 1 Where Rb = Bifurcation Ratio Nu = Total no. of steam segments of order 'u' N.u.1 =The total stream length of its next higher order	Schumn (1956)
6	Mean bifurcation ratio (Rbm)	Rbm. = Average of bifurcation ratios of all orders	Strahler (1957)

7	Relief Ratio (Rh)	Rh = H/L.b where Rb = Relief Ratio H =Total relief (Relative relief) of the basin in Kilometer) Lb = Basin length	Schumn (1956)
8	Drainag Density (D)	D = L.u / A where, D = Drainage Density Lb = Total stream length of all orders. A =Area of the Basin (Km^2)	Horton (1932)
9	Stream Frequency (Fs)	Fs = Nu / A where, Fs = Stream Frequency Nu = Total no. of streams of all orders A =Area of the Basin (Km^2)	Horton (1932)
10	Drainage Texture (Dt)	Dt = Nu / A where, Dt = Drainage Texture Nu = Total no. of streams of all orders P =Perimeter (km)	Horton (1945)
11	Form Factor (Rf)	Rf = A / $L.b^2$ where, RF = Form Factor A =Area of the Basin (Km^2) Lb^2=Square of Basin length	Horton (1932)
12	Circularity Ratio (Rc)	Rc = 4* A / P^2 where, RC = Circularity Ratio Pi = 'Pi' Value i.e. 3.14 A =Area of the Basin (Km^2) P = Perimeter (km)	Miller (1953)
13	Elongation Ration (Re)	Re = 2V (A / Pi / L.b) where, Re = Elongation Ratio A =Area of the Basin (Km^2) Pi ="Pi" value i.e. 3.14 L.b =Basin length	Schumn (1956)
14	Length of overland flow (Lg)	L.g = 1 / D*2 Where, Lg = Length of overland flow D =Drainage Density.	Horton (1945)
15	Constant channel Maintenance (C)	C = 1/D	Schumn (1956)
16	Slope	Sb = $\frac{H-h}{Lr}$	Mesa (2006)
17	Gradient Ratio	Gr = $\frac{H-h}{L}$	Sreedevi et al (2005)
18	Infiltration number (If)	If = D*Fs Where, If = Infiltration number, D = Drainage Density, Fs = Stream frequency.	

3.1. Linear Aspects

Linear aspects includes drainage parameters such as stream order (Nu), stream length (Lu), Mean Stream Length (Lsm), Stream Length Ratio (Rl), Bifurcation Ratio (Rb) and Mean Bifurcation Ratio (Rbm).

***Table 3 (a):** Linear Aspect of Abdan Basin*

Basin	Stream Number in Different Orders						Orders Total Stream Length (Km)					
	1st order	2nd order	3rd order	4th order	5th order	Total	1st order	2nd order	3rd order	4th order	5th order	total
Abdan Basin	248	58	14	2	1	322	455.9	186.6	88.19	54.03	21.26	806

***Table 3 (b):** Linear Aspect of Abdan Basin*

Basin	Perimeter (Km)	Mean stream length (Km)						Stream length ratio (Rl)					Bifurcation ratio (Rb)				Mean bifurcation ratio (Rbm)
		1st order	2nd order	3rd order	4th order	5th order	total	2/1	3/2	4/3	5/4	Rl	1/2	2/3	3/4	4/5	
Abdan Basin	163.115	1.838	3.275	6.299	27.015	21.269		0.409	0.472	0.613	0.394	0.472	4.276	4.143	7	2	4.355

3.1.1. Stream Order (U)

The designation of stream orders is the first step in drainage basin analysis. It is based on hierarchic ranking of streams proposed by Strahler (1964). The first order streams have no tributaries. The second order streams have only first order streams as tributaries. Similarly, third order streams have first and second order streams as tributaries and so on. In present study, Abdan watershed has fifth stream order. With increasing stream order the number of stream is decreases (Figure 4, Table 3a).

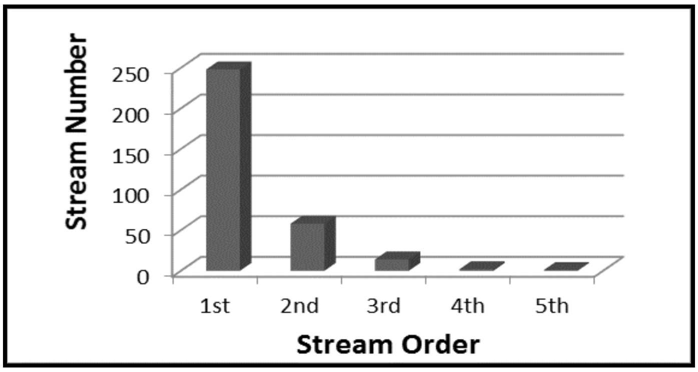

***Figure 4**: Stream Number Vs Stream order*

3.1.2. Stream Length (Lu)

It is the total length of streams in a particular order. The numbers of streams of various orders in watershed were counted and lengths were measured with help of ArcGIS 9.3. Generally, the total length of stream segments decreases with stream order. The maximum length of the total basin is 806.093 km. Generally the total length of stream segments decreases with increasing stream order (Figure 5, Table 3a).

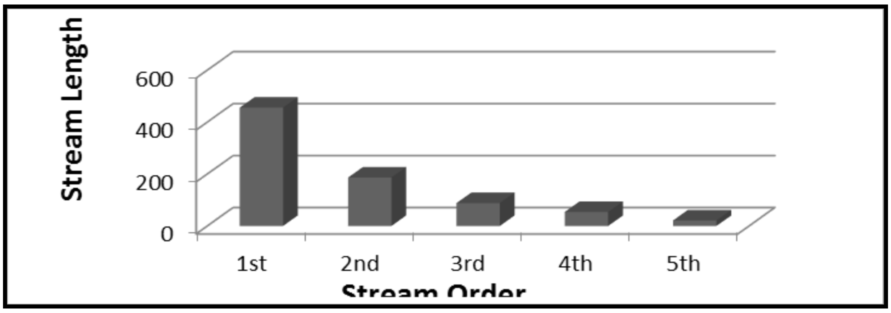

Figure 5: *Stream length Vs Stream order*

3.1.3. Mean Stream Length

The mean stream length of a channel is a dimensional property and reveals the characteristic size of drainage network components and its contributing basin surfaces (Strahler, 1964). The mean stream length (Lsm) is calculated by dividing the total stream length of order by the number of streams.

3.1.4. Stream Length Ratio (Rl)

The stream length ratio (Rl) is defined as the ratio of mean stream length (Lu) of segment of order u, to mean stream segment length (Lu-1) of the next lower order u-1. The stream length ratios (Rl) are changing haphazardly at the basin and sub-basin levels. The values of the Rl vary from 0.394 to 0.613. It is noticed that the Rl between successive stream orders of the basin vary due to differences in slope and topographic conditions. The Rl has an important relationship with the surface flow discharge and erosional stage of the basin (Table 3b).

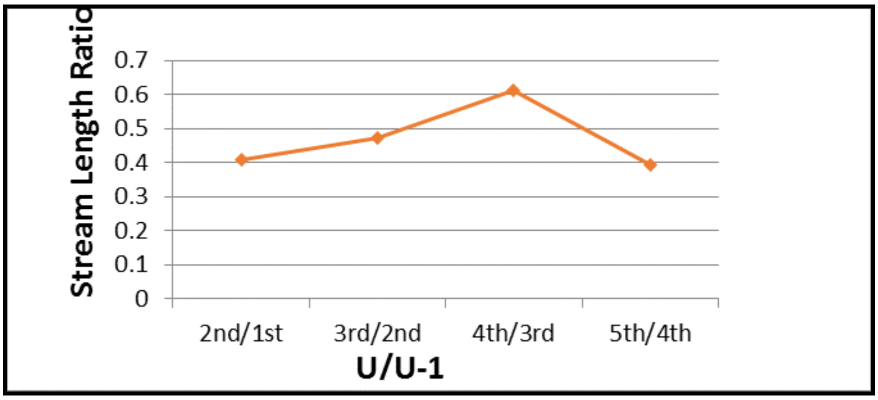

***Figure 6**: Stream Length Ratio Vs U/U-1*

3.1.5. Bifurcation Ratio (Rb)

It is the ratio of the number of a given order to the number of streams of the next higher order (Schumm, 1956). Horton (1945) considered bifurcation ratio (Rb) as an index of relief and dissection. Strahler (1957) demonstrated that Rb show only a small variation for different regions on different environment except where powerful geological control dominates. Lower Rb values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag, 1998). In this study area, mean Rb varies from 2 to 7 and the mean Rb of the entire basin is 4.355.

3.2. Aerial Aspects

Aerial Aspect includes drainage parameters such as Drainage Density (Dd), Drainage Texture (Dt), Stream Frequency (Fs), Form Factor (Rf), Circulatory Ratio (Rc), Elongation Ratio (Re).

Table 4: *Aerial Aspect of Abdan Basin*

Basin	Drainage Density (D)	Stream Frequency (Fs)	Circularity Ratio (Rc)	Form Factor (Rf)	Elongation ratio (Re)	Drainage Texture(Rt)
Abdan Basin	0.873	0.349	0.436	0.315	0.633	1.974

3.2.1. Drainage Density (Dd)

Drainage density (Dd) expresses the closeness of spacing of channels. It is the measure of the total length of the stream segment of all orders per unit area. It is affected by factors which control the chrematistics length of the stream like resistance to weathering, permeability of rock formation, climate, vegetation etc (Langbein, 1947).

Slope gradient and relative relief are the main morphological factors controlling drainage density.

Strahler (1964) noted that low Dd is favored where basin relief is low, while high Dd is favored where basin relief is high. The Dd for the whole basin is 0.873 km/km^2.

3.2.2. Drainage Texture (Dt)

It is the total number of stream segment of all orders per perimeter of that area (Horton, 1945). Horton recognized infiltration capacity as the single important factor which influences drainage texture (Rt) and considered the drainage texture to include drainage density and steam frequency. The Rt of the whole basin is 1.974, shown in Table 3. Smith (1950) classified drainage density into five different texture i.e. very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8). In the present study Basin has very coarse drainage texture as its drainage density is 1.974.

3.2.3. Stream Frequency (Fs)

Horton introduced stream frequency (Fs) or channel frequency which is the total number of stream segments of all orders per unit area (Horton, 1932). Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of same stream frequency differing in drainage density. Reddy et al. (2004b) state that low values of Fs indicate permeable sub-surface material and low relief. The Fs of the whole basin is 0.349.

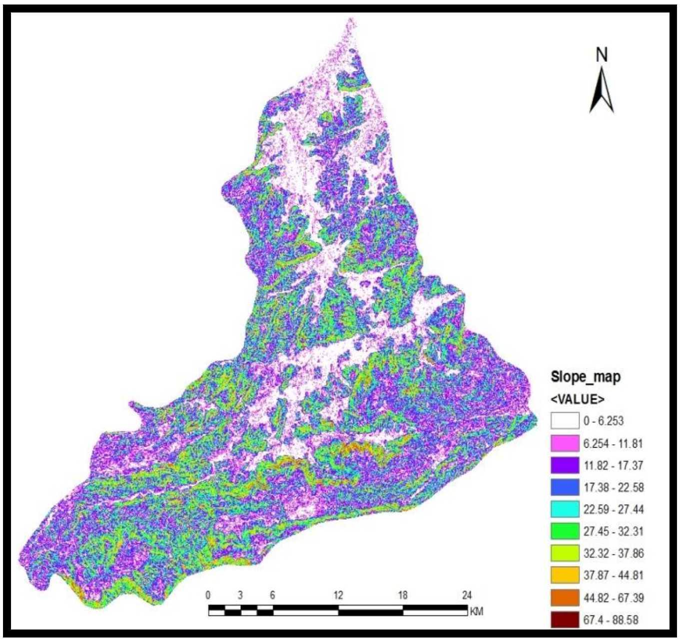

***Figure 7**: Slope Map of Abdan Basin*

3.2.4. Form Factor (Rf)

Horton (1932) defined Form factor (Rf) as a dimensionless ratio of basin area (A) to the square of basin length (Lb). The value of Form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factors have high peak flows for shorter duration, whereas elongated basins with lower values of form factor have lower peak flow for longer duration . Flood flows of elongated basins with low form factor are easier to manage than those of the circular basins with higher values of form factor (Nautiyal, 1994). The Rf of the whole basin is 0.315.

3.2.5. Circularity Ratio (Rc)

Miller (1953) defined circulatory ratio (Rc) as the ratio of the area of the basin (A) to the area of circle having the same circumference as the perimeter of the basin (P). The circulatory ratio (Rc) is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin (Chopra et al, 2005). The circulatory ratio remained remarkably uniform in the range 0.6 to o.7 for first order and second order basins in homogeneous shales and dolomites, indicating the tendency of small drainage basins in homogeneous geologic material to preserve geometrical similarity. However, first and second order basins situated on flanks of moderately dipping strata are strongly elongated with circularity ratio between 0.4 and 0.5 (Chow, 1964). The Rc of the whole basin is 0.436.

3.2.6. Elongation Ratio (Re)

It is the ratio between the diameter of the circle with the same area as that of the basin (A) and the maximum length (L) of the basin. A circular basin is more efficient in run-off discharge than an elongated basin (Singh and Singh, 1997). The value of elongation ratio (Re) generally varies from 0.6 to 1.0 associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope (Strahler, 1964). These values can be grouped into three categories, namely circular (>0.9), oval (0.9-0.8) and less elongated (<0.7). The Elongation Ratio (Re) for the basin is 0.633. The Re value indicated the basin to be elongated with high relief and steep slope.

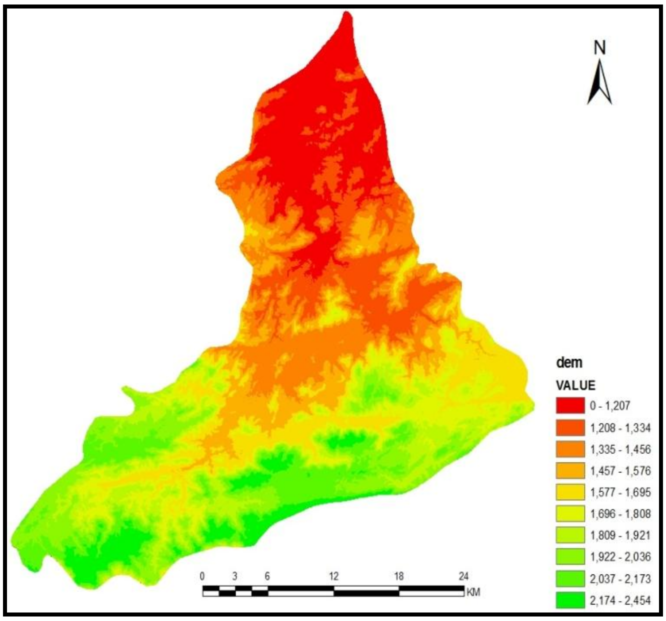

***Figure 8**: Digital Elevation Model of Abdan basin*

3.2.7. Relief Aspect

Relief Aspect includes Relief Ratio, Length of Overland Flow, and Constant of Channel Maintenance (Table 5).

3.2.8. Relief Ratio (Rh)

The elevation difference between the highest and lowest points on the valley floor of a sub-watershed is its total relief, whereas the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is Relief Ratio (Rh) (Schumn, 1956). It measures the overall steepness of a drainage basin and is an indicator of intensity of erosion processes operating on the slopes of the Basin. The Rh normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). Rh for the basin is 0.0216.

3.2.9. Length of Overland Flow

It is the length of water over the ground before it gets concentrated into definite stream channels (Horton, 1945). This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density (Horton, 1945). The Length of over land flow for whole basin is 0.572.

3.2.10. Constant of Channel Maintenance

Schumm (1956) has used the inverse of drainage density as a property termed constant of channel maintenance. It tells the number of sq.ft of watershed surface required to sustain one linear feet of channel. The Constant of channel maintenance of whole basin is 1.145.

***Table 5**: Relief aspects of Abdan Basin*

Basin	Infiltration number (If)	Elevation (km)		Longest dimension of basin length(Km)	Relief (Km)	Relief Ratio (Rr)	Gradient Ratio (Gr)	Constant channel maintenance (C)	Length of overland flow (Lg)
		Max	Min						
Abdan Basin	0.305	2.241	1.070	54.143	.171	0.0216	0.022	1.145	0.572

4. Conclusion

The study of morphometric analysis of Abdan basin using Remote sensing and GIS software which are very help full to analysis the drainage basin easily and accurately. The study of linear aspects shows that the basin has formed subdendritic to subparallel type drainage pattern with highest order fifth. The study of area concluded that areas drained by drainage orders of 1st, 2nd and 4th have Bifurcation ratio between 2 to 4.276, indicating that these are not distorted by geological structures. The Bifurcation ratio in case of the 3rd order is 7. It is noted, in the drainage basin that this area is dominated by the presence of lineaments. The Drainage density (Dd) is 0.873 reveals that the subsurface strata are impermeable in Abdan basin. This is a characteristic feature of coarse drainage as the density values are less than 5.0. Lower order streams mostly dominate the basin. The form factor and elongation ratio value of the Abdan basin is 0.315 and 0.633 respectively, which indicated that the basin is sub-circular to elongate in shape and the major part of basin is of high relief. The length of overland flow is 0.572 which indicated young topography of the study area.

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References

Ali, S.A. and Khan, N. *Evaluation of Morphometric Parameters- A Remote Sensing and GIS Based Approach*. Open Journal of Modern Hydrology. 2013. 3; 20-27.

Ali, S.A., 1988: *Morphometric Analysis of the Hiyunl River Basin at Rishikesh, Garhwal Himalayas, India.* Proceedings of the IX Asian Conference on Remote Sensing, Bangkok, 23-29 November, B-9-1-B-9-8.

Ali, U., and Ali, S.A. *Analysis of Drainage Morphometry and Watershed Prioritization of Romushi - Sasar Catchment, Kashmir Valley, India using Remote Sensing and GIS Technology*. I. Jour. of Advanced Research. 2014. 2 (12) 5-23.

AL-Khirbash, S., Takla, M., Abdul Wahed, M.S., and Sakran, Sh. *Tectonic Evolution of the Southeast Precambrian Basement Complex, Yemen.* Faculty of Science Bulletin-Sana'a University. 2001. 14; 67-83.

Chow V.T., 1964*: Handbook of Applied Hydrology*. New York: McGraw Hill Inc.

Clarke, J.I., 1966: *Morphometry from Maps*. Essays in Geomorphology. New York: Elsevier Publ. Co., 235-274.

Dornkamp, J.C., and King, C.A.M., 1971: *Numerical Analyses in Geomorphology, an Introduction.* New York: St. Martin's Press, 372.

Geological Survey & Minerals Resources-Yemen (GSY), 1990, 1978: Geological and Topographical maps of Abdan Area D-38-57, D-38-58, D-38-69, and D-38-70.

Gottschalk, L.C., 1964: Reservoir Sedimentation. In: Chow, V.T. (ed.) Handbook of Applied Hydrology., New York: McGraw Hill Book Company Section. 7-1.

Horton, R.E. *Drainage Basin Characteristics.* Transaction of American Geophysical Union. 1932. 13; 350-361.

Horton, R.E. *Erosional Development of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology*. Bulletin Geological Society of America. 1945. 56; 275-370.

Langbein, W.B. *Topographic Characteristics of Drainage Basins.* Geological Survey of America. Water-Supply Paper. 1947. 986 (C) 157-159.

Magesh, N.S., Jitheshlal, K.V., Chandrasekar, N., and Jini, K.V. *GIS based Morphometric Evaluation of Chimmini and Mupily Watersheds, Parts of Western Ghats, Thrissur District, Kerala, India*. Earth Sci Inform. 2012b, 5; 111-121.

Mesa, L.M., *Morphometric Analysis of a Subtropical Andean Basin (Tucumam, Argentina).* Environmental Geology. 2006. 50 (8) 1235-1242.

Miller, V.C. *A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area.* Virginia and Tennessee, Project Number 389-402. Technical Report-3, Columbia University, Department of Geology, New York, 1953.

Nag, S.K. *Morphometric Analysis using Remote Sensing Techniques in the Chaka Sub-Basin, Purulia District, West Bengal.* Journal of the Indian Society of Remote Sensing. 1998. 26 (1&2) 69-76.

Nag, S.K., and Chakraborty, S. *Influence of Rock Types and Structures in the Development of Drainage Network in Hard Rock Area.* Journal of the Indian Society of Remote Sensing. 2003. 31 (1) 25-35.

Nautiyal, M.D. *Morphometric Analysis of a Drainage Basin Using Aerial Photographs: A Case Study of Khairkuli Basin, District Dehradun, U.P.* Journal of the Indian Society of Remote Sensing. 1994. 22 (4) 251-261.

Obi Reddy, G.P., Maji A.K., and Gajbhiye K.S. *Drainage Morphometry and its Influence on Landform Characteristics in a Basaltic Terrain, Central India- A Remote Sensing and GIS approach*. Int J Appl Earth Obs Geoinfo. 2004. 6; 1-16.

Rajiv Chopra, Raman Deep Dhiman and Sharma, P.K. *Morphometric Analysis of Sub-Watersheds in Gurdaspur District, Punjab Using Remote Sensing and GIS Techniques.* Journal of the Indian Society of Remote Sensing. 2005. 33 (4) 531-539.

Rakesh, K., Lohani, A.K., Sanjay, K., Chatterjee, C., and Nema, R.K. *GIS Based Morphometric Analysis of Ajay River Basin up to Sarath Gauging Site of South Bihar.* Journal of Applied Hydrology. 2001. 14 (4) 45-54.

Reddy, O.G.P., Maji, A.K., and Gajbhiye, S.K. *Drainage Morphometry and its Influence on Landform Characteristics in a Basaltic Terrain, Central India- A Remote Sensing and GIS Approach.* International Journal of Applied Earth Observation and Geoinformatics. 2004b. (6) 1-16.

Schumm, S.A. *Evolution of Drainage Systems and Slopes in Badlands at Perth Amboy, New Jersey.* Bulletin of the Geological Society of America. 1954. 67; 597-646.

Singh, S., and Singh, M.C. *Morphometric Analysis of Kanhar River Basin.* National Geographical Journal of India. 1997. 43 (1) 31-43.

Sreedevi, P.D., Subrahmanyam, K., and Shakeel, A. *The Significance of Morphometric Analysis for Obtaining Groundwater Potential Zones in a Structurally Controlled Terrain.* Environmental Geology. 2005. 47 (3) 412-420.

Strahler, A.N. *Quantitative Analysis of Watershed Geomorphology.* Transactions of American Geophysical Union. 1957. 38; 913-920.

Strahler, A.N. *Quantitative Geomorphology of Drainage Basins and Channel Networks.* In: Chow, V.T. (ed). Handbook of Applied Hydrology. New York: McGraw Hill Book Company. 1964, Section 4-1I.

Subba, Rao. *A Numerical Scheme for Groundwater Development in a Watershed Basin of Basement Terrain: A Case Study from India*. Hydrogeology Journal. 2009. 17; 379-396.