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Quantification of Morphometric Analysis using Remote Sensing and GIS Techniques in the Qa' Jahran Basin, Thamar Province, Yemen

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Abstract— **Demand for irrigation water increases day by day along with meteorological vagaries and extension of irrigated area in the drought-prone Jahran district. The study is aimed at studying the morphometric parameters of the Qa' Jahran basin in Jahran district and on their relevance in water resource management. The drainage network was prepared from the ASTER (DEM) and verified with survey and mineral resources board of Yemen's maps in GIS environment.Quantitative morphometric analysis was carried out for different sub basins for linear aspects, areal aspects and relief aspects.The results of the morphometric analysis reveal that the Qa'Jahran basin is of dendritic pattern, high erosion activity, basin is underlined by uniform materials, basin is flat, Drainage density is moderate spacing streams, permeable sub soil materials with dense vegetated cover and low relief (alluvial plain), susceptible to flooding, gully erosion, enhanced ground water recharge potentiality, Form factor and circularity ratio results represent an elongated shape, have a flatter peak flow for longer duration and drainage system were subject to less structurally controlled on the drainage development in over all the basin, low relief for most portion of the basin, high surface runoff and high susceptibility of the basin for both soil erosion and flooding.The higher slope gradient in the study area is contributed by the eruption of basaltic flow in northern, eastern and western parts. Higher slope gradient results in rapid runoff with potential soil loss or erosion. The Qa' Jahran basin relief value is 110m for sub basin 1 to 640m for sub basin 2 indicates low infiltration and high runoff conditions. The ruggedness number ofthe subbasins 1 and 2 indicates higher soil erosion susceptibility.**

Index Terms— **Basin, GIS, Jahran Basin, Morphometric analysis, Remote sensing, Yemen.**

I. Introduction

The morphometric analysis is essential for hydrological investigations such as groundwater potentiality assessment, groundwater management, hydrological behavior, environmental assessment and pedology.Morphometry of drainage basin is the measurement and mathematical analysis of the configuration of earth surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy et. al., 2002).Water demand and increasing population have become most important growing issues due to more and more urbanization taking place worldwide. Drainage basin analysis based on morphometric parameters is very significant for watershed planning since it gives an idea about the basin physical characteristics in terms of slope, topography, soil condition, runoff characteristics, surface water potential etc. The morphometric analysis of drainage basin and its stream system can be better achieved through measurement of linear, areal and relief aspects of drainage basin (Biswas et al, 1999). Comprehensive morphometric analysis of a basin is of great help in understanding the effect of drainage morphometry on landforms and their characteristics.One of the advantages of quantitative analysis is that many of the basin parameters derived are in the form of ratios, and dimensionless numbers, thus providing an effective comparison irrespective of the scale (Krishnamurthy et al. 1996).Remote sensing and GIS plays an important role in the study of morphometric characterization.GIS techniques are currently used for measuring various terrain and morphometricparameters of the drainage basins or watersheds, as they provide a flexible environment and a prevailing tool for the manipulation and analysis of spatial information. Morphometric analysis helps in characterizing the watershed by revealing the hydrologicaland geomorphic processes intertwined and happens in the watershed by means of developing and employing the methods to quantify the land exteriors (Singh, 1992; and Daret al. 2013).Thus, the process is responsible for a full understanding of hydrologic behavior of awatershed. Similarly, some of the morphometric parameters, like, circularity ratio and bifurcation ratio are input parameters in the hydrological analysis (Esper, 2008) and evaluation of surface water potentiality of an area. A more realistic approach of drainage morphometric analysis is employed by using the drainage network extracted from the Digital Elevation Model (DEM) as suggested by Bhat, 2009. In this perspective, this study forms a basis for characterizing hydrologic behavior of Qa' Jahran basin, Thamar Province, Yemen using morphometric procedures.

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II. Study Area

The Qa' Jahran basin is locatedin the Middle Western part of Yemen, at the Central Highland Plains in Ma'ber district. It represents the main catchments of Ma'ber plain **(Fig. 1)**. The geographic extent of basin area lies between longitudes 44°12'20" and 44°22'30"E and latitudes14°38'11" and 14°57'30"N with total area extent 342.11 $km^2$and it's about 25 km a distance toward north of Thamar city.The villages in the catchment around 20 village. The Qa' Jahran basin is one of the largest and most completely flat areas of its size in the Highland Plains of Yemen. The land use of the catchment area is agricultural,mainly qattree.The catchment area of the basin is affected by soil erosion. The intensive drilling activity for water quest in the catchment and water scarcity related to human interface with water storage has resulted inground water to sink down and the basin threated by drought due to ground water depletion. The basin consists of three geomorphological units i.e. the plain, the plateaus and the mountains. These units consist of different lithological units of steep slopes in which the surface water flow (Runoff) started and flows towards the plain which consist of alluvial deposits. Scattered isolated volcanic plateau can be observed within the study area. Based on the physiographical classification of Yemen, the study area is located on the Central Highland Plains.

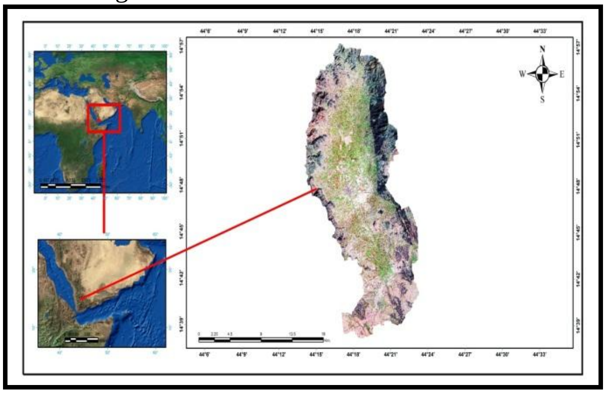

Figure 1: Location map of the study area

III. Geological Setting

Geologically the area can be divided into two broad areas, area covered over to large extent by alluvial deposits (wind-blown soils and sands generally fertile land) and area covered by Paleogene-Neogene continental magmatisms which was erupted due to opening the Red Sea and Gulf of Aden.In the late Oligocene-early Miocene to the present time, large volumes of flood basalts emplaced at discrete eruptive centers along the western margin of the Arabian plate from the Gulf of Aden to the Mediterranean (Albaroot et al, 2016). The continental magmatisms of varying volume and composition exposed in the marginal of the catchment area and can be divided into Yemen trap series (older) and Yemen volcanic series (YVS). The Yemen trap series (YTS) forming the lower part of the Qa' Jahran basin volcanic anddeveloped through the period from the Late Oligocene toEarly Miocene (31–26 Ma) (Bosworth et al, 2005) related to the Afar plume thatimpacted the Arabia–Africa area during the Oligocene andalso to the opening of the Red Sea and the Gulf of Aden. TheYTS occurs in the form of lava flows and intrusions and consist of Ignimbrite, ash flow, Rhyolite, Dacite, Trachyte, Basalt and Granite in the study area. It is outcropping towards the Northern, Eastern and Western periphery of the study area forming a series of mountain of semi steep slopes (less than 60°). The maximum altitude of these mountains is present at the northern and western parts of the study area. They also, outcrop on the western boundary of the pilot area and extend towards south. The geological map (Fig. 2) shows, the presence of a huge granitic intrusion of amorphous shape towards the north-western part of the study area. It has an age similar to the Tertiary Granitic Intrusive of Jabal Saber (Taiz), JabalBura (Hodeidah) and JabalHufash (AL-Mahwait). It has a strong relation to the opening of the Red Sea Rift system.YVSwas initially cited by (M. A. Mattash, 1994, Beydoun et al, 1998) on the basis of both geochronological and geochemical evidence. They were generated and developed through the post-rift stage (Miocene to Recent), and are separated by an unconformity. The age assigned for TVS range from 11.3 to 0.04 MA (Mattash et al, 1994). The YVS exposed mainly in the south and south east of study area, with minor exposer scatter in the western part in the study area. Basaltic lava hasbeen emplaced on huge body of Ignimbrite trending N-S inherited that from major normal fault straddling the basin. Quaternary deposits are represented in the study area as plain and as sheet of loss quaternary sediments in the elongated depressions found in the area of study. These deposits are represented by gravels, sand, silt, clay, basin alluvium and alluvial terraces. Quaternary alluvial deposits form thick accumulations in central of the catchment area, it eroded out towards the margins of the basin and they are strongly deformed and uplifted by normal faultto the east of the basin. Structurally the basin has been formed due to half graben motion which formed elongated shape basin bounded by normal fault to the east of the basin.

IV. Methodology

The base map of Qa' Jahran basin was Prepared based on geological survey and mineral resources board of Yemen topographic maps on a 1:50,000 scale. The drainage network was prepared from the ASTER Digital Elevation Model (DEM) with a spatial resolution of 20m and then verified with survey and mineral resources board of Yemen maps. The primary morphometric parameters such as number of stream segments, stream order, subbasin length, perimeter, and area were delineated from the Digital Elevation Model in GIS environment. Quantitative morphometric analysis was carried out for different catchments as mentioned above for linear aspects, areal aspects and relief aspects. The analysis was carried out using GIS Arc Map 10.1 software. The detailed list of various morphological characteristics derived for sub basin is presented in Table 1 and 2. System of stream ranking (Strahler, 1957) has been used for calculating the morphometric parameters of the reservoir and lake catchments of the present study.

The calculation of drainage analysis of Qa' Jahran basin was based on the methods (Table 1) given by various workers.

V. Data Analysis and Results

Quantitative Morphometric analyses were carried out of Qa' Jahran basin. The basin is divided into 4 sub basins with codes Sub basin 1 to Sub basin 4.

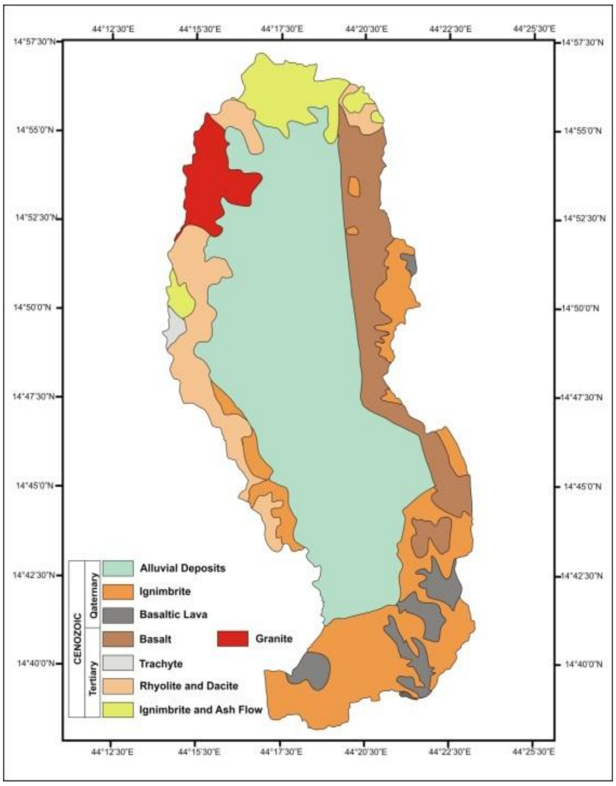

Figure 2: Geological map of Qa' Jahran Basin.

The results of Morphometric characteristics are presented in Tables 2 and 3.

A. Drainage Pattern

The drainage pattern of the Qa' Jahran basin area is dendritic pattern is characterized by irregular branching of tributary streams in all directions and is influenced by the topography of the area. Presence of dendritic drainage pattern shows homogenous and uniform soil type, gentle regional slope, and lack ofstructural control. The Qa' Jahran basin is primarily covered by Tertiary and Quaternary sediments and the extensive development of dendritic pattern in the whole of the basin is due to the fact that the area is covered by low-flat dipping alluvial sediments. Total number of stream segments in first order is 383 and maximum frequency is observed in first order streams (Fig 3).

B. Linear Aspects of the Qa' Jahran basin

Linear aspects of a drainage network reveal the behavior of river and its tributaries from head to mouth and reflect lithological and structural controls of the drainage basin. The important linear aspects of a drainage basin includes stream order, stream number, bifurcation ratio, mean bifurcation ratio, stream length, mean stream length and stream length ratio etc. table 3.

Basin Perimeter (P)

Basin perimeter is the length of watershed boundary that encloses the catchment area. It is used in conjunction with the basin area to give a measure of the departure of the basin from a true circle and in conjunction with relief to give a measure of the general steepness of the basin. The Qa' Jahran basin with perimeter 115.8 km is divided into first, second, third and fourth order subwatersheds (Table 2). Among the subwatersheds, the sub basin 1 has largest perimeter (80.31km) and sub basin 4 has smallest perimeter (19.85km) (Fig 3).

Basin Length

Basin length of the watershed is the distance between the watershed outlet and the farthest point on the perimeter of the watershed. The basin length of the study area is 34km (Fig 3).

Stream Length (Lu)

Stream length is indicative of the contributing area of the basin for a given order Horton (1945). The length of stream segments is high for first order streams and decreases as the stream order increases. The mean and total stream lengths of of each stream order are given in Table 3.

Table 1. Linear, areal and relief aspects calculated for morphometric analysis

S. No.	Morphometric Parameters	Formula	Reference
Linear Aspect			
1	Perimeter (P)	Length of the drainage basin boundary	Arc measurement tool
2	Basin length(Lb)	Maximum length of the basin measured parallel to the main drainage line	Arc measurement tool
3	Streamlength (Lu)	Length of the Major stream	Horton (1945)
4	Mean stream length(Lsm)	Lsm = Lu / Nu , Lu = Total stream length of order 'u' Nu = Total no. of stream segments of order 'u'	Strahler (1964)
5	Stream length ratio (RL)	RL = Lu / Lu – 1 , Lu = The total stream length of the order 'u' Lu – 1 = The total stream length of its next lower order	Strahler (1964)
6	Bifurcation ratio (Rb)	Rb = Nu / Nu + 1, Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	Schumm (1956)
7	Mean bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
Aerial Aspect			
8	Total Area (A)	Total area of the basin	Arc measurement tool
9	Drainage density (Dd)	$Dd = \sum Lu / A$	Horton (1945)
10	Drainage texture (T)	$T = Dd \times Fs$	Horton (1945)
11	Stream frequency (Fs)	$Fs = \sum Nu / A$	Horton (1932)
12	Form factor (Rf)	$Rf = A / Lb^2$	Horton (1932)
13	Circularity ratio (Rc)	$Rc = 4\pi A / P^2$	Miller (1953)
14	Elongation ratio (Re)	Re = 1.128vA / Lb	Strahler (1964)
15	Length of overland flow (Lg)	Lg = 1/2Dd	Horton (1945)
Relief Aspects			
16	Basin Relief (R)	R = H- h, H is maximum elevation and h is minimum elevation within the basin.	Schumm (1956)
17	Relief ratio (Rh)	Rh= H/ Lb, where H= maximum basin relief Lb = maximum basin length	Schumm (1956)
18	Ruggedness number (Rn)	$Rn = R \times Dd$, R is the basin relief and Dd is the drainage density	Strahler (1958)

Table 2:Morphometric characteristics of catchments in the study area.

S. No.	Subbasins Parameters	Units	S.B. 1	S.B. 2	S. B.3	S. B.4
1	Catchment Area (A)	Sq.km	172.90	113.74	40.38	15.09
2	Perimeter of the Catchment (P)	km	80.31	60.53	36.23	19.85
3	Catchment Stream Highest Order		6	5	4	4
4	Maximum Length of catchment (L)	Km	25	20.019	9.35	6.30
5	Maximum width of Catchment (W)	Km	11.8	9.48	8.14	4.00
6	Cumulative Stream segment	No.	383	274	96	37
7	Cumulative stream length	Km	403.85	269.13	89.62	34.08
8	Mean Bifurcation ratio (Rbm)		3.31	3.77	4.31	3.09
9	Length of over land flow (Lg)	km/km2	0.86	0.85	0.90	0.89
10	Drainage density (Dd)	km/Sq.km	2.34	2.37	2.22	2.26
11	Drainage Texture (T)	km/Sq.km	4.77	4.53	2.65	1.86
12	Stream frequency (Fs)	No./Sq.km	2.22	2.41	2.38	2.45
13	Form factor (Ff)		0.28	0.28	0.46	0.38
14	Circularity ratio (Rc)		0.34	0.39	0.39	0.48
15	Elongation ratio (Re)		3.37	3.04	2.66	1.98
16	Minimum relief	km	2.29	2.31	2.31	2.31
17	Maximum relief (Km)		2.89	2.96	2.46	2.42
18	Mean relief (Km)		2.43	2.55	2.55	2.35
19	Basin Relief (R)	Km	0.60	0.64	0.15	0.11
20	Relief Ratio (Rh)		0.12	0.15	0.26	0.38
21	Ruggedness Number (Rn)		1.41	1.53	0.33	0.25
22	Relative Relief (Rr)		3.60	4.88	6.78	12.12

Table.3: Linear Morphometric characteristics of catchments in the study area.

Subbasin	Stream order	No. of Segments Nu	Bifurcation ratio (Rb)	Total Length (Km) Lu	Mean Length (Km) Msm	Cumulative no of streams ∑ Nu	Cumulative Length (Km) ∑Lu	Stream Length Ratio RL	Mean Bifurcation ratio (Rbm
SB1	1	284	3.94	189.60	0.67	284	189.60	0.67	3.31
	2	72	3.60	116.72	1.62	356	306.33	1.62	
	3	20	5.00	53.39	2.67	376	359.71	2.67	
	4	4	2.00	15.11	3.78	380	374.83	3.78	
	5	2	2.00	10.69	5.35	382	385.52	5.35	
	6	1	-	18.33	18.33	383	403.85	18.33	
SB2	1	183	2.77	132.42	0.72	183	132.42	0.72	3.77
	2	66	3.30	66.10	1	249	198.52	1.00	
	3	20	5.00	47.28	2.36	269	245.80	2.36	
	4	4	4.00	16.65	4.16	273	262.46	4.16	
	5	1	-	6.67	6.67	274	269.13	6.67	
	-	-	-	-	-	274	269.13	-	
SB3	1	71	3.94	46.44	0.65	71	46.44	0.65	4.31
	2	18	3.00	22.02	1.22	89	68.45	1.22	
	3	6	6.00	14.85	2.48	95	83.30	2.48	
	4	1	-	6.31	6.31	96	89.62	6.31	
	-	-	-	-	-	96	89.62	-	
	-	-	-	-	-	96	89.62	-	
SB4	1	25	2.78	17.92	0.72	25	17.92	072	3.09
	2	9	4.50	8.93	0.99	34	26.85	0.99	
	3	2	2.00	5.32	2.66	36	32.17	2.66	
	4	1	-	1.92	1.22	37	34.08	1.92	
	-	-	-	-	-	37	34.08	-	
	-	-	-	-	-	37	34.08	-	

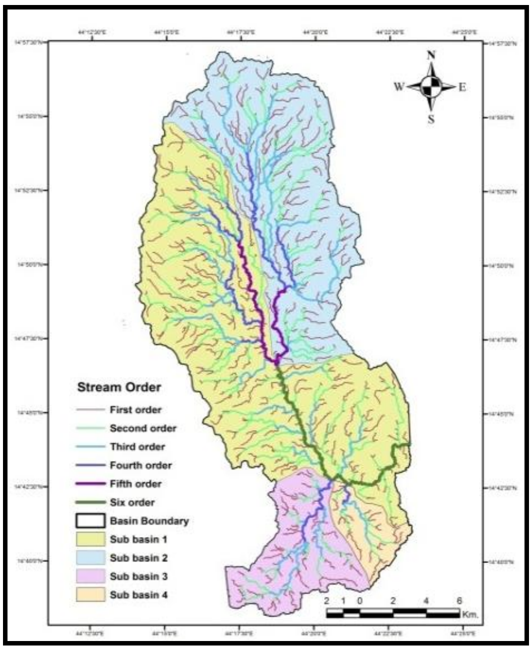

Figure 3: Drainage network of the Qa' Jahran basin.

It is noticed that the RL between successive stream orders of the basin vary (fig 5) due to differences in slope and topographic conditions (Rakes Kumar et

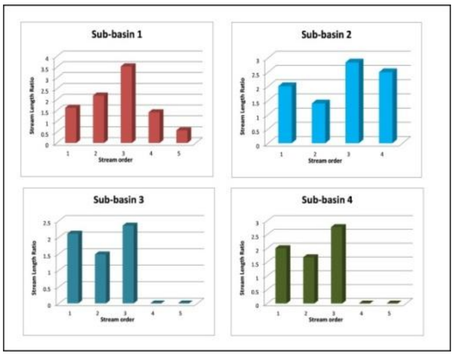

Figure 4: Linear aspect stream length ratio vs stream order

al., 2001; Sreedevi et al., 2005). Higher stream length ratio in sub basin 1 indicates high erosion activity.

Stream order (U)

In the Strahler scheme for ordering the network, all the "fingertips" tributaries are designated as first order streams and where two of them join, they form a second order stream. Likewise, two second order streams join to form a third order stream and so on to the streams of fourth, fifth and higher order. Figure 3 illustrates the stream network of Qa' Jahran basin. The stream orders vary from 1 to 6 and the total number of stream segments of all orders recorded was 790. Orders of stream network indicated 563 of 1st orders, 165 of 2nd, 48 of 3rd, 10 of 4th, 3 of 5th, and 1 of 6th order streams. The number and length of stream segments of each order are given in table 3.

Bifurcation ratio (Rb)

Bifurcation ratio is the ratio of a number of the stream segments of specified order and a number of
stream in the next higher order (Rai, et al, 2017, Chandrashekar et al, 2015, Vittalaet al, 2004,
Yangchan et al, 2015).The bifurcation ratio is range from 2-6 in case of overall drainage system of the basin. The majority of bifurcation ratio (Rb) table 3 is less than 5 indicates that the drainage basin is underlined by uniform materials, and streams are usually branched systematically with large number of first, second and third order streams. The maximum value recorded in the sub basin-3 particularly in the third order which cuts through different bedrocks of geological units such as basaltic lava, ignimbrite and alluvial deposits.Generally, the less bifurcation values are common in the areas where geological structures are less disturbing the drainage pattern of the Qa' Jahran Basin. The bifurcation ratio of the zones of alluvial deposits is comparatively low than the rocks exposures zone.

Mean Bifurcation ratio (Rbm)

In the present study Mean bifurcation ratioRbm for the eachsub-basin of the Qa' Jahran basin is given in Table 3. Mean bifurcation ratio of all the subwatershed of the Qa' Jahran basin is varies from 3.09 to 4.31. The Rbm usually ranges between 3.0 and 5.0 for a basin when the influence of geological structures on the drainage network is insignificant (Verstappen, 1983). The lower valus of Rbm in all over the basin is indicative that the basin is flat (Fig. 5). In case of sub basin 3 show higher Rbm, this indicate the area is situated in relative higher altitude, geological structures exercise a dominant influence on the drainage pattern and topography mature area.

C. Areal Aspects of the Qa' Jahran basin

Basin Area (A)

The area of the Qa' Jahran basin is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total basin areas and the total stream lengths, which are supported by the contributing areas. The basin area is computed 342.11 km^2 with the help of Arc GIS-10.1 software in Table 2.

Drainage density (Dd)

Drainage density (Dd) is the total length of streams of all orders (km) per drainage area (km) (Rai, et al, 2017, Chandrashekar et al, 2015, Vittala et al, 2004, Sukristiyanti et al, 2017 and Yangchan et al, 2015). Dd express the closeness of the spacing of the streams and indirectly reflect the structural framework of the underline rocks of the watershed. It is an important parameters for in evaluating thegroundwater zone (Sultan et al, 2015).

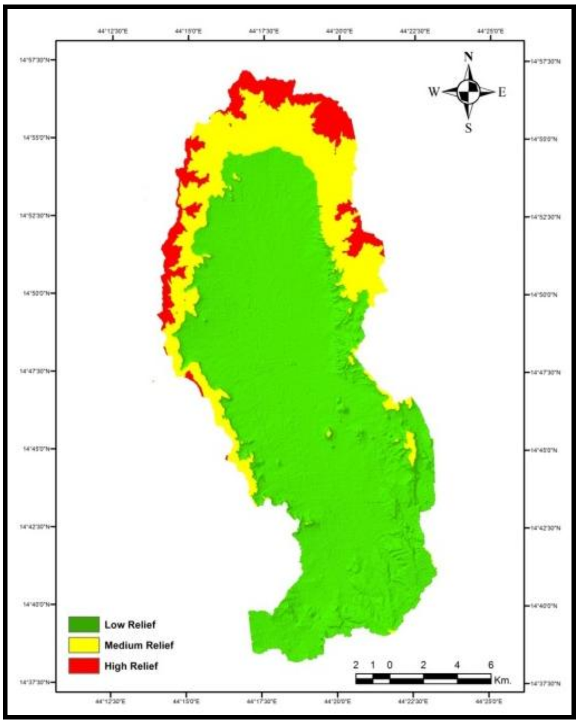

Figure 5: Classes of relative relief map of the Qa'Jahran basin.

There are five classes of drainage density with the following value ranges (km/km), i.e., very coarse <2), coarse (2-4), moderate (4-6), fine (6-8), and very fine (>8) (Chandrashekar et al, 2015, Vittalate al, 2004). The results of Dd tabulated in table 2 reveals the drainage density is moderate spacing streams. Low Dd is favored in regions of highly resistance or highly permeable strata under dense vegetation and low relief. From the resulted values in Table 3 it was observed (Dd) value for the entire basin is 2.29 are moderate Dd as the average value fall between 2-4, and for the sub basins it ranges from 2.22 (Sub basin 3) to 2.37 (Sub basin 2) among the sub basins of Qa' Jahran basin (Fig. 6). The low values of Dd are indicative of the regions of highly resistant and permeable sub soilmaterials with dense vegetated cover and low relief (alluvial plain) (Nag, 1998). The resulted values of Dd makes Qa' Jahran basin susceptible to flooding, gully erosion, etc. (Rai, et al, 2017, Chandrashekar et al, 2015, Vittalate al, 2004)

Drainage texture (T)

According to Horton (1932), drainage texture is the total number of stream segments of all orders per unit perimeter.The drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development(Smith, 1950). The classification of drainage texture is the same withthe classification of drainage density (Yangchan, 2015). Horton recognized infiltration capacity as the single important factor which influences drainage texture (T) and considered the drainage texture to include drainage density and steam frequency. The T of all the sub basins is shown in table 2. In the present study the Qa' Jahran basin has intermediate drainage texture as the average value fall between 2- 4. The maximum value of T is recorded in sub basin 1 (4.77) which imply it is a prone for of risk of soil erosion. The minimum value of T is recorded in sub basin 4 1.86 have coarse drainage texture, which signify higher permeability and enhanced ground water

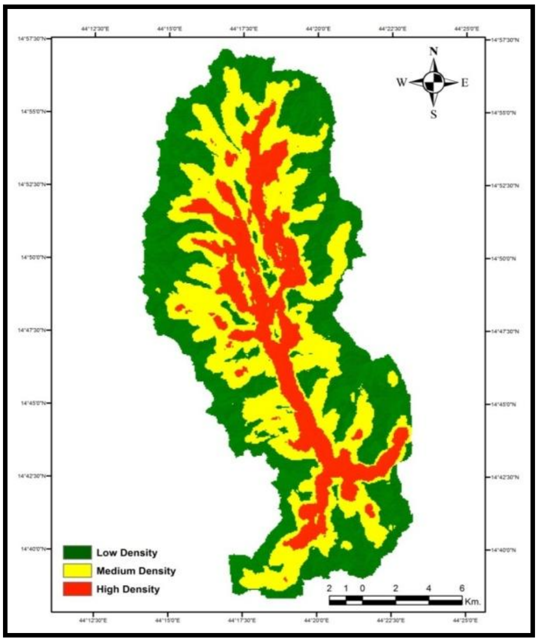

Figure 6: Drainage Density map of the Qa' Jahran basin.

recharge potentiality followed by sub basin 2 (T less than 4).

Stream frequency (Fs)

The stream frequency (Fs) of a basin may be defined as the number of streams per unit area (Horton, 1945). Fs mainly depend on the lithology of the basin
and the texture of the drainage network. A higher
value of stream frequency reflects greater surface runoff, resistance sub surface material, sparse Lower stream frequency values indicate surface watershed material and low relief (Reddy et al, 2004). Sub study wise values of stream frequency in the basin 1) to 2.45 (sub basin 4). Approximately two infiltration vegetation and a steeper ground surface, whereas area are tabulated in table 2 and vary from 2.22 (sub streams per unit area indicating low relief, high capacity and a dense stream network which will promote irrigation farming.The study revealed that the sub basin 2, sub basin 3 and sub basin 4 watersheds have high stream frequency because of the fact that it falls inthe zone of fluvial channels and the presence of ridges on both sides of the basin which results in highest stream frequencywhile as sub basin 1has low stream frequency because of low relief (Fig. 5). Highest value of stream frequency noted for sub basin 4 (2.45) produces more runoff in comparison to others.It is also seen that the drainage density values of the sub basins exhibits +ve correlation with the stream frequency suggesting that there is an increase in stream population with respect to increasing drainage density.

Form factor (Rf)

Horton (1932) defined Form factor (Rf) as a dimensionless ratio of basin area (A) to the square of basin length (Lb) commonly used to represent different basins shapes. The range values for form factor are <0.78 (elongated) and >0.78 (circular) (Rai, et al, 2017, Chandrashekar et al, 2015, Vittalate al, 2004, Yangchan et al, 2015). In this study, the computed value of Rf is tabulated in table 2, and range from (0.28) sub basin 1 and 2 to 0.46 sub basin 4 indicating the lower value of form factor which represents an elongated shape. The elongated sub basins with low value of form factor indicate that the Qa' Jahran basin will have a flatter peak flow for longer duration. Flood flows of such elongated basins are easier to manage than from the circular basin.

Circularity ratio (Rc)

Circularity ratio is the ratio of the basin area to the area of a circle having the samecircumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin (Miller 1953). The values of circularity ratio vary from zero (for a line) to one (for a circle) and it is influenced by stream length, stream frequency (Fs), geological structures, land cover, climate, relief and slope of the basin (Bali et al. 2012). In the study area, the Rc values table 2 are ranging from 0.34 to 0.48. The Qa' Jahran sub basins have value of Rc less than 0.5 indicating that it is elongated, and are characterized by the low to moderate relief and the drainage system were subject to less structurally controlledon the drainage development in over all the basin.

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.Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin (Singh et. al., 1997).Values of the elongation ratio (Table 2) are in the range of 1.98 to 3.37 indicating low relief and ground slope for maximum portion of Qa' Jahran basin (Fig. 5). In sub basin 4 the Re value is minimum indication of high relief and steep slope. In general the high values of Re is indicative Qa' Jahran basinas flat land with low relief and low slope.

Length of overland flow (Lg)

It is the length of water over the ground before it gets concentrated into definite stream channels and is equal to half of drainage density (Horton, 1945). Table 2 indicates the length of overland flow for various sub basins which ranges from 0.85 for sub basin 2 to 0.90 for sub basin 3. The shorter length of overland flow for sub basin 2 point out the quicker runoff process and higher length of overland flow for sub basin 3 point out slower runoff process. Sub basins 3 and 4 have higher values of Lg indicates the water had to flow longer distance before it gets concentrated in to stream, whereas sub basin 1 and 2 fall in low value of Lg indicates the water get concentrated in to stream quickly. In this study, the length of overland flow of the Qa' Jahran basin is 0.87, indicating a high surface runoff in the basin and it further confirms the high susceptibility of the basin for both soil erosion and flooding.

Slope

The slope of a terrain to the amount of inclination of physical feature, landform is the horizontal surface. Slope analysis is an important parameter in morphometric studies. The slope elements, in turn are controlled by climatemorphogenic processes in areas having rock of varying resistance. According to Burrough (1986), it is the maximum rate of change in value from each cell to its neighbors is identified as slope grid. The present of slope exhibited by Qa' Jahran basin varies from 0 to 66 degree. The slope map of the Qa' Jahran basin is shown in Fig. 6. The higher slope gradient in the study area is contributed by the eruption of basaltic flow in northern, eastern and western parts. Higher slope gradient results in rapid runoff with potential soil loss or erosion in Fig. 7

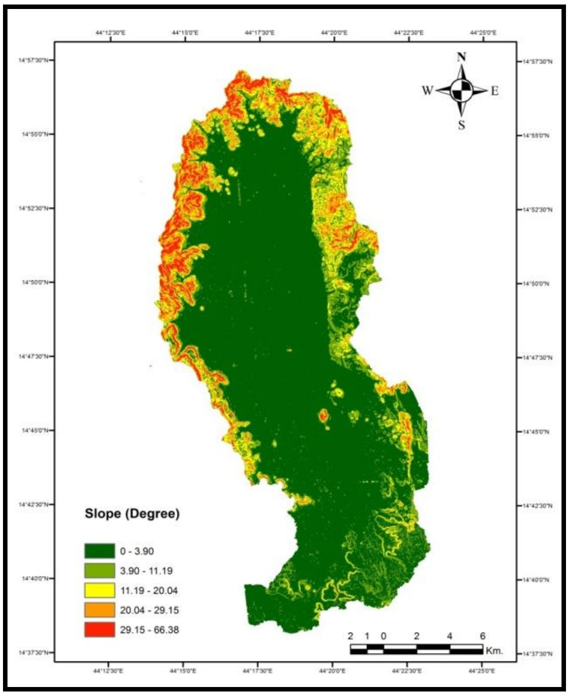

Figure7: Slope map of study area

D. Relief Aspects of Qa' Jahran Basin

Relief ratio (Rh)

The maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumn, 1956).It generally indicates the overall steepness of a basin. The relief ratio of the study watershed is 0.23 (Table 2) from which we can say that the study area has an overall gentle slope. It is noticed that high value of relief ratio is associated with steep slope and high relief (sub basin 4), whereas low value of relief ratio is associated with gentle slope and low relief (sub basin 1).

Basin relief (Bh)

Basin relief is defined as the maximum vertical distance between the lowest and the highest points of a sub basin.Bh is an imperative factor for understanding the denudational characteristics of the basin. The Qa' Jahran basin relief value is 110m for sub basin 1 to 640m for sub basin 2 (Table2) indicates low infiltration and high runoff conditions.

Ruggedness number (Rn)

Ruggedness number (Rn) is the product of drainage density (Dd) and basin relief (H) (Strahler, 1957; Melton, 1958a) in the same unit.Rn analysis is very useful for steepness and slope of the drainage network. For all the sub basins, Rn was found to be in the range of 0.25–1.53 (Table 2).
The ruggedness number of the sub-basins 1 and 2 indicates higher soil erosion susceptibility.

VI. CONCLUSIONS

The comprehensive morphometric characterization carried out for the Qa' Jahran Basin in Thamar, Yemen using Remote Sensing and GIS Techniques led to the following conclusions:

1- The Qa' Jahran basin consists of Quaternary alluvial deposits are represented in the study area as plain and as sheet of loss quaternary sediments in the elongated depression and the deposits form thick accumulations in central of the catchment area.

2- The basin is divided into 4 sub basins with codes Sub basin 1 to Sub basin 4. The drainage pattern of the Qa' Jahran basin area is dendritic pattern in the whole of the basin.

3- Total number of stream segments in first order is 383 and maximum frequency is observed in first order streams.

4- The Qa' Jahran basin with perimeter 115.8 km is divided into first, second, third and fourth order sub basins. Among the sub basins, the sub basin 1 has largest perimeter 80.31km and sub basin 4 has smallest perimeter 19.85km.

5- The majority of bifurcation ratio (Rb) values are less than 5 indicate that the drainage basin is underlined by uniform materials. The drainage density of the basin is moderate spacing streams and the basin susceptible to flooding, gully erosion.

6- The minimum value of drainage texture is recorded in sub basin 4 have coarse drainage texture, which signify higher permeability and enhanced ground water recharge potentiality.

7- The sub basin 2, sub basin 3 and sub basin 4 watersheds have high stream frequency, while as sub basin 1 has low stream frequency because of low relief.

8- Form factor results represent an elongated shape of Qa' Jahran basin and indicate that the Qa' Jahran basin will have a flatter peak flow for longer duration.

9- Length of overland flow of the Qa' Jahran basin is indicating a high surface runoff in the basin and it further confirms the high susceptibility of the basin for both soil erosion and flooding.

10- The higher slope gradient in the study area is contributed by the eruption of basaltic flow in northern, eastern and western parts.

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