Geomorphological Study of the Wadi Bayy Al Kabir and vicinities, middle region, Libya

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Abstract: The present paper attempts to study the quantitative geomorphological analysis of three main Wadis in the middle part, north of Libya namely; Wadi Zakir, Wadi Bayy and Wadi Zamzam these Wadis drain their water to Mediterranean Sea. A morphometric analysis of the studied basins has been carried out using geoprocessing techniques in GIS. This study aimed to use the Geographic Information Systems technology as an advanced means that provides accurate automated methods in extracting the morphometric characteristics of the studied basins by analyzing the digital elevation model (DEM) and building a geographical database with morphometric variables for the basins.The study showed that the areas of the basins are 7161.6 Km², 67888.9 Km² and 35923.8 Km² for Zakir, Bayy and Zamzam, respectively, which are providing a high runoff volume. The analysis of the basins reflects the following stream orders (6th order for Zakir basin, 9th order for Bayy basin and 8th order for Zamzam basin), and the dominant type of the drainage pattern of stream network in the three studied basins is the dendritic patter, which indicates the homogeneity in texture and lack of structural control. The bifurcation ratio values are (4.90 for Zakir basin, 3.75 for Bayy basin and 4 for Zamzam basin) indicating that the area is not much influenced by geological structures and undisturbed drainage patterns. The relative flood hazard degree shows that Wadi Bayy has highly flood hazard degree than Wadi Zamzam and Wadi Zakir which have moderately hazard degree.

KEY WORDS: Morphometric parameters, GIS, Basin, Ordering and Wadi Bayy Al Kabir and Libya

1. Introduction

The study of drainage basin provides valuable information about the geological and evolutionary history of the area. In hydrology, the morphometric of drainage basin and river networks provide clues on water discharge, maximum and minimum specific runoff and their spatial variation. A systematic study of the drainage patterns and quantitative studies like morphometric and their statistical details aid in finding the similarities and differences between drainage basin (Horton, 1945; Strahler, 1957; Melton, 1958 a &b; Pakhmode, 2003; Gangalakunta, 2004). In recent years, several workers have been used remote sensing data and GIS technique for estimation of morphometric parameters and concluded that remote sensing technique has emerged as a powerful tool in analyzing the drainage morphometry (Agarwal, 1998; Nag, 1998; Das and Mukhrjee, 2005; Pareta and Pareta, 2012). Morphometric studies of most drainage basins in Libya lack of the applied studies that rely on modern technologies to study the topographic characteristics and water networks of drainage basins and build an automated model that simulates the natural reality on the surface of the earth. Also after the flash flood of Wadi Darnah in September 2023 (Daniel storm), and climatic changes in general, there is an urgent need to study the morphometric characteristics of Libyan wadis, especially in the coastal areas. Therefore, this research aims to employ advanced technical methods represented in the use of Geographic Information Systems (GIS) and Digital Elevation Models (ASTER GDEM) to build a digital morphometric database, draw the drainage network of the major basins in Northwest Libya, then extract and calculate many morphometric characteristics of these basins and their geomorphological implications.

Study area description: The area under consideration is located in the north-middle region of Libya on the Mediterranean coast to the southeast of the capital of Tripoli, at a distance of approximately 300 km. It is located between Longitudes 12°0'58.619" and 16°40'17.713"E and Latitudes 28°20'27.496" and 31°35'49.378"N Figure (1). Three Wadis are selected for this study (Wadi Zakir, Wadi Bayy al Kabir and Wadi Zamzam) occupies an approximate area of 110974.3 km^2, i.e. 6.30 % of the total country's area. The main cities in the study area are Abu Nujaim and Ash Shwayrif. To the north, area has a shoreline on the Mediterranean Sea and bordered by Wadi Jarif in the east, Wadi Suf al Jin in the west, jabal al-Hasawna and jabal al Sawda in the south, Hun graben in the southeast and Hamada Al-Hamra in the southwest. The most important drainage system in the study area is the Wadi Zamzam system; which originates on the east flank of al Hamada al Hamra and parallels Wadi Suf al Jin. It empties into the extreme southern part of the Tauorga sebcha. Another important drainage system is Wadi Bayy al Kabir; which has several tributaries that originate in the southeastern part of the Hamada. North of Abu Nujaim these tributaries join to form Wadi Bayy al Kabir, which, trending northeast, reaches the sea east of Buerat Al Hasun. Wadi Zakir; the smallest north-south drainage system of the study area, which originates on the west flank of Sirte basin and parallels Wadi Bayy. It empties into the sea west Sirte City. *The climate of the study area;* is influenced by the Mediterranean Sea along the coastal regions (dry summers and relatively wet winters), while the desert in all other parts (torrid temperatures and large daily thermal amplitudes). Rain is rare and irregular and diminishes progressively towards zero in the south. The bulk of the annual rain falls during the fall and winter months that is, from October to March. Rainfall during the remainder of the year is generally insignificant. The average annual precipitation decreases from about 170 mm (millimeters) in north to less than 50 mm in south Figure (2). The temperature is approximately 40˚C in the summer and decrease on the other seasons (Salem, 1997). Dust storms lasting four to eight days are pretty common during spring ***"Libya profile"*** (2016).

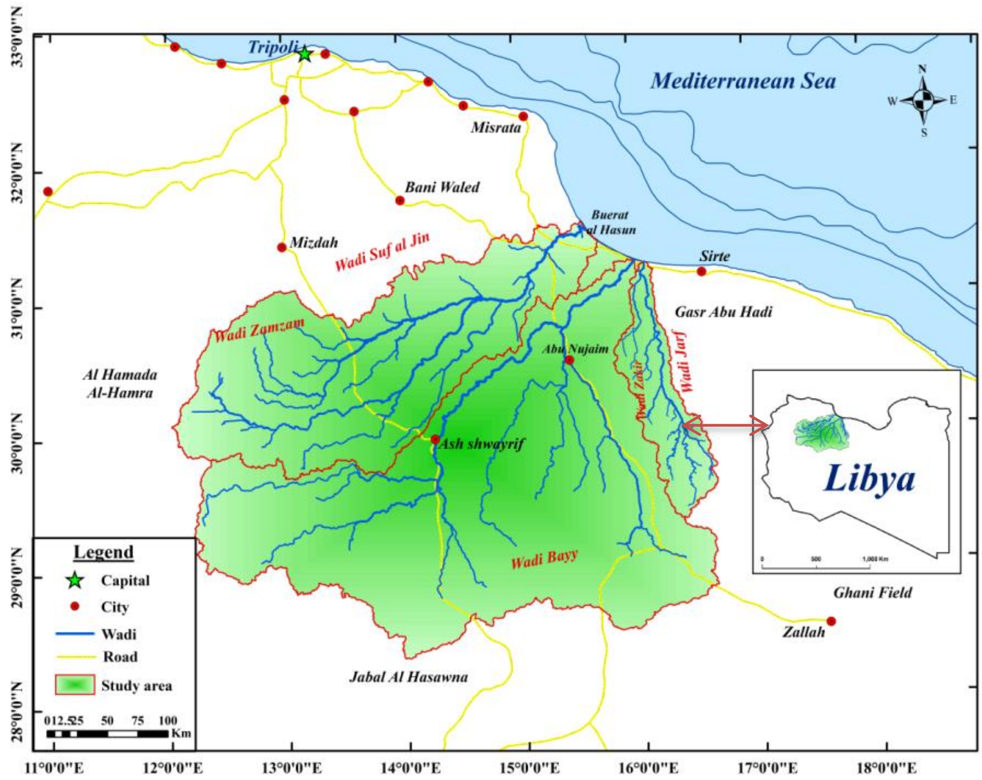

Figure 1. Location map of the study area

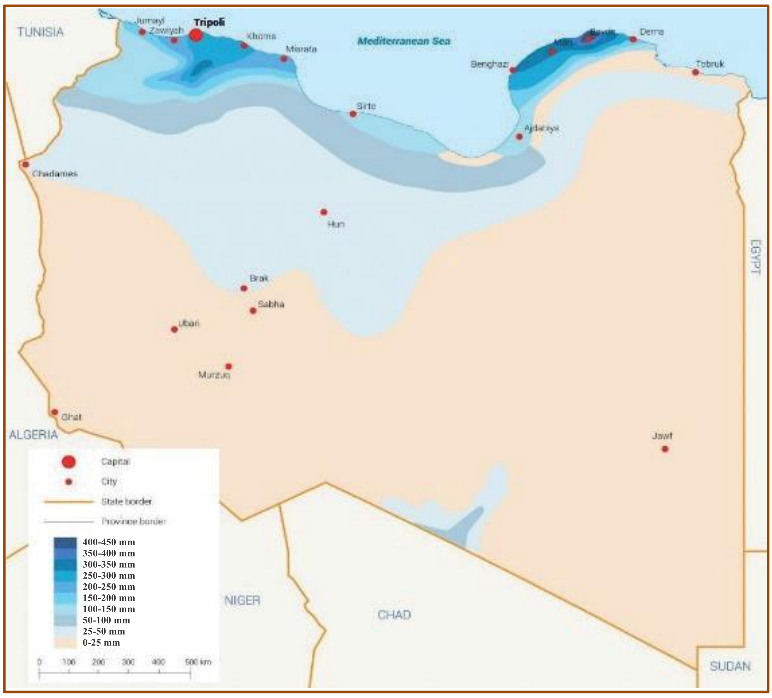

Figure 2. Annual average Rainfall (Sadeg, et al. 2023)

2. Geological Setting: Based on the geologic map of Libya Industrial Research Center (IRC) 2009 (scale 1:100000) and from the literatures (Gefli, 1973; IRC, 1985 and Halcrow, 2001), the following can be noticed:

- ***Stratigraphy;*** the exposed rock units in the study area are belonging to the Upper Cretaceous and Quaternary times from base to top respectively. The following rock units were distinguished in the study area from base to top Figure (3):

Upper Cretaceous rocks

The Upper Cretaceous sequence in the study area is represented by ***Sidi as-Sid formation;*** tis formation represented by two members; *Ayn Tobi Member* it is consist of limestone and dolomitic limestone with intrusions of marl. *Yfren Member*, consisting mainly of marl and marly limestone. ***Nalut Formation*** consists of limestone and dolomitic limestone with intercalations of thin beds and nodels of flint. ***Qasr Tigrinah Formation***; which consist of limestone, chalky limestone and marly limestone which change to marl and sand in some places. ***Mizda Formation;*** it is divided into two members; *Mazuzah member***,** the lower part of this member composed of marly limestone while the upper part composed of limestone and dolomite rocks and the second member is *Thala member*, it consists of calcilutite, chalky, dolomitic limestone, partly laminated with cherts, marl and gypsum.

Tertiary deposits;

- **The Paleocene Deposits;** is represented by ***Zimam formation*** which composed of limestone of incompatible stratification, and formations of dolomitic limestone alternating with chalky limestone. The Zimam formation can been divided into two members; the *Tar beds* which divided also into two parts***;*** *Lower Tar Member* which consists of clay, marl with gypsum, dolomitic limestone and partly laminated with cherts, marl and gypsum. *Upper Tar Member* it is dominated by marl and claystone with intercalations of limestone and it is rich in fossils**.** The second member in Zimam Formation is *Had Member* which composed of dolomite, dolomitic calcarinite with chert and intercalations of calcilolites. ***Al- Shurfah Formation*** which consist of dolomite limestone containing fossils with intrusion of marl limestone, and deposits of chalk, chalk limestone, dolomitic limestone and marl, in addition to limestone and chalky limestone.
- The Al- Shurfah Formation has been divided into two members; *Bu Ras Member,* consisting mainly of marl interbedded by calcilutite, calcarenite, dolomitic limestone, clay with gypsum, sandstone and conglomerate. *Qaltah Member* it consists of massive breccious chalky calcilutite interbedded by calcarenite and dolomite.
- ***The Eocene deposits;*** which are represented by ***Bishimah Formation***. The formation has been divided into three members, the *Khayir Member;* which consist of chalky and gypsiferous marl with thin dolomitic limestone. The *Wadi Zakim Member*; is made up of dolomite, dolomitic micrite and chalky limestone. *The Rawaghah Member* forms the upper unit of the Bishimah Formation. It is consists of Hard and massive dolomite and contains numerous chert nodules and lenses of silicified dolomite. ***Al Jir Formation*** included two members. The lower unit *Bin Isa Member;* which consist of hard, compact chalk and chalky limestone containing chert nodules and thin stringers of gypsum. The upper unit was named the *Bi'r Zaydan Member*. It is composed of compact white limestone. ***Wadi Thamat Formation*** is subdiveded into three members. *The Al Gata Member* consists of a series of marls, dolomitic limestones

and micritic limestones containing oyster-rich coquinas. The *Thmed al Qusur Member*; which mainly represented by white chalk and chalky limestone with chert nodules. The *Qararat al Jifah Member* is composed of fossiliferous and coquinoid limestone, dolomitic limestone with traces of gypsum, and greenish marl.

– ***The Oligocene*** is represented by ***Umm ad Dahiy Formation*** which consists of Chalky, oolitic and coquinoid limestone interbedded with dolomitic marls and clays. ***Bu Hashish Formation; i***n the type area it comprises 40 m of soft chalky marls, vuggy dolomites, chalky limestones and chalk.

– ***The Miocene deposits;*** represented mainly by ***Marada Formation*** which divided into two members. These are *Qarat Jahannam Member*, it comprises 123 m of stacked clastic sequences of cross-bedded fluvial sandstones, grading into siltstones and silty claystones with traces of gypsum. *The Ar Rahlah Member* was defined from outcrops to the east of Maradah. At the type locality 120 m of calcarenites, calcareous sandstones and sandy limestones overlie the Qarat Jahannam Member. ***Al Khums Formation*** is subdivided into two superimposed members. The lower unit the *Wadi Yunis Member* is represented by 60 m of skeletal, chalky, dolomitic and gypsiferous limestones, with occasional siltstones, marls and bedded gypsum. The *Quwayrat al Jibs Member* comprises about 15 m of marls, bedded gypsum, calcarenites and sandstones.

– ***The Pliocene deposits;*** represented mainly by ***Al Hishah Formation***, which composed of calcarenite and sandstone with gypsum, which reaches a thickness of 20 m in the Al Qaddahiyah area. Similar deposits have been found at Al Aqaylah, Maradah, Bi'r Zaltan and Sabkhat Ghuzayil which have also been referred to the Al Hishah Formation.

Quaternary *deposits;*

– ***The Pleistocene formations*** include ***Qarat Weddah Formation*** which consists of aeolian sands, with intervals of lacustrine clays and marls with traces of gypsum. ***Gargaresh Formation*** formed of oolitic and ooskeletal calcarenite and calcareous sandstone that the grains of which were derived from reworking of marine sediments of older deposits. ***Old Sabkha Sediments*** consist of intercalations of greenish siltstones, claystones and evaporites consisting of coarsely crystalline gypsum, gypsarenite and halite.

– ***The Holocene deposits*** include ***recent wadi deposits***; these deposits occur along the courses of Wadi Jarif, and consist of non-cemented, fine to coarse grained sand and some gravel varying in thickness from 1 to 5 m. ***Beach sands*** occurs along the present coast line only, and consists mostly of light-gray sand, produced by the weathering of the Gargaresh Formation, with highly abundant shell fragments. ***Fluvio-Eolian Deposits*** are represented by fine-grain sand, silt with thin intercalations of gravels of variable degree of roundness. The thickness of these deposits various from 1 to 10 m. Eolian deposits (sand dunes) are represented by pinky and light over dark sand that's the gain diameter is 0.1-0.2 mm around, well sorted. Most of the grains are carbonate with plenty of quartz. The thickness of the deposits is usually less than 1 m. ***The coastal dunes*** consist of shell fragments with small amounts of silica sands. It is worth mentioning that the eolian material composing both field dunes and coastal dunes contains a large amount of grains of gypsum. ***Sabkha sediments*** occupy the depression along the Sabkha Al Kabirah controlled on the western side by a structural lineament that influence the location of thermal springs and associated mineralization. The sabkha deposits attain a maximum thickness of 10 m and consist of reddish silt and sand which are mainly of eolian origin and evaporite precipitated minerals such as gypsum and halite.

– ***Structural Setting:*** There are three structural units in the study area; Sirte Basin in the east, Al Hamada al Hamra Basin in west and Hun Graben in the south, which determine the structure of the whole region. In the northern part of the study area, the landform is wide coastal plain, and the distribution of the stratum is horizontal or sub-horizontal. The sediments are undisturbed and no fold-type structures were formed except some faults. In the southern part of the study area, the stratums have fluctuation, but the hypsography doesn't exceed 1-2 m. The fold has not developed there. However, there are obvious north-west toward faults due to the influence of the Hun Graben structure (IRC, 1985). The Hun Graben is represented the main structure in the area. Its axis would be located to the north where the throw is minimal, while to the south, in the zone of Al Jufrah, the deepening into the graben reaches 1000 m. It is probably occurred in the Miocene age. In the entire region, only a few minor faults are visible on the ground. But it is more probable that numerous faults exist since there is a large network of wadis in the region, which would suggest that they follow the axes of these faults.

- ***Geomorphologic Setting:*** The geomorphologic features of the study area can be recognized into the following units (Figure 4):
  - *The coastal* plain in the north is a flat area covered mostly by Tertiary and Quaternary deposits and characterized by extensive sabkhas (Sabkhat al Hishah, Sabkhat Bayy and Sabkhat Abu Qasbah etc.) developed at the estuaries of Wadi Zamzam, Wadi Bayy al Kabir and Wadi Zakir. Along the coastal plain, narrow but well elevated stripe of dune sands and calcarenites are characteristics and these separate the sea from salt marshes-sabkhas, developed at the estuary of the wadis. The coastal plain has a relief which does not exceed 150 m above sea level (a.s.l) sloping gently towards the coast.
  - *The plateau area* to the east and northeast of Al Hamadah al Hamra slopes gently NE towards the Mediterranean Sea. The plateau embraces by several elevations that reach a height of (840 m) as in the Jabal al-Sawda and 1058 in Jabal Al Hasawna (Figure 4). The plateau characterized by a group of large wide wadis. A major part of the study area is covered by Paleocene and Upper Cretaceous rocks. The lithology of water and oil wells drilled in the area shows that there are two distinct sets of deposits. The upper part, down to the base of the Upper Cretaceous, is dominated by limestone, dolomites, dolomitic limestone, marl and argillaceous sediments of different ages with occasional sandy, shaly, silty and gypsiferous bands. Some of these beds are often fractured. In the deeper parts of the boreholes, from the Lower Cretaceous downwards, the beds are mainly

comprised of thick layers of granular sediments (Mesozoic and Paleozoic sandstone) with interbeds of shale, clay, and silt. Beds of limestone with gypsum (Triassic and Jurassic) are also present.

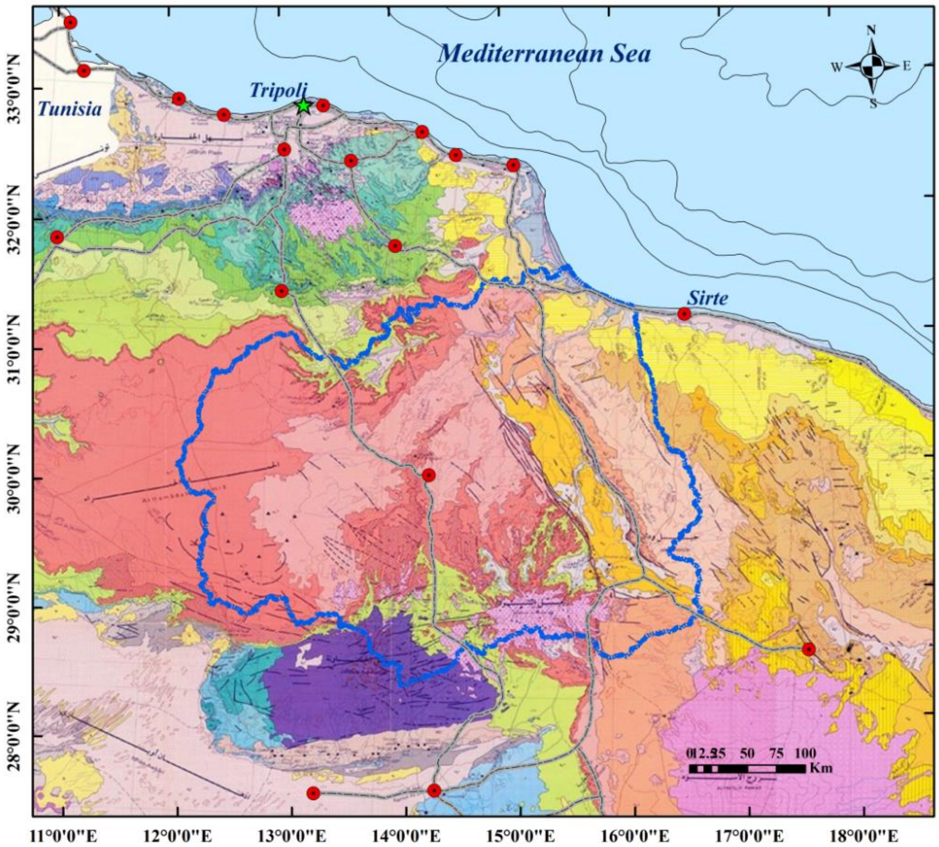

Figure 3. Geological map of study area (Adapted from Industrial Research Center 2009)

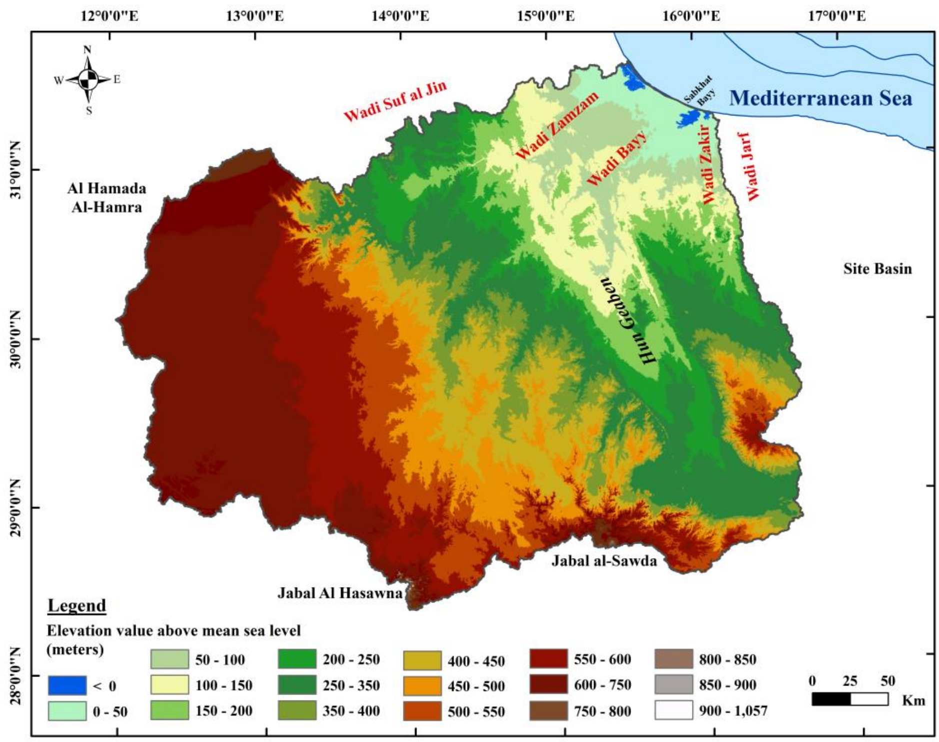

Figure 4. Digital Elevation Model (DEM) of study area

3. Methodology

The morphometric analysis of the studied basins (Zakir, Bayy and Zamzam basins) was carried out on the ASTER-DEM 3 Arc spatial resolution. The extracting wadi basins and their paths, determining their drainage networks, ranks, lengths of the streams, areas of the basins were measured by using Arc GIS-10.3 software, and stream ordering has been generated using Strahler (1953) system, and Arc Hydrology tool in ArcGIS-10.3 software. As well as, to extract the surface derivatives such as digital elevation, relief and slope maps. The work steps are summarized as follows; twenty adjacent tiles of (SRTM1 DEM) were used and combined to form a mosaic covering the entire study area. Some of the hydrologic analysis was done to extract the network of stream network and drainage basins affecting studied wadis, (Relying on Hydrology tools, like Fill, flow direction, flow accumulation, basin, stream order, stream link and stream to feature). After that, the area required for analysis was clipped, then calculations were made on it using (Arc GIS 10.3) program. The various morphometric parameters of studied wadis were computed and Graphical representation of the analyzed results, were carried using Excel 2010 software program. Several previous studies and reports about climate, lithology, structure and stratigraphy of the study area have been collected.

4. Result And Discussion

4.1.Basin Geometry

Basin configuration is an important aspect in hydrological study. In order to determine the shape of the basin, a quantitative study is done using the two dimensional ratio, such as elongation ratio suggested by Schumm (1956).The geometry characteristic of the studied basins is completely showed in (Table 1):

Table 1. Geometry properties of the studied basins

Parameters	*Unit*	*W. Zakir*	*W. Bayy*	*W. Zamzam*
Basin Area (A)	Km^2	7161.6	67888.9	35923.8
Basin Perimeter (P)	Km	668.05	1979.57	1458.05
Basin length (L_b)	Km	215	434	380
Valley length (Lv)	Km	294	706	572
Mean width (W)	Km	34.45	123.84	81.89
Length of overland Flow (Lg=1/2D)	Km^-	0.57	0.55	0.52

Drainage Dimension Characteristics

The characteristics of the drainage dimension are including area, perimeter, length, and width.

- **Basin Area (A):** The area of the sub-basin is an important parameter in the basin geometry. Schumm (1956) established an interesting relation between the total sub-basin area and the total stream length, which are supported by the contributing area. According to Sen (2008) classification, the drainage basin located within a big area, which classified the basins based on its areas (< 5 km^2= small, 5-99 km^2= medium, 100-1000 km^2= big, > 1000 km^2 = very big). Then all basins of the study area were classified by size into the category of very big basins, then Wadi Bayy basin is considered the biggest basin 67888.89 Km^2, and Wadi Zamzam basin 35923.83 Km^2, while Wadi Zakir basin attains 7161.64 km^2 (Table 1).

– **Basin Perimeter (P):** Perimeter is considered as the main element of basin dimensions because it is used to compute a lot of elements in morphometric analysis i.e. basin shape, circulation ratio, and relief ratio. In addition, the basin perimeter is the total length of the drainage basin boundary which reflects the geomorphological stage of basins. The perimeter of each studied basin was determined by using ArcGIS-10.3 software. Wadi Bayy basin perimeter is 1979.57 km, followed by Wadi Zamzam basin 1458.05 km, while Wadi Zakir basin has the lowest length of perimeter 668.05 km (Table 1).

– **Basin Length (Lb):** Schumm (1956) defined basin length as the longest dimension of the basin parallel to the principal drainage line. The length of the studied basins are determined in accordance to the definition of Schumm (1956) are 215 Km, 380 Km, and 434 Km for Zakir, Zamzam and Bayy respectively (Table 1). (Basin length indicates the travel time of water especially the flood waves passing through the basin). The travel time of Bayy basin is greater than that of Zamzam basin while the travel time of Zakir basin is the smallest one.

– **Valley Length (Lv):** The valley length is the path length of the main stream from the source to the mouth. It was measured by using ArcGIS-10.3 software. Wadi Bayy basin comes in the top of length of main channel where its valley length is about 706 km, followed by Wadi Zamzam basin 572 km while Wadi Zakir basin has the lowest length, 294 km (Table 1).

– **Mean Basin Width (Wb):** The main limitation of the width of a basin is the surface slope. If it is steep, the basin should be narrow; otherwise too much sediment movement will be needed to obtain level basins. Basin width is an important element to study the shape of basins (Sherief, 2008). There are two methods to measure the width of a basin; the first is the average of some measurements of basin width, the second is the result of division of the basin area ($\boldsymbol{A}$) with the basin length ($\boldsymbol{L_b}$):

$$\boldsymbol{W = \frac{A}{L_b}}$$

(Table 1) by applying the first method, it shows that Bayy basin is the widest basin in the study area 123.84 km, Wadi Zamzam is 81.89 km. But Wadi Zakir basin is considered the narrowest basin in the study area whereas the width reaches only 34.47 km.

– **Length of Overland Flow (Lg):** The length of overland flow (Lo) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). (Lo) is one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. It is expressed as:

$$\boldsymbol{Lg = 1/D \times 2}$$

Where: $\boldsymbol{Lg}$ is length of overland flow, $\boldsymbol{D}$ is drainage Density.

Table (1), shows that there are no significant difference between the length of the over land flow values of studied basins. These values reach 0.57 Km (Zakir basin), 0.55 Km (Bayy basin) and 0.52 Km (Zamzam basin). This reflects that water concentrates faster in Zamzam basin than in other basins.

4.2. Shape Properties

The geometry characteristic of the studied basins is completely showed in (Table 2): The basin shapes compare to its geometrical shapes such as circle, rectangle, triangle, and square, like the following:

Table 2. Shape properties of the studied basins

Parameters	*Unit*	*W. Zakir*	*W. Bayy*	*W. Zamzam*
Circularity Ratio (Rc) $Rc=4\pi A/(P^2)$	-	0.20	0.22	0.21
Elongation ratio (Re) $Re = 2 / Lb *(A/\pi)^{0.5}$	-	0.44	0.68	0.56
Form Factor Ratio (Fr) $Fr = A / Lb^2$	-	0.15	0.36	0.25
Sinuosity Index (Si) $Si=Lv/Lb$	-	1.37	1.63	1.51
Compactness Coefficient (Cc) $Cc = p / pa$	-	2.23	2.14	2.17

– **Circularity Ratio (Rc):** For the quantitative analysis of basin, Miller (1953) defined it as the ratio of basin area to an area of the circle that has the same perimeter in the drainage basin, which is expressed by a standard value ranging between (0-1), (0 inline), (1 in a circle). Many variables have been taken into account affecting the circularity ratio; climate, land use/land cover, the slope of the basin, stream length, stream frequency, and geological structure. The calculated values of the circularity ratio reaches (0.20, 0.21 and 0.22) of the Zakir, Zamzam, and Bayy basins respectively (Table 2). Morphometrically, the circularity ratio approaches one if the basin shape is circle, and it tends to zero if the basin is a rectangle. This means that all studied basins have elongation shape. This is confirming that the basins are non-circular in shape, high permeability of soil components and low discharge of runoff.

– **Elongation ratio (Re):** According to Schumm (1956), elongation ratio is defined as the ratio of diameter of a circle of the same area of the basin to the maximum basin length. The elongation ratio is calculated by using the following formula:

$$\boldsymbol{Re = 2/L_b \times (A / \pi)^{0.5}}$$

Where $\boldsymbol{Re}$ is Elongation Ratio, $\boldsymbol{L_b}$ is the maximum basin length, $\boldsymbol{A}$ is area of the basin and $\boldsymbol{\pi}$ (Pi) is mathematical factor =3.14.

Strahler (1964) classified basins as more elongated (<0.5), elongated (0.5 – 0.7), less elongated (0.7– 0.8), oval (0.8 – 0.9), and circular (0.9 –1.0). The values that are close to (1.0) are very low relief, whereas values that are close to (0) are associated with high relief. The elongation ration of Zakir basin is 0.44, Zamzam basin is 0.56 and Bayy basin is 0.68 (Table 2), which indicates that Zakir basin is more elongated in shape.While Zamzam and Bayy basins are elongated in shape, low steep slope, low runoff discharge and high evaporation and infiltration capacity.

– **Form Factor Ratio (Fr):** Introduced by Horton, (1932) it is the ratio of width to the length of the basin. The value of form factor varies between (0) elongated to (1) rounded basin form (Horton 1941; Horton 1945). This parameter is suggested to estimate the flow intensity of a basin. The value of the form factor generally remains below (0.754) in an ideal circular shape, and the low value of the form factor will be a more elongated shape (Aldharab et. al, 2019). The high form factor shows high flow intensity, whereas the low form factor shows a low water flow for a long time.

The values of form factor (0.15) in Wadi Zakir basin, and 0.25 in Wadi Zamzam basin (Table 2), which indicates lower value of form factor and thus represents oval shape tending towards elongation. Whereas higher values of form factor in Bayy basin (0.36) suggesting it is relatively near from square or circular in shape. In general the oval basin tending towards elongation with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin.

– **Sinuosity Index (Si):** The valley length (L_v) is the total length of the main trunk, while the basin length (L_b) is the short distance between the mouth and source of stream (Mueller, 1968). The sinuosity ratio is the ratio between the valley length and the basin length. It is expressed as:

$$Si = L_v / L_b$$

In general, the value varies from 1 to 4 or more. Rivers having a sinuosity of 1.5 are called sinuous, and above 1.5 are called meandering (Wolman and Miller, 1964). It is a significant quantitative index for interpreting the significance of streams in the evolution of landscapes and beneficial for Geomorphologists, Hydrologists and Geologists. For the measurement of sinuosity index Mueller (1968) has suggested some important computations that deal various types of sinuosity indices. He also defines two main types i.e., topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains respectively.

The computed value of sinuosity index of Zakir, Zamzam and Bayy basins is 1.37, 1.63 and 1.51, respectively (Table 2). These values indicate that the Wadi Zamzam and Wadi Bayy have meandering main channels. While Wadi Zakir basin is sinuous main channel.

– **Compactness Coefficient (Cc):** A study suggested compactness coefficient as one of the basin shape properties which defined it as the ratio basin perimeter to a circle of an equal area. This Coefficient is used to find out the regularity degree between perimeter and area in the drainage basin and also used to recognize the erosional phases of the basin (Gravelius, 1941). The low values of Cc indicate that the river drainage basin has gone a long way in the stages of its geomorphological development, while the high value indicates an increase in the length of its perimeter, or simply implying that the basin perimeter is extremely tortuous.

The values of compactness coefficient of the studied basins are 2.23, 2.17, and 2.14 for Zakir, Zamzam and Bayy respectively (Table 2), which indicates low runoff intensity and lack of consistency between the perimeter and the area, and also points out that the basin is at its youth stage, and also at the beginning of its erosional cycle.

4.3.Topographic Properties

Topographic properties have significant importance in Geomorphological and hydrological studies. Basin slope determines the stream gradient, flood effectiveness, and amounts of transported sediment during the stream flow. A digital elevation model map was used in the studied basins Figure (4) calculating topographic aspects, where the elevation starts at (- 4) m to (1056) m. The topographic properties determined include Basin relief (R), Relief ratio (Rf), Relative relief (Ri) and Ruggedness Number (Rn).The results of the analysis are given in table (3).

- **Basin relief (R):** Basin relief is the elevation difference of the highest and lowest point of the valley floor. The basin relief of Wadi Zakir basin is 643m, followed by Wadi Zamzam basin is 748m and Wadi Bayy basin has comparatively high relief (1058m); shows relatively high relief of southern part than northern part of the study area. Computed basins relief are tabulated in the table (3).

Table 3. Topographic properties of studied basins

Parameters	*Unit*	*W. Zakir*	*W. Bayy*	*W. Zamzam*
Upstream Elevation (Z)	m	642	1057	744
Downstream Elevation (z)	m	-1	-1	-4
Basin Relief R = Z-z	m	643	1058	748
Relief Ratio (R_f=R/L_b)	m/km	2.99	2.44	1.97
Relative relief (Ri) Ri= R/P	m/km	0.96	0.53	0.51
Texture Ratio Rt = N1 / P		3.85	12.62	9.08
Ruggedness No. Rn=D(R/1000)*	m/km	0.56	0.97	0.71

- **Relief ratio (R_f):** Relief ratio is defined as the ratio between the basin relief and the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956).The relief ratio can be computed as follows:

$$R_f = R/L_b$$

Where: R_f is the relief ratio, R is basin relief and L_b is basin length.

Relief ratio normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). Table (3) shows that Wadi Zamzam basin has the lowest relief ratio (1.9m/km), followed by Wadi Bayy basin (2.44m/km), whereas Wadi Zakir basin has the highest ratio in relief (2.99 m/km) due to the smallest basin area (Zakir catchment 7161.642 square kilometers, seen in table (1). Hence, this catchment can be considered the most topographical-complex basin in the study area (Gottschalk, 1964).

- **Relative relief (Ri):** Relative relief is defined as the ratio between total basin relief, and basin perimeter. Relative relief is the difference between summit level, (the highest altitude for a given area), and base level (lowest altitude for a given area) divided by perimeter. Relative relief can be used as an index of the relative velocity of vertical tectonic movements. It can be computed by Melton's formula (1957):

$$Ri = R/P$$

Where: ***Ri*** is the relative relief, ***R*** is the total basin relief, and ***P*** is perimeter of basin.

The results in (Table 3) showed that the values of relative relief of Zakir basin equals 0.96 m/km, Bayy basin is 0.53 m/km and Zamzam basin is 0.51 m/km. Zakir basin has the maximum relative relief even though it does not have the maximum height difference (total relief). That might be due to the smallest basin area of that catchment (only 7161.64 square kilometers as seen in table (1).

- **Texture ratio (Rt):** The texture ratio is an important element to study the discharge networks and the extent of the surface cutting of basins within this basin, regarding as that the surface of basin has been affected by another factor such as: geological formations, wild, nature plants, and the stage of the cycle of erosion the basin has reached. The texture ratio can be computed by:

$$Tr = \frac{\sum Nu}{P}$$

Where: ***Tr*** is the Texture Ratio**,** ***Nu*** is the number of streams, and ***P*** is the perimeter of the basin.

Smith (1958), classified the texture of the basins into coarse (<6.4 Km^{-1}), intermediate (6.4-16 Km^{-1}) and fine (>16 Km^{-1}). In the present study, the texture ratio of the Zakir basin is 4.91 Km^{-1}, Zamzam is 11.75 Km^{-1}, and Bayy basin is 16.28 Km^{-1} (Table 3). This means that Zakir and Zamzam basins are of intermediate texture, while the Bayy basin is fine texture.

- **Ruggedness Number (Rn):** Strahler (1968) describes ruggedness number ***(Rn)*** as the product of maximum basin relief and drainage density and it usually combines slope steepness with its length. It is calculated by using the following formula:

$$Rn = D \times R$$

Where: ***Rn*** is ruggedness number, ***D*** is drainage density, ***R*** is the total basin relief.

The high value of ruggedness number reflects greater runoff. Applying this factor on the basins of the study area, it has been shown that, the Zakir basin has a lower ruggedness number (0.56), Zamzam basin has 0.71 and Bayy basin has a higher value 0.71 (Table 3). This means that wadi Bayy generates the greater runoff, followed by wadi Zamzam, whereas wadi Zakir generates the lowest runoff.

4.4. Stream Network

Characteristic of basin network has a great significance in morphometric and hydrologic analysis. Delineating stream network, digital elevation model (DEM) images were used with GIS techniques. The elements of stream network have found as (Table 4):

- **Stream Order (u):** It is a system that measures the stream branches in the drainage basin network from upstream to downstream within a basin. Each branch or order has a singular number that combines with its identical branch to form the next mainstream and thus continues. This system has been provided by Horton in the 1930s

(Horton, 1932; Horton, 1945). And thus, others applied another scheme with some modifications. The results of the studied basins are shown in table (4) and Figures (5, 6 and 7), which showing the following stream orders (6th order for Zakir basin, 9th order for Bayy basin and 8th order for Zamzam basin).

– **Stream Number (Nu):** The total order stream segments are known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number. According to Strahler's classification and to the drainage network map of studied basins (Table 4 and Figures. 5, 6 and 7), it is noticed that the main trunk streams in Wadi Zakir streams carrying the sixth order, Wadi Bayy streams of ninth order and Wadi Zamzam streams of eighth order. They exhibit a direct relation with the surface area and stream number. The numbers of streams of the first order represent a ratio of 78.46% of Zakir basin, 77.52% of Bayy basin and 77.31% of Zamzam basin. The second order streams represent about 17.74% of Zamzam basin, 17.34% of Bayy basin and 17.31% of Zakir basin. The relationship between stream orders and stream numbers is shown in Figure (8), which shows a strongly inversely proportion (Negative regression relation).

Table 4. Stream network properties of studied basins

	U	Nu	Lu	Rb	WMRb	D	Fs
W. Zakir	First	2572	3216.78		5.66	0.87	0.46
	Second	567	1519.88	4.54			
	Third	112	732.65	5.06			
	Fourth	20	310.06	5.60			
	Fifth	6	291.70	3.33			
	Sixth	1	180.37	6.00			
	Total	***3278***	***6251.45***				
	Mean			***4.91***			
W. Bayy	First	24986	31962.26		5.45	0.92	0.47
	Second	5589	14969.89	4.47			
	Third	1312	7875.57	4.26			
	Fourth	273	3764.21	4.81			
	Fifth	49	1588.60	5.57			
	Sixth	13	1183.29	3.77			
	Seventh	5	472.07	2.60			
	eighth	2	293.08	2.50			
	ninth	1	104.05	2.00			
	Total	***32230***	***62213.01***				
	Mean			***3.75***			
W. Zamzam	First	13240	17621.99		5.41	0.96	0.48
	Second	3038	8482.81	2.08			
	Third	668	4054.54	2.09			
	Fourth	139	2122.89	1.91			
	Fifth	31	1095.17	1.94			
	Sixth	7	520.22	2.11			
	Seventh	2	290.03	1.79			
	eighth	1	153.75	1.89			
	Total	***17126***	***34341.39***				
	Mean			***4.02***			

U:Stream order -Nu: Stream Numbers - Lu: Stream Length (km)
D: Drainage Density Km^{-1} – Fs: Stream frequency (St/km^2)

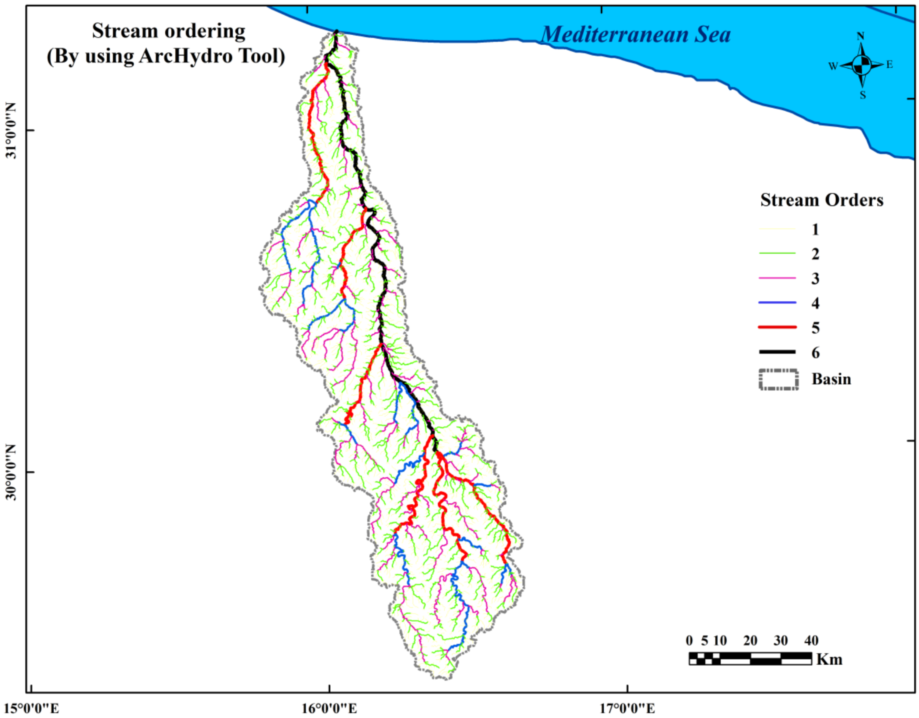

Figure 5. Drainage map of Zakir basin (by using Arc Hydro Tool)

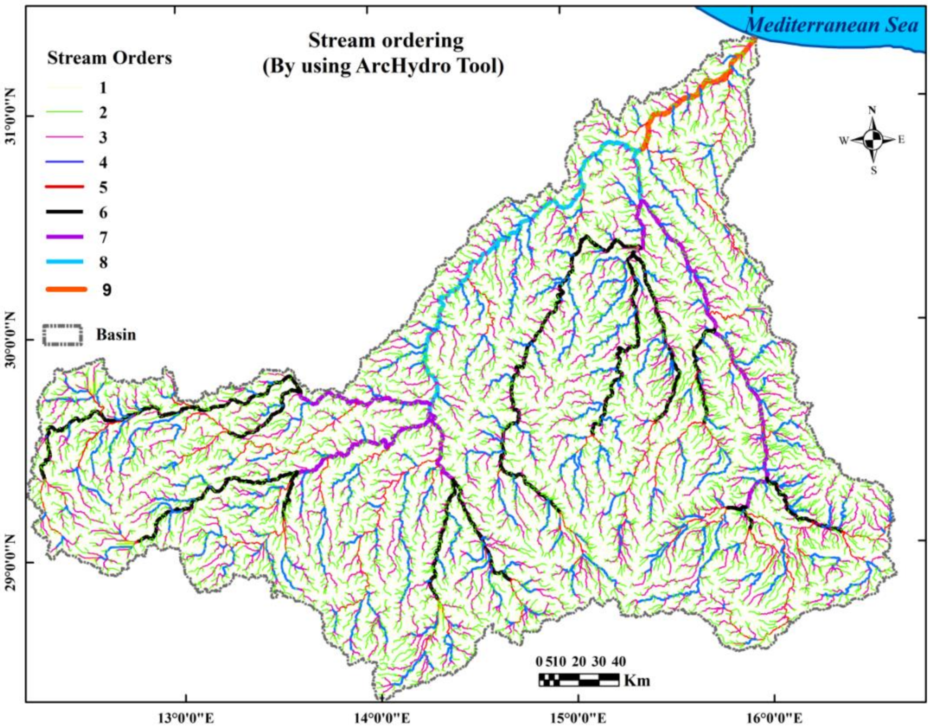

Figure 6. Drainage map of Bayy basin (by using Arc Hydro Tool)

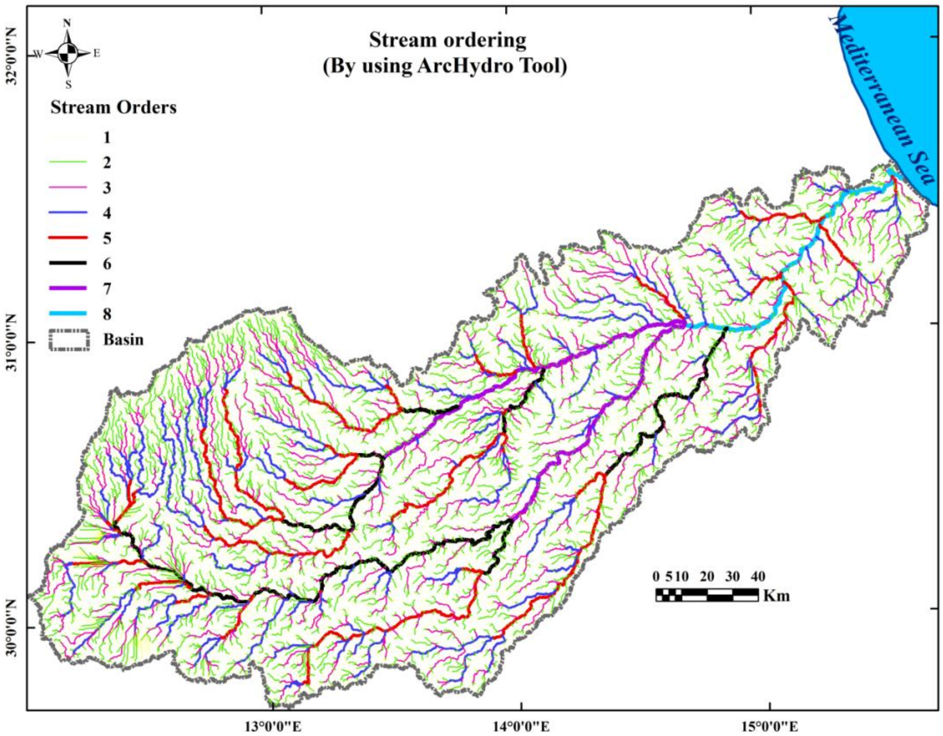

Figure 7. **Drainage map of Zamzam basin (by using Arc Hydro Tool)**

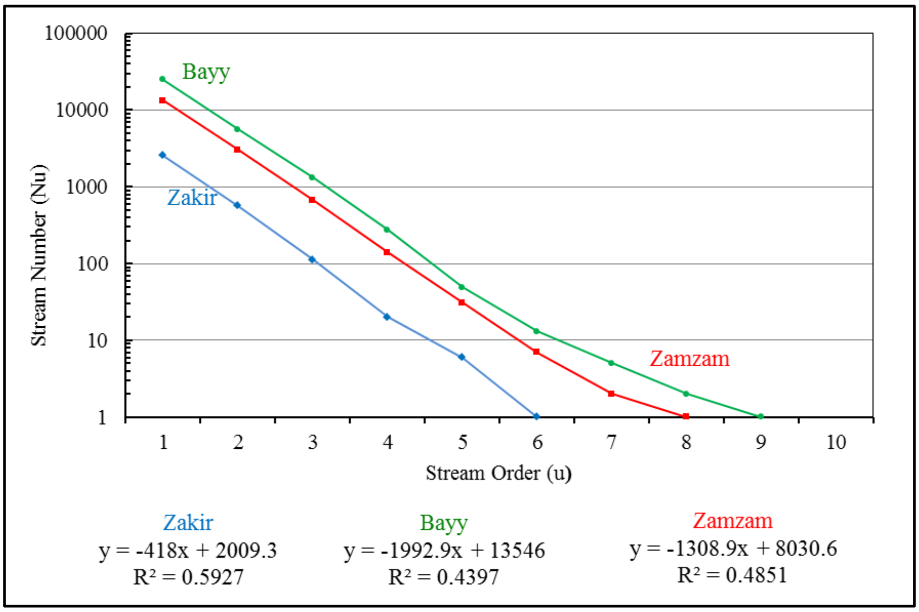

Figure 8. **The relationship between stream numbers (Nu) and stream orders (u) in the study area**

- **Stream Length (Lu):** The stream length is the total length of all the streams in a stream particular order. Horton's law of stream lengths is assisting the theory of geometric similarity in basins that is commonly increasing order (Horton, 1945). Stream length, generally, decreases with increasing stream order; in the first order, the total length of stream segments is high and decreases with the increasing stream order (Aldharab et al. 2018). The stream lengths for the studied basins were measured using Arc GIS-10.3 software program. The total stream length of the basins reaches 6251.45 Km (Zakir basin), 62213.01Km (Bayy basin) and 34341.39 Km (Zamzam). The stream length revealed a direct relationship with the number of the stream, area, perimeter, and length of the basin .Table (4) shows that the streams of the first order of studied basins occupy (51.46 % in Zakir basin, 51.38% in Bayy basin and 51.31% in Zamzam basin), the second order (24.31% in Zakir basin and 24.06% in Bayy and 24.70% in Zamzam basin), and the fifth order occupy (4.67% in Zakir basin, 2.55% in Bayy basin and 3.19% in Zamzam basin). On the other hand, there is an obvious increase in the total length of high tributary streams (1st, 2nd and 3rd 87.97%) and an obvious decrease in the total length of the streams of higher order. Due to the increment in the number of the first, second and third order streams. The relationship between the total stream lengths and the stream orders is an inversely proportion Figure (9).

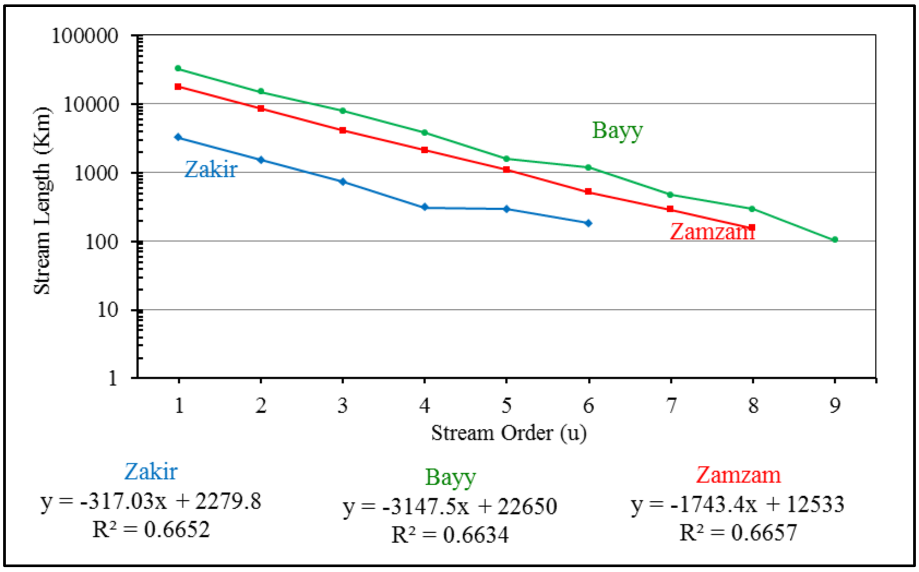

Figure 9. The relationship between the total stream length (Lu) and stream orders (U) in the study area

- **Bifurcation Ratio (Rb):** The term bifurcation ratio (Rb) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order as represented by the following relation (Schumm, 1956).

$$Rb = \frac{Nu}{Nu + 1}$$

Where ***Rb*** is bifurcation ratio, ***Nu*** is the number of stream order, ***Nu+1*** is the number of streams of the next higher order.

The bifurcation ratio (Rb) is considered as one of the most important morphometric scale, which control the rate of discharge. The bifurcation ratio (Rb) tends to have relatively narrow ranges between 3 and 5 (Smart, 1972 and Kirchner, 1983) except for conditions of strong geologic control. Basins with Rb values greater than 3 reflect high mountainous dissected area

(Horton, 1945). The bifurcation ratio shows a relation with the geometric shape of basin (elongated and circularity) which reflected on the rate of discharge and time of concentration.

Basins of high bifurcation ratios are elongated in shape that permit the passage of runoff over an extended period of time (long concentration times) thus, result in a higher chance for recharging the shallow aquifers. On the other hand, basins of low bifurcation ratios are circular in shape and allow the runoff to pass in short time (low time of concentration) forming a sharp peak. In the latter case, dams should be constructed to control runoff. The results show that the bifurcation ratio of the studied basins reaches 4.90 (Zakir basin), 3.75 (Bayy basin) and 4 (Zamzam basin) Table (4) indicating that the area is not much influenced by geological structures and undisturbed drainage patterns. The similarity in (Rb) values reflects the similarity in stage of geomorphic development, topographic variations and Climatic conditions. So, Wadi Bayy is relatively circular in shape and has a greater flooding capability than other wadis.

- **Weighted Mean Bifurcation Ratio (WMRb):** To arrive at a more representative bifurcation number Strahler (1952) used a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values.

$$\boldsymbol{WMRb} = \frac{\Sigma(\boldsymbol{Rb_u}/\boldsymbol{Rb_{u+1}})(\boldsymbol{N_u} + \boldsymbol{N_{u+1}})}{\Sigma \boldsymbol{N_u}}$$

Where ***WMRb*** is Weighted Mean Bifurcation Ratio, $\boldsymbol{Rb_u}$ is bifurcation ratio of stream order, $\boldsymbol{Rb_{u+1}}$ is bifurcation ratio of next stream order; $\boldsymbol{N_u}$ is the number of stream order, $\boldsymbol{N_{u+1}}$ is the number of streams of the next higher order.
The values of the weighted mean bifurcation ratio calculated for each Wadi, are very close to each other (Zakir basin 5.65, Bayy basin 5.45 and Zamzam basin 5.41) (Table 4).

- **Stream Frequency (Fs):** Stream frequency or channel frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932). Stream frequency has been calculated by applying the following formula:

$$\boldsymbol{Fs} = \Sigma \boldsymbol{Nu}/\boldsymbol{A}$$

Where: ***Fs*** is stream frequency, **Σ*Nu*** is total number of stream segments of all orders, and ***A*** is basin area.

High values of stream frequency tend to provide more possibilities for the collection of runoff water. Quantitatively, the stream frequency is one of the main effective parameters in the flood hazard assessment. From studying the values of the stream frequency of the study area (Table 4), it shows that the stream frequency values of the basins are 0.46 stream\km^2 in Wadi Zakir basin, 0.47 stream\km^2 in Wadi Bayy basin, and 0.48 stream\km^2 in Wadi Zamzam basin. The presence of low stream numbers in the studied basins is due to the maturation of the topography, low erosion rate, and rare vegetation cover. The values of stream frequency are very close to each other might be due to the Similarity of the source of basins, the kind of geological formations, orders of streams, and the slope.

- **Drainage Density (D):** Experimental relationship between drainage density and drainage frequency that has been tested and found valid for several basins was expressed by Melton (1957).

$$D = \sqrt{\frac{Fs}{0.694}}$$

Where ***D*** is drainage density, ***Fs*** is stream frequency and ***0.694*** is constant value.
Drainage density reflects the type of the surface layer, its permeability and roughness. It is an inverse function of permeability.
Table (4), shows the drainage density in the drainage basins of study area, the values reaches to 0.87 km^{-1} for Wadi Zakir basin, 0.92 km^{-1} for Bayy basin and 0.96 km^{-1} in Wadi Zamzam basin. The values of drainage density are low which means that the permeability of the studied basins is high. Consequently, basins have high drainage density is characterized by areas of low permeability and/or steep surface less density of plant cover (Abdel-Mogheeth et al., 1985).

4.5. Drainage Pattern

A set of channels connecting together and joining to the main riverbed, drainage pattern might contain one or more drainage networks (Goudie, 2006). The drainage pattern is effecting by many factors; topography, lithology, geological strata, homogeneity of the rock layers, structures of the beds, climate, and development of the drainage basins as well. There are many types of drainage patterns controlled by slop and topography that are related to the structural controls such as dendritic drainage, Parallel drainage, Trellis drainage, Radial drainage, Centrifugal drainage, Centripetal drainage, Distributary drainage, Rectangular drainage, and annular drainage (Morisawa, 1985). In the study area, the dendritic drainage pattern is most common pattern which forms and looks like the branching pattern of tree roots Figures (5, 6 and 7).This pattern has related to structural controlled drainage which comprises irregular tributaries with different angles (not at a right angle) in the areas that spreading of complex folded strata (Summerfield, 2013).

4.6. Determination of Relative Flood Hazard Degrees

On a trial to drive the empirical relation between the relative hazard degree of a basin with respect to flash floods and the morphometric parameters, the equal spacing or simple liner interpolation between data points procedure was chosen. Assuming that a straight liner relation exists between sample points, intermediate values can be calculated from the geometric relationship (Davis, 1975):

$$Y = \frac{(Y_{max} - Y_{min})(X - X_{min})}{(X_{max} - X_{min})} + Y_{min}$$

Where: ***Y*** is the relative hazard degree.
Y_{max} & Y_{min} are the upper and lower limits of the proposed scale (class five or 5 degree & first class or 1 in this case).
X_{max} & X_{min} are the higher and lower estimated values
X is the estimated value of any parameter between higher and lower values.

Eight morphometric parameters having a direct effect on flood were chosen. These parameters are: basin area (A), drainage density (D), stream frequency (F_s), Form Factor Ratio (Fr), relief ratio (Rf), ruggedness ratio (Rn), texture ratio (Rt) and bifurcation ratio (Rb). The relative hazard degree for each morphometric parameters of studied basins are tabulated in table (5). The results show that Wadi bayy has highly hazard degree than Wadi Zakir and Wadi Zamzam which have moderately hazard degree. On the other hand Wadi Zakir is more hazardous than Wadi Bayy and Wadi Zamzam due to its high relief (R_f) value ($R_f = 5$) compared with that of Wadi Zamzam ($R_f = 1$) and Wadi Bayy ($R_f = 2.86$).

Table 5. Flash flood hazard degree for the studied Wadis

Basin Name	Hazard degree of the chosen parameters								Sum	Basin Hazard degree
	A	D	Fs	Fr	R_f	Rn	Rt	Rb		
Wadi Zakir	1	1	1	1	5	1	1	5	16	2
Wadi Zamzam	2.8	5	5	2.9	1	2.46	3.39	1.93	24.48	3
Wadi Bayy	5	3.22	3	5	2.86	5	5	1	30.08	4

5. Conclusions

In this study can been used GIS technique with the mathematical and statistical formulas that are proposed by senior researchers in the field of basin morphology. The study concluded that the total area of the basins constitutes (67888.89, 35923.83 and 7161.64 Km^2 for Wadi Bayy, Wadi Zamzam and Wadi Zakir respectively) which are providing a high runoff volume. The characteristics of the drainage dimension are including basin perimeter (Wadi Bayy is 1979.57 km, Wadi Zamzam is 1458.05 km and Wadi Zakir is 668.05 km), basin length (215 km, 380 km, and 434 km for Zakir, Zamzam and Bayy respectively), Valley Length (Wadi Bayy is 706 km, Wadi Zamzam is 572 km and Wadi Zakir is 294 km, and basin width (Wadi Bayy basin is 123.84, Wadi Zamzam is 81.89 and Wadi Zakir is 34.47 km).

Shape properties of studied basins observed that all the basins are non-circular in shape, Wadi Zakir basin is more elongated in shape, while wadi Zamzam and wadi Bayy basins are elongated in shape, low form factor, sinuosity index values indicate that the Wadi Zamzam and Wadi Bayy have meandering main channels, while wadi Zakir basin is sinuous main channel. Low Compactness Coefficient which indicates low runoff intensity and lack of consistency between the perimeter and the area of the basin. *A study of the topographic parameters* of the basins referred that the basins have relatively high relief of southern part than northern part of the study area. The total relief value of Zakir basin reaches 643m, Wadi Zamzam basin reaches 748m and Bayy basin reaches 1058m. While the relief ratio for Zakir basin reaches 2.99 m/km, Bayy basin reaches 2.44m/km and Zamzam basin reaches 1.9m/km. The relative relief reaches of 0.96 m/km in Zakir, 0.53 m/km in Bayy basin and 0.51 m/km in Zamzam basin. The texture ratio of the Zakir basin is 4.91 Km^{-1}, Zamzam is 11.75 Km^{-1}, and Bayy basin is 16.28 Km^{-1}. The ruggedness values reach 0.56 in Zakir basin, 0.71 in Zamzam basin and 0.71 in Bayy basin. This means that wadi Bayy generates the greater runoff, followed by wadi Zamzam, whereas wadi Zakir generates the lowest runoff.

In relation to the stream network feature, the study follows the law of stream length and stream number proposed by Horton, where the stream order was classified into 6^{th} order for Zakir basin, 9^{th} order for Bayy Basin and 8^{th} order for Zamzam Basin. The number of streams is negatively correlated with the order. This is also valid for the relation between the stream length and stream order. The Bifurcation ratio (Rb) of the studied basins reaches 4.90 in Zakir basin, 4 in Zamzam basin and 3.75 in Bayy basin. Basins of high bifurcation ratio (Rb) (Zakir and Zamzam) are usually elongated in shape and permit the passage of runoff over an extended period of aquifers. On the other hand basins of low bifurcation ratios (Bayy basin) is circular in shape, allowing the runoff to pass in a short time (low time of concentration) forming a sharp peak of flow. The low values for each of drainage density and stream frequency attributed that high infiltration of water and low erosion rates. *The drainage pattern* of the studied basins are dendritic, this pattern has related to structural controlled drainage which comprises irregular tributaries with different angles (not at a right angle) in the areas that spreading of complex folded strata. *The relative flood hazard degree* shows that Wadi Bayy has highly flood hazard degree than Wadi Zamzam and Wadi Zakir which have moderately hazard degree.

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