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HYDRO-MORPHOMETRIC ANALYSIS USING GEOSPATIAL TECHNOLOGY: A CASE STUDY OF WADI GABGABA AND WADI ALLAQI WATERSHEDS, SOUTHERN EGYPT-NORTHERN SUDAN

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ABSTRACT

Hydro-morphometric parameters analysed to understand the hydrological process and are prerequisite for assessment of hydrological characteristics of surface water basin. The aim of this study is an attempt to determine the watershed characteristics and hydro-morphometric analysis using ASTER data and GIS techniques of the two largest basins and most extensive drainage systems (Wadi Gabgaba and Wadi Allaqi basins) in the eastern desert at Southern Egypt/Northern Sudan region. Thermal Emission and Reflection Radiometer (ASTER) data were used for preparing Digital Elevation Model (DEM), flow direction, stream orders, and slope maps. Geographical information system (GIS) was used in evaluation of drainage network characteristics, drainage texture, basin geometry, and relief aspects of morphometric parameters. Watershed boundary, flow direction, flow accumulation, stream ordering, and flow length have been prepared using Arc-Hydro Tool. Relief-aspect, contour, and slope have been prepared using Surface Tool in ArcGIS-10.5 software, and ASTER (DEM). More than 41 morphometric parameters of all aspects for study basins have been computed. The degrees of hazard due to flooding were analysed based on nine morphometric parameters which have an effect on the hydrologic behavior of the study basins. Correlation coefficient analysis is evaluated between morphometric variables with the help of statistical analysis for ascertaining the basins characteristics which helps in mapping hydrological potentiality and preparing a comprehensive plan for sustainable management of the watersheds.

Contribution/ Originality: This study contributes the assessment of the hydrogeological characteristics of surface water basins. It uses Geospatial Technology in earth science (Remote Sensing (RS), ASTER data, and GIS techniques). It is one of few studies which have investigated hydro-morphometric analyses of very large basins and most extensive drainage systems.

1. INTRODUCTION

Geospatial Technology in earth science is emerging tools by which the hydrogeologist can assess the watershed properties using Geographic Information System (GIS), Remote Sensing (RS) and Global Positioning System (GPS). It is comprehensively used in various fields of engineering and earth science applications as an indirect tool for predicting groundwater movement, estimation of landslide susceptibility mapping, and analysing topography. Geomorphologists and hydrologists have recognized that certain morphometric relations are very important in determining geomorphic characteristics of drainage basin systems and the runoff characteristics.

Across various branches in geo-science, earlier morphometric studies were carried out by conventional methods, but the advent of GIS and remote sensing techniques made it faster and very popular.

GIS-based drainage morphometric analysis is not only faster but also computationally efficient, which have been used for hydrological response, understanding basin characteristics and watershed prioritization studies. The use of GIS and ASTER GDEM data enables rapid, precise and inexpensive alternative for the morphometric analysis [1-4]. The aim of this work is an attempt to use Advanced Space-borne Thermal Emission and Reflection Global Digital Elevation Model (ASTER GDEM), owing to its better accuracy particularly in hilly and complex terrain than Shuttle Radar Topography Mission (SRTM) DEM to analysis of drainage system requires delineation of all existing streams and study the hydro-morphometric parameters in the study basins.The study area is Wadi Gabgaba and Wadi Allaqi which are the two largest wadis and most extensive drainage systems in the eastern desert at Southern Egypt-Northern Sudan region. Wadi Allaqi covers an area of approximately 30179 km^2 and its upstream tributaries drained westward direction from the Red Sea mountains into Khore Allaqi, Nasser Lake, Egypt. (20º 55` - 23º 20`N and 32º 55` - 35º 30` E Figure 1). Wadi Gabgaba, the upstream tributaries drain from northern Sudan into Nasser Lake, Southern Egypt Figure 1). It covers an area of 44321 Km^2 and trends to North–South (20º 00` - 22º 40`N and 32º 20` - 35º 05` E, Figure 1). Wadi Gabgaba and Wadi Allaqi were still led to the River Nile till the establishment of the high Dam. Their tributaries receive occasional precipitations accumulating into the main drainage of the two valleys torrents and discharge into Nasser Lake.

2. MATERIAL AND METHODS

The morphometric analysis of drainage system requires delineation of all existing streams. different techniques were used for collecting the essential data of this manuscript such as: 1) Shuttle Radar Topography Mission (SRTM) data with 30 m spatial resolution, 2) topographic maps (1:50,000 scale), 3) Advanced Space-borne Thermal Emission and 4) Reflection Global Digital Elevation Model (ASTER GDEM). All data extraction and analysis in the study basins is carried out using the Arc Hydro tool of ArcGIS 10.5 software that used to create the base for better understand of the watershed and the drainage system of both W. Gabgaba and W. Allaqi. The digital elevation model (DEM) derived from SRTM data is used as input data pre-processing Figure 2). As well as, ASTER GDEM is processed by filling the sinks, followed by generated the flow direction and the flow accumulation grids. The stream ordering and channels were classified based on Strahler's method [5]. Basic morphometric parameters were estimated and analysed.

Figure-1. Location map of the study basins (W. Gabgaba and W. Allaqi).

3. RESULTS AND DISCUSSION

3.1. Morphometric Characteristics of Study Basins

The morphometric characteristics of Wadi Gabgaba, Wadi Allaqi basins and their sub-basins used in estimating the Hydro-morphometric analysis of the watersheds. The study basins boundaries were extracted. Accordingly, Wadi Gabgaba watershed can be divided into 14 sub-basins as shown in Figure 3 and Table 1. Wadi Allaqi watershed also can be divided into 14 sub-basins Figure 3, Table 2.

3.1.1. Drainage Network Characteristics

3.1.1.1. Stream Order (Sμ) and Stream Number (Nμ)

The stream order of the study basins using Strahler method are ranged from 5 to 8 order Tables 1 & 2 and Figure 4. In Wadi Gabgaba basin, 81470 stream segments were identified, 50.2% (40898) are first-order, 23.75% (19201) are second-order, 12.53% (10209) are third-order, 6.71% (5469) are fourth-order, 3.87% (3154) are fifth-order, 1.94% (1578) are sixth-order, 0.47% (383) are seventh-order, and 0.71% (578) are eighth-order. At Wadi Allaqi basin, 55477 stream segments were identified, 50.21% (27854) of them are first-order, 23.54% (13058) are second-order, 12.6% (6991) are third-order, 6.57% (3645) are fourth-order, 4.07% (2257) are fifth-order, 1.93% (1068) are sixth-order, 0.34% (189) are seventh-order, and 0.75% (415) are eighth-order. It has clearly observed that the maximum frequency is in the case of the first order streams and it has also noticed that there is a decrease in stream frequency as the stream order increases. The higher streams order of network in the study basins, the greater infiltration and run off so the hazard increase with increasing stream order. From the study the relationship between stream number and their orders of each order, its noted that the highest stream number is linked to the first order in both Wadi Gabgaba and Wadi Allaqi basins Figure 5.

3.1.1.2. Stream Length (Lμ)

Stream length (Lμ) indicate the steepness of the basin area, and the degree of drainage. The total stream length of Wadi Gabgaba watershed is 65393 km, while for its sub-basins vary from 885.7 km for Tamamah sub-basin to 7324.6 km for W. Huwayt sub-basin. Total stream length of first-order streams is 33479 km (51.2%), whereas (Lμ) are 16529 km (25.28%), 7869 km (12.03%), 3876 km (5.93%), 2007 km (3.07%), 981 km (1.50%), 262 km (0.40%), and 387 km (0.59%) for second-, third-, fourth-, fifth-, sixth-, seventh- and eighth-order, respectively. For Wadi Allaqi basin, total stream length is 43012 km and reached its minimum (628.9 km) at W. Um Tor sub-basin, while its maximum (7777.8 km) calculated at W. Elei-Husheim sub-basin. Total stream length of Wadi Allaqi basin are 21806 km (50.70%), 10792 km (25.09%), 5400 km (12.56%), 2538 km (5.90%), 1463 km (3.40%), 660.8 km (1.54%), 121.9 km (0.28%), and 228.7 km (0.53%) for first-, second-, third-, fourth-, fifth-, sixth-, seventh- and eighth-order, respectively.

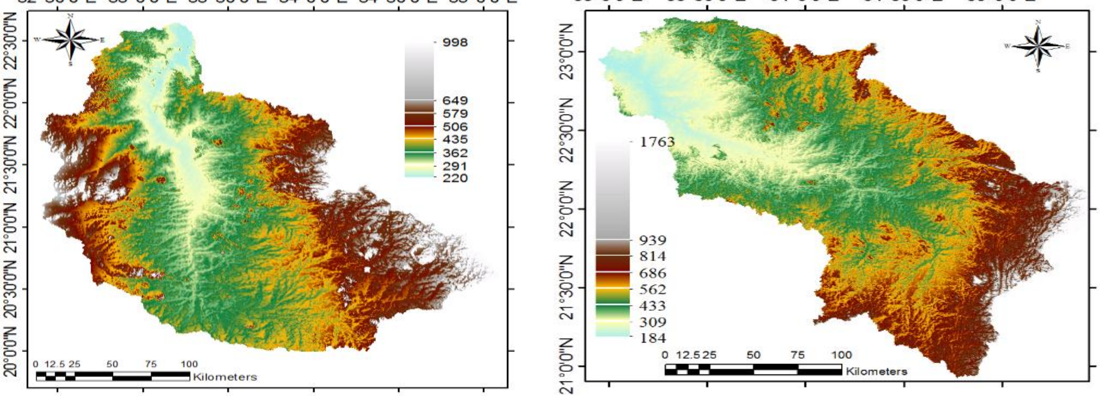

Figure-2. Digital Elevation Models (DEM) of the study basins (Wadi Gabgaba and Wadi Allaqi basins).

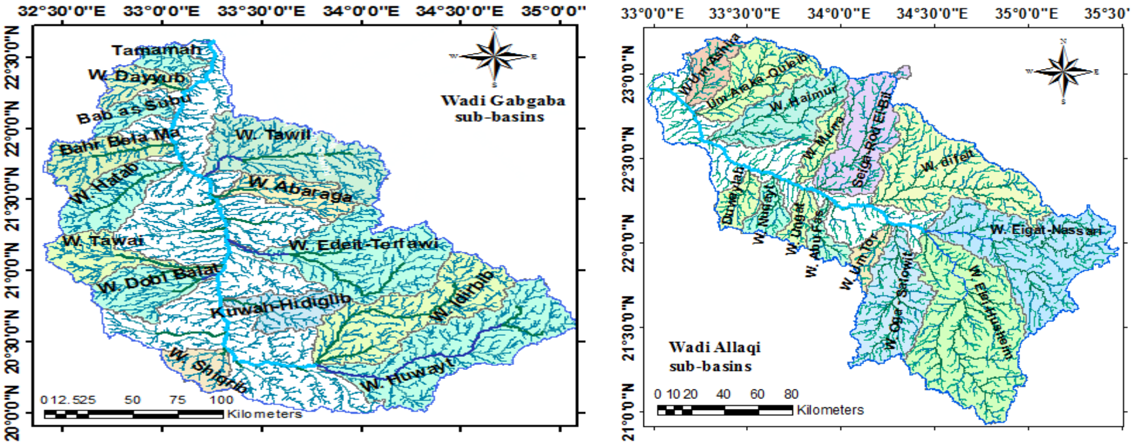

Figure-3. Sub-basins boundaries maps of Wadi Gabgaba and Wadi Allaqi basins.

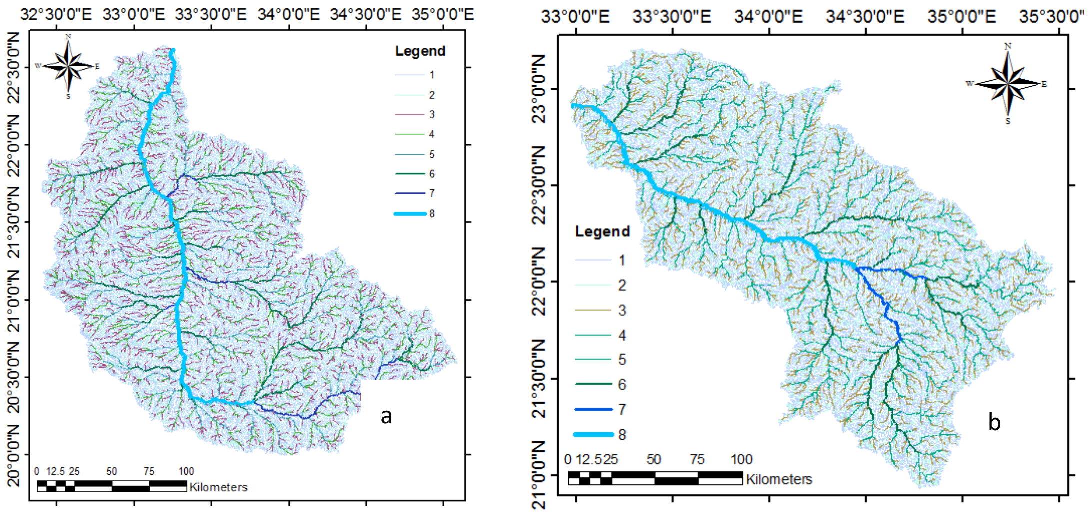

Figure-4. Stream Orders map of the study basins, a)- Wadi Gabgaba b)- Wadi Allaqi.

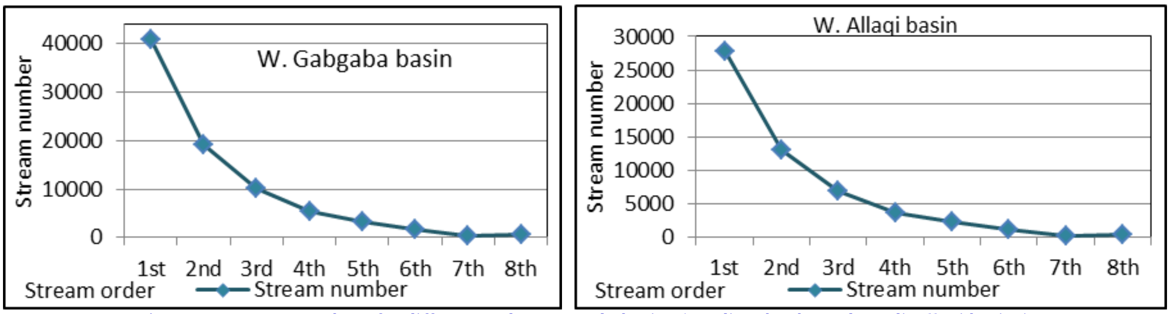

Figure-5. Stream numbers for different orders at study basins (Wadi Gabgaba and Wadi Allaqi basins).

Total length of stream segments reached its maximum in first order streams (longest order) and decreases as the stream order increases Figure 6. In the study basins and sub-basins, the stream segments of various orders show some variations Tables 1 & 2 indicating the link between the streams flowing and the lithological variation, high altitude, and moderately steep slopes.

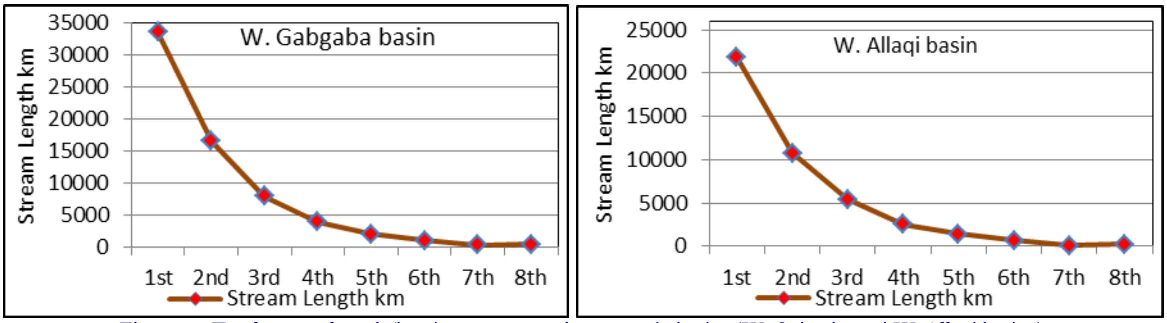

Figure-6. Total stream length for given stream orders at study basins (W. Gabgaba and W. Allaqi basins).

The logarithmic relationship for Wadi Gabgaba and Wadi Allaqi Figure 7 basins show linear relationships with a limited deviation from a straight line and nearly perfect negative correlation (correlation coefficients are 0.97 and 0.94 for both respectively). The logarithmic relationship between stream length and its order show negative correlations (inverse relationship) with coefficient of correlation are 0.97 and 0.96 for Wadi Gabgaba and Wadi Allaqi basins respectively Figure 7.

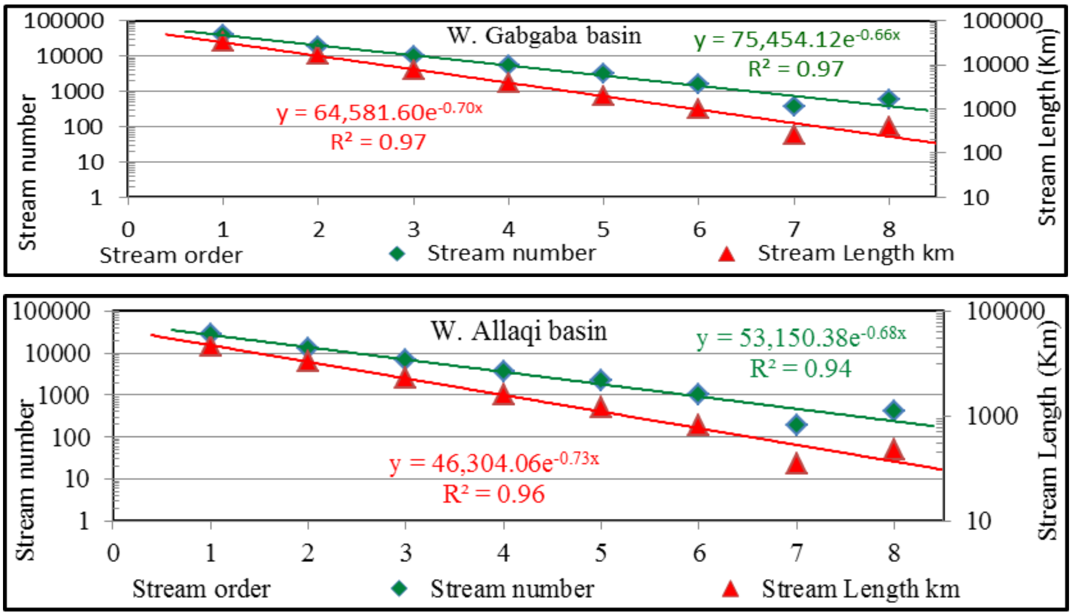

Figure-7. Relationship between stream numbers, stream length against the stream order at study basins.

3.1.1.3. Mean Stream Length (Lsm)

The Mean Stream Length of Wadi Gabgaba is 0.721, while for its sub-basins vary from 0.662 for W. Kuwah-Hidiglib sub-basin to 0.842 for W. Tawai sub-basin. Lsm of first-order streams is 0.819, whereas they are 0.861, 0.771, 0.709, 0.636, 0.622, 0.684, and 0.670 for second-, third-, fourth-, fifth-, sixth-, seventh- and eighth-order, respectively. The Lsm for Wadi Allaqi basin is 0.693 and reached its minimum (0.697) at W. Um Araka-Quleib and W. Difeit sub-basins, while its maximum (0.749) calculated at W. Duwaylah sub-basin. Lsm of Wadi Allaqi basin are 0.783, 0.826, 0.772, 0.696, 0.648, 0.619, 0.645, and 0.551 for first-, second-, third-, fourth-, fifth-, sixth-, seventh- and eighth-order, respectively. In all basins and sub-basins, it has observed that the Lsm value of any given order is generally greater than that of the lower order and less than that of its next higher order.

3.1.1.4. Stream Length Ratio (RL)

The average RL values of Wadi Gabgaba basin is 0.974 and in its sub-basins the minimum, maximum, and average are 0.89 (W. Idirbib sub-basin), 1.016 (W. Edeit-Terfawi sub-basin), 0.923 respectively Table 1. At Wadi Allaqi basin, average RL value is 0.953 and it ranged between 0.804 (W. Elei-Husheim sub-basin) and 0.987 (W.

Abu Fas sub-basin) with average of 0.927 in its sub-basins Table 2. The RL between streams of different order in the study basins (W. Gabgaba and W. Allaqi) and their sub-basins reveals that there is a variation in RL in each sub-watershed may due to the changes in the topographic conditions and/or the slope.

3.1.1.5. Bifurcation Ratio (Rb)

It is observed from the calculated Rb Tables 1 & 2 that, Rb values changes for each order mainly caused by the change of the geological and lithological setting of the drainage systems. Horton [6] states that (Rb) ranged about 2.0 for the flat area, up to 3.0 for the rolling drainage basins and 4.0 for the highly dissected or mountainous basins. Strahler [5] stated that Rb values ranged between 3.0 and 5.0 are for basins in which the geologic structures don't distort the drainage pattern. Tables 1 & 2 shows that the bifurcation ratios are relatively low in the study area (86.42% and 96% from different stream orders for Wadi Gabgaba and Wadi Allaqi basins respectively) due to that most of the drainage basins and sub-basins have Rb less than the normal range (3.0) as a result of weak effect of the structural disturbances. Some basins and sub-basins have high Rb (have values greater than 3.0) may be a due to a high structural control effect and reflect high mountainous dissected areas and elongated basins as shown in different stream orders at sub-basins (i.e. W. Dayyub, Tamamah, Bab As-Subu, W. Hatab, W. Shiqrib, W. Idirbib, W. Huwayt, W. Edeit-Terfawi, W. Dobi Balat, W Um Ashira, and W. Murra) Tables 1 & 2. The bifurcation ratio is indicative of the basin shape; a circular basin is likely to have low Rb, whereas an elongated basin is likely to have relatively high Rb.

3.1.1.6. Weighted Mean Bifurcation Ratio (WMRb)

WMRb for Wadi Gabgaba sub-basins is varying from 1.49 (W. Tawai) to 2.06 (Tamamah sub-basin), whereas for Wadi Allaqi sub-basins ranged between 1.45 (W. Um Tor) and 2.33 (W. Murra) Tables 1 & 2.

3.1.1.7. Main Channel Length (CL)

Main channel length of Wadi Gabgaba basin is 611.2 Km, and its sub-basins ranged from 53.4 Km for W. Shiqrib sub-basin to 223.6 Km for W. Huwayt sub-basin with an average is 117.3 km Table 1. The CL value of Wadi Allaqi basin is 443.2 km and for its sub-basins it ranged between 50.3 km (W. Ungat sub-basin) and 193.7 (W. Elei-Husheim sub-basin) with an average is 104.4 km Table 2. The variations between the main channel length values of the study basins is linked to the variations of the geological features of the study area.

3.1.1.8. Sinuosity (Si)

The Sinuosity value at Wadi Gabgaba basin is 1.41 and at its sub-basins ranged between 1.29 (Tamamah and W. Kuwah-Hidiglib sub-basins) and 1.67 (W. Tawil sub-basin) with an average is 1.45 Table 1. The Si value at Wadi Allaqi basin is 1.43 and at its sub-basins ranged between 1.23 (W Um Ashira sub-basin) and 1.58 (W. Um Araka-Quleib sub-basin) with an average is 1.39 Table 2. Streams basis of sinuosity classified into: a) meandering channel (Si is >1.50) b) sinuous channel (Si is from 1.05 to 1.50) and c) straight channel (Si is < 1.05) [7]. Based on that classification all major basins and sub-basins determined as sinuous channels. High sinuosity values, as observed at most sub-basins in reflects a good potentiality due to the longest travel time. whereas the low Sinuosity values (as in W. Ungat, W. Duwaylah, W. Murra, W. Seiga-Rod EL-Bil, Tamamah, and W. Kuwah–Hidiglib sub-basins) indicate the shortest travel time of water flow to the outlet.

3.1.1.9. Rho Coefficient (ρ)

Higher values of the (ρ) coefficient indicate higher water storage, during the flood periods and as such attenuate the erosion effect during elevated discharge according to Mesa [8]. The low (ρ) values indicate low capacity of water storage. This parameter is controlled by geological, climatical, and geomorphological changes [9]. Average (ρ) values of Wadi Gabgaba basin is 0.602 and in its sub-basins the minimum, maximum, and average are 0.451 (W.

Shiqrib sub-basin), 0.836 (W. Huwayt sub-basin), and 0.574 respectively Table 1. At Wadi Allaqi basin, the average (ρ) value is 0.651 and its values ranged between 0.429 (W. Eigat-Nassari sub-basin) and 0.808 (W. Murra sub-basin) with average of 0.578 in its sub-basins Table 2 suggesting higher hydrologic storage during floods and attenuation the effects of erosion during elevated discharge.

3.1.2. Basin Geometry

3.1.2.1. Watershed Area (A)

The area of Wadi Gabgaba basin is 44321 Km² and for its sub-basins ranged between 624 Km² for Tamamah sub-basin and 2128 Km² for W. Huwayt sub-basin Table 1. Watershed area for Wadi Allaqi basin is 30179 km² and its sub-basins areas ranged between 442 km² for W. Um Tor sub-basin and 5472 km² for W. Elei-Husheim sub-basin Table 2. All basins areas more than 100 km² were classified as large basins according to Horton [6] accordingly, Wadi Gabgaba and Wadi Allaqi and their sub-basins are classified as large basins and they are considered as the two largest basins in the eastern desert at Southern Egypt/Northern Sudan region. The relationship between stream length and the area at the study basins estimated Figure 8. The regression equations for Wadi Gabgaba and Wadi Allaqi basins represented by Equation 1 and Equation 2 respectively.

$$\text{Stream length} = (1.47 \times area) - 14.31 \qquad (1)$$

$$\text{Stream length} = (0.701 \times area) - 1.39 \qquad (2)$$

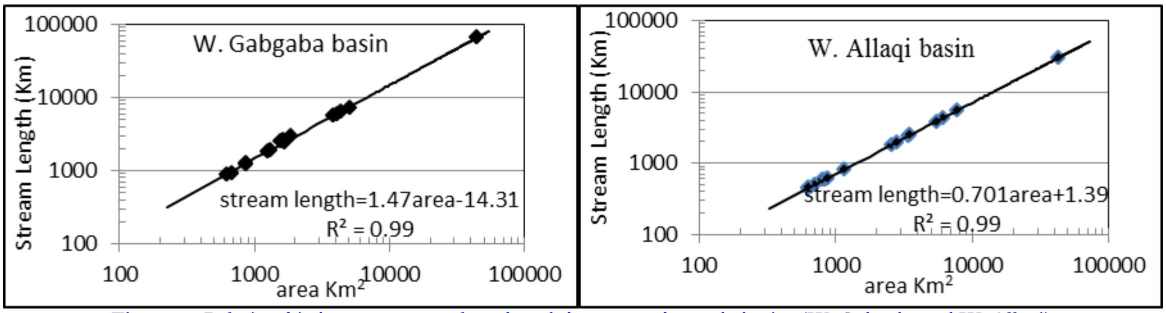

Figure-8. Relationship between stream length and the area at the study basins (W. Gabgaba and W. Allaqi).

3.1.2.2. Basin length (Lb)

It indicates the travel time of surface runoff specially the flood waves passing through the basin Tables 1 & 2. Basin length of Wadi Gabgaba is 434.2 Km, and for its sub-basins, vary from 37.1 Km of W. Shiqrib to 140.6 Km of W. Huwayt sub-basin with average of 79.4 km Table 1. Lb of Wadi Allaqi is 309.1 Km, and for its sub-basins, ranged between 40.7 Km of W. Ungat and 132.6 Km of W. Elei-Husheim sub-basin with average of 33.9 km Table 2. The travel time of W. Elei-Husheim, W. Huwayt, W. Idirbib, and W. Eigat-Nassari sub-basins are the greatest basins that gives a good potentiality for groundwater recharge than the shortest travel time once.

3.1.2.3. Basin perimeter (Pr)

The (Pr) of Wadi Gabgaba and Wadi Allaqi basins are 1593 and 1385 km respectively Tables 1 & 2. For Wadi Gabgaba sub-basins, Pr values differ from 159.2 km at Tamamah sub-basin to 610.5 km at W. Huwayt sub-basin with average of 328.5 km. Whereas the Perimeter values for Wadi Allaqi sub-basins ranged between 157.2 km (W. Ungat sub-basin) and 506.9 km (W. Eigat-Nassari sub-basin) with average of 292.3 km. The relationship between basin area, perimeter and length plotted in Figure 9. It is noticed that there is direct positive relationship between the area, length and perimeter of study basins with coefficient of correlation vary from 0.86 to 0.95.

3.1.2.4. Basin width (w)

The basin width of Wadi Gabgaba and Wadi Allaqi basins are 102.1 and 97.6 km respectively Tables 1 & 2. Basin width for Wadi Gabgaba sub-basins ranged between 14.8 km (Bab As-Subu sub-basin) and 39.8 km (Wadi Tawil sub-basin) with average of 24.3 km. For Wadi Allaqi sub-basins, its values vary from 8.94 (W. Um Tor sub-basin) to 41.2 km (W. Elei-Husheim sub-basin) with average of 21.3 km. The narrow basin width at the study basins indicate nearly elongated shape that led to groundwater recharge potentiality more than the wider basins.

3.1.2.5. Circularity Ratio (Rc)

The Rc ratio is computed Tables 1 & 2 and its value for Wadi Gabgaba basin is 0.219 while for its sub-basins ranged between 0.165 (W. Tawai sub-basin) and 0.31 (W. Shiqrib sub-basin). The circularity ratio for Wadi Allaqi basin is 0.198 with an average of 0.228 for its sub-basins. In the present study, the calculated Rc values are low circularity ratio. This indicate that the study basins and their sub-basins have nearly elongated basin shape, low discharge of runoff and highly permeability of the subsoil condition. Some sub-basins have relatively high circularity ratio with nearly circular basin shape as W. Shiqrib (3.11), Tamamah (3.09), W. Hatab (2.83), and W. Duwaylah (2.89).

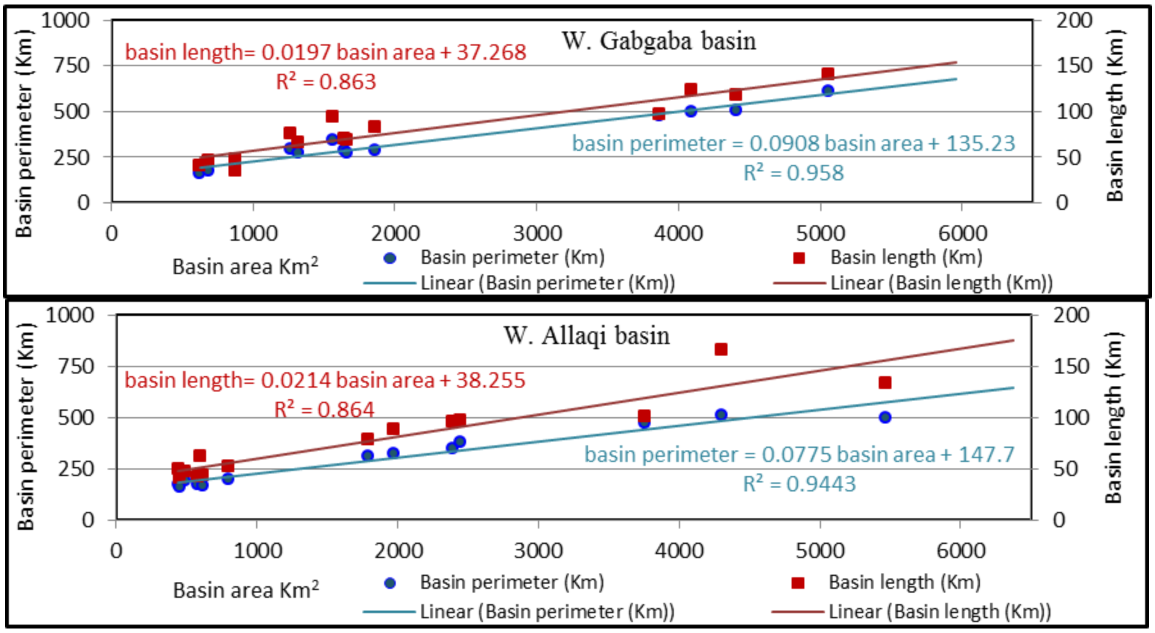

Figure-9. Relationship between basin perimeter, length against the basin area at study watersheds.

3.1.2.6. Elongation Ratio (Re)

The elongation ratio used to understand the basin hydrology and to estimate the flood hazards. The higher value of elongation ratio the more circular shape of the catchment and vice-versa. An elongated basin is less efficient in the discharge of run-off than a circular basin [10]. The elongation ratio of Wadi Gabgaba watershed is 0.547, and in its sub-basins its values vary from 0.427 (W. Tawai sub-basin) to 0.898 (W. Shiqrib sub-basin) Table 1. for Wadi Allaqi, the calculated (Re) is 0.634 and in its sub-basins ranged between 0.448 (W. Murra sub-basin) and 0.691 (W. Eigat-Nassari sub-basin) Table 2. According to the elongation ratio, most of sub-basins are elongated indicate an ideal case of elongation with high time of concentration, and high groundwater potentialities. Some sub-basins characterized as more elongated (W. Tawai, W. Murra, and W. Um Tor sub-basins), is less elongated (W. Tawil), and oval shape (W. Shiqrib sub-basin). The variations of elongated shapes of the study basins and their sub-basins are due to geological and structural effects.

3.1.2.7. Drainage Texture (Dt)

Wadi Gabgaba basin has a drainage texture of 51.14 Km^{-1} (very fine drainage texture). While (Dt) in its sub-basins ranged between 6.805 Km^{-1} for Bab As-Subu sub-basin and 15.908 Km^{-1} for W. Edeit-Terfawi sub-basin with an average of 10.74 Km^{-1} Table 1. Wadi Gabgaba sub-basins have drainage textures vary from fine of W. Dayyub, Bab As-Subu, W. Tawai, and W. Abaraga sub-basins to very fine for the other sub-basins. Wadi Allaqi basin has a drainage texture of 40.05 Km^{-1} (very fine drainage texture), and its sub-basins ranged from 4.72 Km^{-1} (for W. Abu Fas sub-basin) to 20.03 Km^{-1} (for W. Elei-Husheim sub-basin) with an average of 9.81 Km^{-1} Table 2. The Dt of Wadi Allaqi sub-basins varies from moderate (W. Murra, W. Um Tor, W. Abu Fas, and W. Ungat sub-basins), fine (W Um Ashira, W. Nuqayt - Um Domi, and W. Duwaylah sub-basins), and very fine drainage texture for others sub-basins. In the study basins, the lower values of drainage texture indicate that the basins and their sub-basins have a good chance for groundwater recharge, while the basins and their sub-basins of high values have good chance to produce flash flood.

3.1.2.8. Texture Ratio (Rt)

The texture ratio depending on the infiltration capacity, underlying lithology, and relief aspect of the terrain. The texture ratio for Wadi Gabgaba sub-basins ranged between 3.41 and 7.99 streams/km, the lowest value of texture ratio is recorded in Bab As-Subu sub-basin, and the highest value is recorded in W. Edeit-Terfawi sub-basin with an average of 5.39 streams/km Table 1. The texture ratio of the whole Wadi Gabgaba basin is 25.67 stream/km. The value of Rt for whole Wadi Allaqi basin is 20.11 and at its sub-basins ranged between 2.38 streams/km (W. Abu Fas sub-basin) and 10.05 streams/km (W. Elei-Husheim sub-basin) and the Rt average is 4.93 streams/km Table 2. Classification for the texture ratio according to Morisawa [11] consists of: i)- coarse texture (Rt less than 8 streams/km), ii)- medium texture (Rt from 8 to 20 streams/km), iii)- soft texture (Rt from 20 to 200 streams/km), and iv)- very soft texture (Rt more than 200 streams/km). Therefore, the study basins and their sub-basins belong to first class (coarse texture) except the whole Wadi Gabgaba and Wadi Allaqi basins plotted in third category (soft texture) and W. Elei-Husheim sub-basin lied in second class (medium texture).

3.1.2.9. Lemniscate Ratio (K)

The lemniscate values for the watersheds ranged between 3.13 (W. Gabgaba basin) and 3.78 (W. Allaqi basin) Tables 1 & 2 which show that the watersheds occupy the maximum area in their regions of inception with large number of streams of higher order and indicate high runoff. Low values of Lemniscate ratio represent sub-basins nearly rounded and prevailing lateral and vertical erosions, which refer to geomorphic stage development of a basin [12]. Highest values indicate high runoff and represent elongated basins and sub-basins with nearly tear-shaped, pear-shaped a lemniscate.

3.1.2.10. Basin Shape Index (Ish)

In the present study, the calculated value of (Ish) of Wadi Gabgaba basin is 0.299 and in its sub-basins ranged between 0.22 and 0.804 Table 1. While (Ish) value for Wadi Allaqi basin is 0.401 and in its sub-basins ranged between 0.2 and 0.477 Table 2. The calculated (Ish) values are relatively high, reflects that most of the study basins and their sub-basins have elongated shape and indicate that the basin length is long which resulted in a good chance for groundwater recharge. The elongated basins are not efficient in runoff discharge as compared with circular basins. Some sub-basins have relatively low (Ish) values as W. Shiqrib (3.11), Tamamah (3.09), W. Hatab (2.83), and W. Duwaylah (2.89). The lower values as sub-basins of W. Tawai (0.22), W. Murra (0.2), and W. Um Tor (0.23) indicate that basins length are short that causes more flash flood hazard if these areas were developed.

3.1.2.11. Compactness Coefficient (SH)

Compactness coefficient used to express the relationship of a hydrologic basin to that of a circular basin having the same area [6]. In the study area, most of study basins and sub-basins have low (SH) values (2.14 and 2.25 at Wadi Gabgaba and Wadi Allaqi, respectively) Tables 1 & 2. For Wadi Gabgaba sub-basins, it ranged between 1.79 (W. Shiqrib) and 2.47 (W. Tawai), while for Allaqi sub-basins, it ranged between 1.86 (W. Duwaylah) and 2.46 (W. Abu Fas). Lower (SH) values in the study basins and sub-basins indicate the more basins elongation with less erosion. It refers also to the homogeneity between the basin area and the shape of basin perimeter and similar in its sense to circularity ratio (Rc).

3.1.3. Drainage Texture

3.1.3.1. Drainage Pattern (Dp)

Dendritic pattern is the main pattern in most of the study basins and their sub-basins as shown in Figure 4.This formed in drainage basins have less of underlying geologic structural control and composed of fairly homogeneity in texture. Some of sub-basins are dendritic with some of rectangular patterns as W. Oga-Salowit, W. Um Tor, W. Um Araka-Quleib, W. Elei-Husheim, Tamamah, W. Edeit-Terfawi, and W. Abaraga sub-basins and with some of parallel patterns as W. Eigat-Nassari, W. Seiga-Rod El-Bil, W. Murra, W. Dobi Balat, and W. Tawai sub-basins. Where in that case, most of the basin is dendritic but, in some parts of the basin or sub-basin, the dipping and jointing of the topography reveals parallel and rectangular patterns.

3.1.3.2. Drainage Density (D)

Drainage density provides hydrogeologist with useful numerical measure of runoff potential and landscape dissection. Density factor is related to rock types, relief, runoff intensity index, infiltration capacity, surface roughness, and climate. Low drainage density means slow hydrological response while high drainage density reflects rapid hydrologically response to the rainfall events and highly dissected drainage basin Hajam, et al. [13]. Smith [14] classified Drainage density into: (i) very coarse texture (D less than 1.24 km^{1}), (ii) coarse texture (D from 1.24 to 2.49 km^{1}), (ii) moderate texture (D from 2.49 to 3.73 km^{1}), (iv) fine texture (D from 3.73 to 4.97 km^{1} (v) very fine texture (D more than 4.97 km^{1}). (D) values of the study basins have limited variations (1.48 and 1.43 km^{1} for Wadi Gabgaba and Wadi Allaqi basins respectively). (D) for sub-basins of Wadi Gabgaba, ranged between 1.36 (Bab As-Subu) and 1.602 km^{1} (W. Hatab), while (D) values for sub-basins of Wadi Allaqi vary from 1.37 (W. Nuqayt-Um Domi) to 1.64 km^{1} (W. Difeit). The values of drainage density in the study watersheds indicating low drainage density affected by the basins drainage texture influence greater infiltration and indicates a good groundwater potential. Based on classification of Smith [14] all basins and sub-basins are lying in coarse class of drainage density.

3.1.3.3. Drainage Intensity (Di)

The study shows low drainage intensity values, whereas Di are 1.25 and 1.29 for Wadi Gabgaba and Wadi Allaqi watersheds respectively Tables 1 & 2. Accordingly, sub-basins of Wadi Gabgaba have (Di) ranged between 1.1 km^{-1} (W. Tawai) and 1.336 km^{-1} (Tamamah). Also sub-basins of Wadi Allaqi have (Di) values vary from 1.23 (W. Duwaylah) to 1.335 km^{-1} (W. Murra). The Drainage Intensity low values indicate that stream frequency and drainage density have little effect on the rate and/or extent to which the ground surface lowered by erosion. These sub-basins of low drainage densities values (as W Umm Ashira, W. Duwaylah, W. Tawai, W. Bahr Bela Ma, W. Hatab sub-basins) are often associated with widely spaced streams. This due to the presence of less resistant rock types or materials and consequently surface runoff is not quickly removed from the watershed making it highly susceptible to gully erosion and flooding. High drainage intensity basins and sub-basins characterized by high infiltration capacities which give good chance for groundwater recharge as W. Um Araka - Quleib, W. Seiga-Rod EL-Bil, W. Murra, W. Dayyub, W. Kuwah - Hidiglib, W. Tamamah sub-basins.

3.1.3.4. Stream Frequency (F)

The structural hills basins have higher drainage density and stream frequency while the basins of alluvial deposits have low values indicate the direct relation between Stream Frequency and lithological characteristics [6]. Stream frequency can be classified into many classes: i)- poor (F less than 2.5 streams/km^2), ii)- moderate (F from 2.5 to 3.5 streams/km^2), iii)- high (F from 3.5 to 4.5 streams/km^2), and iv)- very high (F more than 4.5 streams/km^2) [15]. Tables 1 & 2 show stream frequency (F) for all study basins and sub-basins. It is noticed that the (F) for Wadi Gabgaba basin is 1.84 and in its sub-basins give minimum value (1.749 streams/km^2) at Bab As-Subu sub-basin and maximum value (1.917 streams/km^2) at W. Kuwah-Hidiglib sub-basin. The (F) for Wadi Allaqi basin is 1.84 and in its sub-basins has minimum value (1.744 streams/km^2) at W. Duwaylah sub-basin and maximum value (1.894 streams/km^2) at W. Difeit sub-basin. All basins and sub-basins are lying in poor class. Stream frequencies of the study basins and its sub-basins have limited variation may be due to near similarity of lithology, relief, rainfall, infiltration rate, the total drainage area of the study basins, and initial resistivity of terrain to erosion.

The relationship between drainage frequency and drainage density analysed in the study basins and their sub-basins. It reflects a direct relationship between these two variables. As well as it notices that, both of the two variables are similar in graph shape when plot their values in one diagram as well as some sub-basins are corresponding in their values Figure 10.

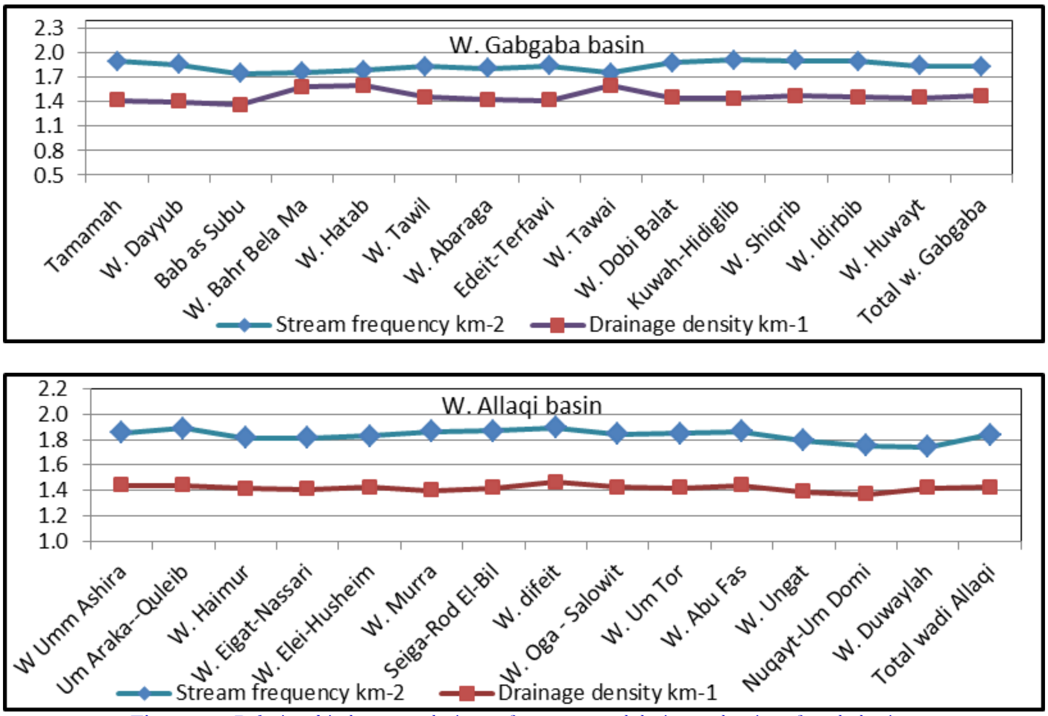

Figure-10. Relationship between drainage frequency and drainage density of study basins.

3.1.3.5. Infiltration Number (FN)

The calculated (FN) of Wadi Gabgaba watershed Table 1 is 2.71 km^{-3} and in its sub-basin ranged between 2.38 (Bab As-Subu sub-basin) and 2.86 km^{-3} (W. Hatab sub-basin). While at the other watershed (Wadi Allaqi), it is 2.62 km^{-3} and in its sub-basin ranged between 2.4 (W. Nuqayt-Um Domi) and 2.77 km^{-3} (W. Difeit) Table 2. All calculated (FN) of Wadi Gabgaba and Wadi Allaqi watersheds have lower values. The higher the infiltration number values (FN), the higher surface runoff and consequently the lower will be the infiltration in the study basins and sub-basins.

3.1.3.6. Form Factor Ratio (Fr)

The form factor effects on basins hydrogeology and provides a measure of relationship between catchment length and catchment area. The high (Fr) value (be greater than 0.78) reflects circular watershed with high peak flows of shorter duration [9]. Smaller form factor value, the basin will be more elongated. The form factor values for sub-basins of W. Gabgaba vary from 0.175 (W. Tawai sub-basin) to 0.633 (W. Shiqrib sub-basin) with an average of 0.328 Table 1 while (Fr) values ranged between 0.158 (W. Murra sub-basin) and 0.375 (W. Eigat-Nassari sub-basin) with an average of 0.279 at sub-basins of W. Allaqi Table 2. The low values of (Fr) for both basins and their sub-basins indicate near elongated in their shapes with flow for longer duration.

3.1.3.7. Length of Overland Flow (Lo)

The length of overland flow of Wadi Gabgaba watershed is 2.71 while in its sub-basins ranged between 2.38 and 2.86 Table 1. The outer water divides of most Wadi Gabgaba sub-basins characterized by presence of high relief and steep slope. At Wadi Allaqi basin, (Lo) value is 2.62 and in its sub-basins ranged between 2.39 and 2.77 Table 2. High values of (Lo) at Wadi Allaqi basin are detected in sub-basins which are characterized by presence of high relief and steep slope at their outer water divides which represent part from the outer major basin extreme as W. Eigat-Nassari, W. Elei-Husheim W. Oga-Salowit, W. Difeit sub-basins. Low values of (Lo) observed in sub-basins as W. Nuqayt-Um Domi, W. Duwaylah, and W. Ungat which are associated with relatively moderate slope and low relief. Generally sub-basins from the two major basins (Wadi Gabgaba and Wadi Allaqi) that have low values of length of overland flow (as Bab As-Subu, W. Abaraga, W. Edeit-Terfawi, W. Nuqayt-Um Domi, W. Duwaylah, and W. Ungat sub-basins), indicate that the surface water is concentrated faster than the basins of high values (as W. Hatab, W. Tawai, W. Bahr Bela Ma, W. Idirbib, W. Difeit, W. Um Araka-Quleib, W. Abu Fas, W Um Ashira, W. Seiga-Rod El-Bil, W. Um Tor, and W. Oga-Salowit sub-basins).

3.1.4. Relief Characteristics

3.1.4.1. Total Basin Relief (Rf)

The discharge point (minimum elevation H_{min}), the remotest point (maximum elevation H_{max}), the mean elevation (Hm), and total basin relief are obtained from the available DEM Tables 1 & 2. Total Basin Relief (Rf) controls the stream channel gradient and therefore influences the sediment amounts that can be transported and flood patterns. The processing analysis results of the DEM of the whole Wadi Gabgaba basin show that basin relief varies greatly where the lowest relief is found to be 155 m above mean sea level (a.m.s.l.) and the highest relief is 998 m a.m.s.l Table 1. The same great relief variations are observed at whole Wadi Allaqi basin, where the lowest relief is found to be 153 m a.m.s.l. and the highest relief is 1763 m a.m.s.l Table 2. The eastern parts of Wadi Allaqi basin, near the Red Sea Hills as well as the northern parts characterizes by highest relief Figure 2. Both basin sides of Wadi Gabgaba have highest relief than others Figure 2. W. Duwaylah sub-basin has lowest total basin relief (292 m a.m.s.l.) and the highest (Rf) detected at W. Eigat-Nassari sub-basin (1434 m a.m.s.l.) form sub-basins of Wadi Allaqi. Lowest total basin relief for sub-basins of Wadi Gabgaba estimated at Tamamah sub-basin (283 m a.m.s.l.) and the highest (Rf) notes at W. Edeit-Terfawi sub-basin (692 m a.m.s.l.). At parts of great slopes with high stream gradients and relief (as W. Eigat-Nassari, W. Difeit, W. Elei-Husheim, W. Seiga-Rod EL-Bil, W. Edeit-Terfawi, W. Huwayt. And W. Idirbib sub-basins), the flood peak will be great and increase. Moreover, distribution of basins and sub-basins slopes also play major role in the discharge characteristics.

3.1.4.2. Relief Ratio (Rr)

The study shows low Relief ratio of 0.002 and 0.005 for Wadi Gabgaba and Wadi Allaqi watersheds respectively. While Wadi Gabgaba sub-basins have (Rr) ranged between 0.005 (W. Huwayt) and 0.0125 (W. Shiqrib, W. Idirbib, and W. Tawai) Table 1. Also Wadi Allaqi sub-basins have (Rr) values vary from 0.006 (W. Elei-Husheim and W. Oga-Salowit) to 0.013 (W. Eigat-Nassari) Table 2. In the present study, it has been observed that areas with low to moderate relief and slope are characterized by low value of relief ratios and the relatively moderate to high values of relief ratio can be explained by the presence of highly resistant rocks (which covered more parts along the study basins and sub-basins), high relief, and steep slope especially at the water divide of the basins as detected in W. Eigat-Nassari, W. Ungat, W. Nuqayt-Um Domi, W. Shiqrib, W. Tawai, and W. Idirbib sub-basins. Relief of study basins and sub-basins controls the rate of conversion of potential to kinetic energy of water draining through the basins and the runoff is generally faster in steeper basins, producing greater erosion process and more peaked basin discharges. The relation between relief ratio (Rr) and the area of given drainage basins (W. Gabgaba and W. Allaqi) and their sub-basins (28 sub-basins) are studied Figure 11. It gives an inverse relationship, where relief ratio values increase with decreasing the areas of the study basins and sub-basins.

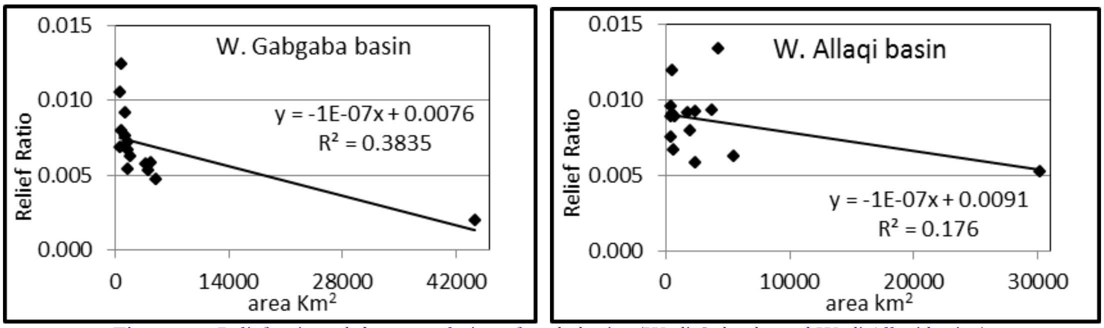

Figure-11. Relief ratio and the area relation of study basins (Wadi Gabgaba and Wadi Allaqi basins).

3.1.4.3. Mean Basin Slope (Sm)

Slope maps for the study basins and their sub-basins were created from ASTER DEM by using Surface Analysis Tool in ArcGIS-10.5 Figures. 12 & 13. Tables 1 & 2 show the mean basin slope values. The highest (Sm) at Wadi Gabgaba basin observed at Bab As-Subu sub-basin (11.65°) and lowest (Sm) recorded at W. Shiqrib sub-basin (2.8°) with average of 5.23°.

While Wadi Allaqi basin, (Sm) values vary from (4.95°) at W Um Ashira sub-basin to (8.99°) at W. Eigat-Nassari sub-basin with average of 6.59°. Slope plays a major role in estimating flood hazardous, stream network generation and runoff. Whereas, water flows along the direction of great slope.

In gentle slope basins, the velocity of overland flow will be low and it takes more time for water to infiltrate thereby reducing the amount surface runoff reaching the stream as in W Um Ashira, Tamamah, W. Dobi Balat, W. Tawai, W. Kuwah-Hidiglib, and W. Shiqrib sub-basins. A steep slope increases stream flow velocity and allows faster removal of the runoff from the watershed, thereby reduces time of concentration and causes erosion as in W. Eigat-Nassari, W. Haimur, W. Oga-Salowit, W. Seiga-Rod El-Bil, W. Elei-Husheim, Bab As-Subu, W. Edeit-Terfawi, W. Abaraga, W. Huwayt, and W. Idirbib sub-basins. From the slope-area histogram Figure. 12 it noticed that at Wadi Gabgaba basin, 28.5% from basin area is less than 2 °, whereas 43.3%, 17.4%, 5.2%, 2.6%, 2.8%, and 0.03% from basin area are up to-5 °, -10 °, -15 °, -20 °, -40 °, and more than 40 ° respectively. The slope as observed from the histogram for Wadi Allaqi basin Figure. 13 17.3%, 37.1%, 24.6%, 10.4%, 5.6%, 4.9%, and 0.04% from basin area are up to-2 °, -5 °, -10 °, -15 °, -20 °, -40 °, and more than 40 ° respectively. The wide variations between the values of mean slope are due to the variation of the lithology and the topography of the basins and sub-basins.

3.1.4.4. Ruggedness Number (Rμ)

Ruggedness number found to be varying between 1.24 and 2.295 at Wadi Gabgaba and Wadi Allaqi basins respectively Tables 1 & 2. For sub-basins of Wadi Gabgaba, Rμ ranged between 0.402 (Tamamah) and 0.982 (W. Edeit-Terfawi) with an average of 0.774. While for sub-basins of Wadi Allaqi, it ranged between 0.414 (W. Duwaylah) and 2.02 (W. Eigat-Nassari) with an average of 0.919. Values of the ruggedness number in the study watersheds are affected by drainage density and variables relief. Extensively high value of (Rμ) occurs for regions of high relief with high stream density (as W. Eigat-Nassari, W. Difeit, W. Seiga-Rod EL-Bil, W. Elei-Husheim, W. Um Araka-Quleib, W. Haimur, W. Edeit-Terfawi, W. Huwayt, and W. Idirbib sub-basins) indicates structural complexity of a terrain highly susceptible to erosion. The low (Rμ) values of sub-basins indicate that the soil along basins can be eroded easily in association with relief and drainage density (as Bab As-Subu, W. Dayyub, Tamamah, W. Ungat, W. Um Tor, and W. Duwaylah sub-basins).

3.1.4.5. Basin Flow Direction (BFD)

Along study main basins (W. Gabgaba and W. Allaqi), the flow directions were determined using ArcView and Arc-Hydro tools. The estimated main direction of the study basins is matching with the direction of the main channel Figurers. 14 & 15. The main direction of Wadi Gabgaba basin flow is north to northwest which drains from northern Sudan into Khore Allaqi, Nasser Lake, Southern Egypt. For Wadi Allaqi basin, main direction flow is northwest which drains from Red Sea Hills and drains also into Khore Allaqi, Nasser Lake.

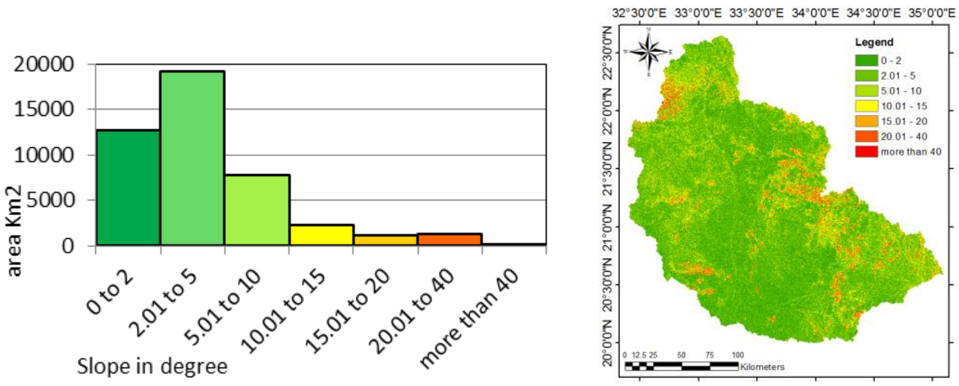

Figure-12. Slope map and histogram of Wadi Gabgaba and its sub-basins.

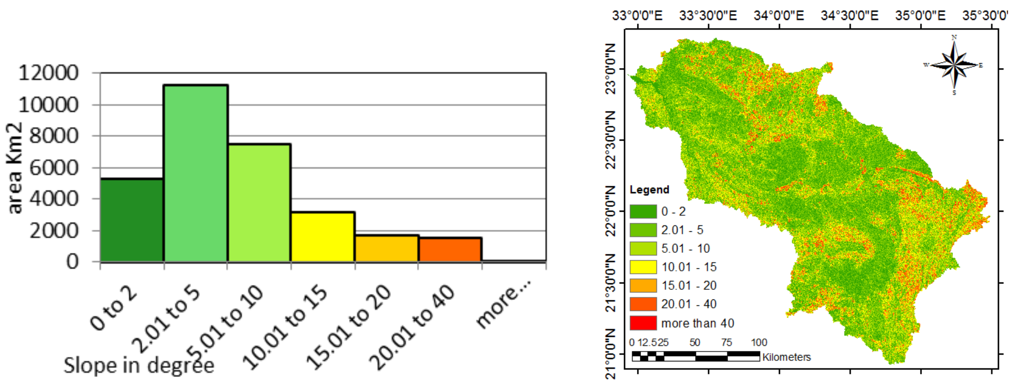

Figure-13. Slope map and histogram of Wadi Allaqi and its sub-basins.

3.1.4.6. Hypsometric Integral (HI)

Singh, et al. [16] classified the main landscape development stages for different basins and sub-basins. The basins with HI values below 0.3 were classified as old or Monadnock basins, whereas basins with HI values above 0.6 were classified as young basins. Finally, mature stage basins have HI values greater than 0.3 and lower than 0.6. Wadi Gabgaba and Wadi Allaqi basins have hypsometric integral ranged between 0.305 and 0.196 respectively.

The HI values for sub-basins of Wadi Gabgaba vary from 0.111 (W. Shiqrib) to 0.506 (Tamamah), while HI values for Wadi Allaqi sub-basins ranged between 0.201 (W. Seiga-Rod El-Bil) and 0.423 (W. Duwaylah) Tables 1 & 2.

According to the Hypsometric Integral (HI) values, the study basins can be classified into three groups:

- Old or Monadnock basins have low hypsometric integral values (below 0.3) indicate that these basins are eroded and dissected drainage basins (as W. Haimur, W Um Ashira, W. Murra, W. Elei-Husheim, W. Um Araka-Quleib, W. Nuqayt-Um Domi, W. Eigat-Nassari, W. Difeit, W. Seiga-Rod EL-Bil, W. Abaraga, W. Dobi Balat, W. Huwayt, W. Idirbib, W. Kuwah-Hidiglib, and W. Shiqrib sub-basins).
- Mature stage basins have intermediate values of HI from 0.3 to 0.6 (as W. Duwaylah, W. Ungat, W. Oga-Salowit, W. Abu Fas, W. Um Tor, Tamamah, W. Hatab, W. Bahr Bela Ma, W. Tawai, W. Dayyub, Bab As-Subu, W. Tawil, W. Edeit -Terfawi sub-basins).
- Young basins that have high values of hypsometric integral values (above 0.6) not recorded in the study basins and sub-basins.

3.1.4.7. Dissection Index (DI)

Dissection index values show the degree of erosion in any watershed. The Dissection index of Wadi Gabgaba watershed is 0.845, and in its sub-basins ranged between 0.607 (Tamamah sub-basins) and 0.727 (W. Edeit-Terfawi sub-basin) Table 1. The other study basin (Wadi Allaqi), the calculated (DI) is 0.913 and in its sub-basins ranged between 0.543 (W. Um Tor sub-basin) and 0.813 (W. Eigat-Nassari sub-basin) Table 2. The dissection index values of the study basins reflect moderate to nearly high dissected. The values of (DI) ranged between zero and 1.0. If Di equal 0.0 that mean presence of flat surface (no erosion happened) while Di value equal 1.0 at seashore or vertical escarpment [9].

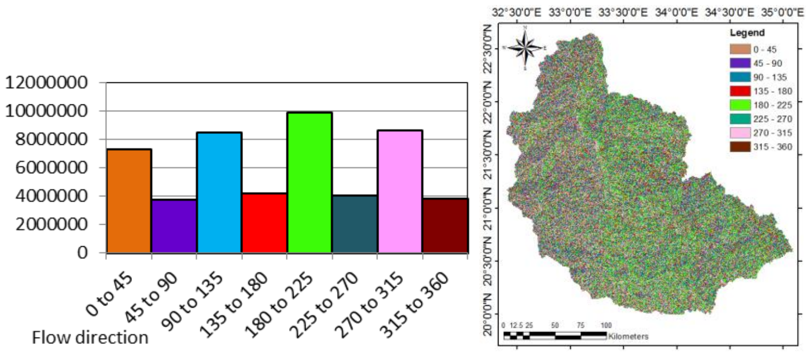

Figure-14. Flow Direction map and histogram of Wadi Gabgaba and its sub-basins.

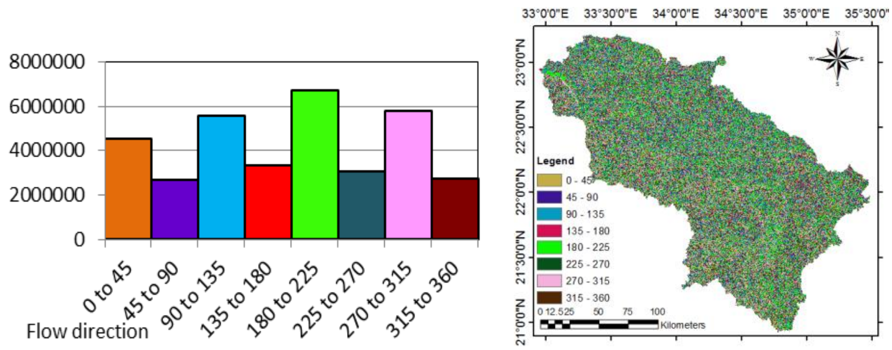

Figure-15. Flow Direction map and histogram of Wadi Allaqi and its sub-basins.

3.2. Correlation Coefficient Analysis of Morphometric Variables

Correlation coefficient analysis (r) between the morphometric variables are evaluated with the help of statistical analysis in Wadi Gabgaba and Wadi Allaqi basins and sub-basins for obtain the basins characteristics. Which helps in mapping the hydrological potentiality of the basins and also helps in preparing a comprehensive plan for sustainable management of the watershed. A correlation matrix Table 3 is generated for Wadi Gabgaba and Wadi Allaqi basins through 21 morphometric parameters. From the correlation matrix can conclude that:

1. Most of morphometric parameters show positive correlation which means that they are dependent on each other's.
2. Strong positive correlation (r greater than 0.99) exists between A, Nμ, and Lμ. As well as it noticed at relations between CL & Pr, CL & Lb, Re & Ish, Re & Fr, Dt & Rt, Ish & Fr, D & Lo, and Rf & Rμ.
3. Direct relations and high positive correlation coefficients with (r) values greater than 0.95 found at relations between Nμ with CL, Pr, W, Dt, and Rt; between Lμ with CL, Pr, W, Dt, and Rt; between CL with A, Dt, and Rt; between A with W, Pr, Dt, and Rt; between Pr with Lb, W, Dt, and Rt; between W with Dt, and Rt; and finally between F with FN Table 3.
4. Weak positive correlation (r less than 0.1) exists between morphometric parameters as detected at relations between D with Rf, Lμ, CL, A, and Pr; between F with Lμ, A, and Pr; between Lo with Rf, Lμ, CL, A, and Pr; and between FN with Nμ, Lμ, CL, A, Rf and Pr which means these parameters are not completely correlated with other parameters and is influenced partially by many terrestrial factors.
5. Rr, Sm, Rc, Re, and Ish show a negative correlation with most of other morphometric parameters suggesting that they are independent and conceivable to effective by various factors.

3.3. Determination of Relative Flood Hazard Degrees

To assess the degree of hazard due to flooding of the study basins (W. Gabgaba and W. Allaqi basins), the studied morphometric parameters of all drainage sub-basins has been taken into consideration. Nine morphometric parameters having a direct effect on flooding, and their relationship with the flash flood analysed Tables 4 and 5. All parameters in the study basins have direct relationship with the hazard except the (*WMRb*), which shows an inverse proportion. The scale number for the hazard degree starting with (1) lowest to (5) highest, has been given to the all parameters at the study basins using Davis' formula [17] as Equation 3.

$$\text{relative hazard degree} = \frac{(Ymax - Ymin)(X` - Xmin)}{(Xmax - Xmin)} + Ymin \qquad (3)$$

Where X′ is the estimated value of any parameter between higher and lower values, X*max* and X*min* are the higher and lower estimated values of any parameter, Y*max* and Y*min* are upper and lower limits of the scale (start from 5 to 1 degree).

The equation no. (3) can be written by apply the values of Y*max* and Y*min as* Equation 4.

$$\text{relative hazard degree} = \frac{4(X` - Xmin)}{(Xmax - Xmin)} + 1 \qquad (4)$$

The hazard degree calculated using the Equation 5 for the weighted mean bifurcation ratio (WMRb) because it shows an inverse proportion:

$$\text{relative hazard degree} = \frac{4(X` - Xmax)}{(Xmin - Xmax)} + 1 \qquad (5)$$

Therefore, the drainage basins can be classified according to the estimated degree of hazards into weakly hazardous (the courses of Wadis have hazard degree (HD) of 1), slightly hazardous (HD of 2), moderately hazardous (HD of 3), highly hazardous (HD of 4), and Extreme highly hazardous (HD of 5).

Table-1. The estimated morphometric parameters of Wadi Gabgaba and its sub-basins.

	serial	Paramet.	unit	Sub-basin of Wadi Gabgaba														Total wadi Gabgaba
				Tamamah	W. Dayyub	Bab As-Subu	Bahr Bela Ma	W. Hatab	W. Tawil	W. Abaraga	W. Edeit - Terfawi	W. Tawai	W. Dobi Balat	W. Kuwah - Hidiglib	W. Shiqrib	W. Idirbib	W. Huwayt	
1- Drainage network	1	$S\mu$	---	5	6	5	6	6	7	6	7	6	8	6	6	7	7	8
	2	$N\mu$	---	1183	1627	1199	2892	3325	7096	2299	8110	2750	3129	2533	1663	7783	9309	81470
	3	$L\mu_{Min}$	Km	0.0307	0.0307	0.0307	0.0307	0.0287	0.0286	0.0287	0.0289	0.031	0.011	0.029	0.028	0.0285	0.029	0.0285
	4	$L\mu_{Max}$	Km	4.311	4.486	4.739	6.722	5.556	5.655	5.097	6.351	7.211	7.996	4.189	4.711	6.842	6.548	9.426
	5	$L\mu$	Km	885.7	1228	934.4	2595	2982.8	5644.9	1811.7	6252.9	2497.3	2407.3	1900.8	1283.1	5981.3	7324.6	65393
	6	L_{sm}	Km	0.705	0.684	0.751	0.821	0.815	0.731	0.746	0.744	0.842	0.676	0.662	0.671	0.673	0.722	0.721
	7	R_L	---	0.916	0.931	0.976	0.923	0.927	0.998	0.995	1.016	0.925	0.930	0.932	0.925	0.890	0.971	0.974
	8	R_{bm}	---	1.868	2.006	1.928	1.772	2.030	2.066	1.914	2.139	1.730	5.208	1.898	2.268	49.37	2.027	2.056
	9	WMRb	---	2.06	1.96	1.75	1.59	2.02	1.61	1.62	1.53	1.49	1.80	1.64	1.55	1.79	2.03	1.68
	10	CL	Km	53.7	65.7	70.7	100.8	113.2	162.4	107.3	196.2	127.8	92.4	85.7	53.4	189.3	223.6	611.2
	11	Si	---	1.295	1.369	1.529	1.424	1.360	1.673	1.410	1.664	1.351	1.345	1.295	1.439	1.523	1.590	1.408
	12	ρ	---	0.589	0.580	0.598	0.567	0.782	0.488	0.526	0.510	0.588	0.491	0.501	0.451	0.534	0.836	0.602
2- Basin Geometry	13	A	Km^2	624.2	873.6	685.7	1640.6	1862	3869	1268	4406	1564	1662	1321	871.5	4095	5054	44321
	14	Pr	Km	159.2	211.7	176.2	287.83	287.3	481.8	295.7	509.8	345.5	272.8	273.7	187.6	499.6	610.5	1593
	15	LB	Km	41.47	47.98	46.23	70.78	83.26	97.1	76.1	117.9	94.6	68.7	66.2	34.6	124.3	140.6	434.2
	16	W	Km	15.05	18.21	14.83	23.18	22.36	39.85	16.66	37.37	16.53	24.19	19.95	23.49	32.94	35.95	102.08
	17	Rc	---	0.309	0.245	0.277	0.249	0.283	0.209	0.182	0.213	0.165	0.280	0.221	0.311	0.206	0.170	0.219
	18	Re	Km	0.680	0.695	0.639	0.646	0.585	0.723	0.528	0.635	0.472	0.670	0.620	0.898	0.581	0.571	0.547
	19	Dt	km^{-1}	7.431	7.685	6.805	10.048	11.573	14.728	7.775	15.908	7.959	11.470	9.255	8.865	15.578	15.248	51.142
	20	Rt	km^{-1}	3.725	3.859	3.417	5.038	5.799	7.391	3.906	7.993	3.988	5.762	4.655	4.462	7.832	7.658	25.674
	21	K	---	2.755	2.635	3.117	3.054	3.723	2.437	4.567	3.155	5.722	2.840	3.318	1.579	3.773	3.911	4.254
	22	Ish	---	0.461	0.482	0.407	0.416	0.341	0.521	0.278	0.403	0.222	0.447	0.383	0.804	0.337	0.325	0.299
	23	SH	km^{-1}	1.798	2.021	1.899	2.005	1.879	2.186	2.343	2.167	2.465	1.888	2.125	1.793	2.203	2.423	2.135
3- Drainage texture	24	(F)	km^{-2}	1.895	1.862	1.749	1.763	1.786	1.834	1.813	1.841	1.758	1.883	1.917	1.908	1.901	1.842	1.838
	25	(D)	km^{-1}	1.419	1.406	1.363	1.582	1.602	1.459	1.429	1.419	1.597	1.448	1.439	1.472	1.461	1.449	1.475
	26	(Di)	km^{-1}	1.336	1.325	1.283	1.114	1.115	1.257	1.269	1.297	1.101	1.300	1.333	1.296	1.301	1.271	1.246
	27	Lo	km^{-1}	0.709	0.703	0.681	0.791	0.801	0.730	0.714	0.710	0.798	0.724	0.719	0.736	0.730	0.725	0.738
	28	FN	km^{-3}	2.689	2.618	2.383	2.788	2.861	2.676	2.591	2.612	2.808	2.727	2.759	2.809	2.776	2.669	2.712
	29	Fr	---	0.363	0.379	0.321	0.327	0.269	0.410	0.219	0.317	0.175	0.352	0.301	0.633	0.265	0.256	0.235

	serial	Paramet.	unit	Sub-basin of Wadi Gabgaba														Total wadi Gabgaba
				Tamamah	W. Dayyub	Bab As-Subu	Bahr Bela Ma	W. Hatab	W. Tawil	W. Abaraga	W. Edeit - Terfawi	W. Tawai	W. Dobi Balat	W. Kuwah - Hidiglib	W. Shiqrib	W. Idirbib	W. Huwayt	
4- Relief Aspects	30	H_{max}	m	466	597	681	719	750	786	810	952	788	739	886	759	989	998	998
	31	H_{min}	m	183	213	195	210	228	226	231	260	275	279	277	297	332	334	155
	32	Rf	m	283	384	486	509	522	560	579	692	513	460	609	462	657	664	843
	33	Hm	m	326.3	365.1	382.4	458.7	487.6	402.4	398.1	471.8	489.4	403.9	354.4	348.5	482.6	506.2	412
	34	Rr	---	0.007	0.008	0.011	0.007	0.006	0.006	0.008	0.006	0.005	0.007	0.009	0.012	0.005	0.005	0.002
	35	Sm	degree	4.02	7.96	11.65	4.78	4.37	4.42	6.04	6.54	3.67	3.83	3.07	2.80	4.88	5.12	4.75
	36	Rμ	---	0.173	0.228	0.311	0.364	0.373	0.351	0.361	0.424	0.362	0.287	0.350	0.267	0.406	0.412	0.535
	37	HI	---	1.026	0.656	0.628	0.955	0.989	0.460	0.406	0.441	0.718	0.373	0.146	0.125	0.297	0.350	0.439
	38	DI	---	0.607	0.643	0.714	0.708	0.696	0.712	0.715	0.727	0.651	0.622	0.687	0.609	0.664	0.665	0.845
	39	E	m	120	180	190	300	290	225	180	230	240	155	75	60	220	240	260
	40	SI%	---	0.298	0.365	0.358	0.397	0.342	0.185	0.224	0.156	0.250	0.224	0.117	0.150	0.155	0.143	0.057

Table-2. The estimated morphometric parameters of Wadi Allaqi and its sub-basins.

	Serial	Paramet.	unit	Sub-basin of Wadi Allaqi														Total w Allaqi
				W Um Ashira	W. Um Araka--Quleib	W. Haimur	W. Eigat-Nassari	W. Elei-Husheim	W. Murra	W.Seiga-Rod EL-Bil	W. Difeit	W. Oga - Salowit	W. Um Tor	W. Abu Fas	W. Ungat	W. Nuqayt-Um Dawmi	W. Duwaylah	
1- Drainage network	1	Sμ	---	6	6	6	7	7	5	6	6	6	5	5	5	6	6	8
	2	Nμ	---	1488	3382	3571	7791	10001	1113	4473	7107	4514	818	909	805	1023	1076	55477
	3	$L\mu_{Min}$	Km	0.0307	0.0284	0.0282	0.0286	0.0287	0.0307	0.0285	.0285	0.0286	0.031	0.0286	0.0286	0.042	0.0286	0.0284
	4	$L\mu_{Max}$	Km	6.215	5.531	4.361	5.994	6.151	4.413	4.445	5.776	5.191	3.96	4.286	4.915	4.147	4.494	9.461
	5	Lμ	Km	1156	2574	2782	6054.8	7777.8	833.5	3402	5496	3486	628.9	703.8	623.4	798.3	874.1	43012
	6	L_{sm}	Km	0.740	0.697	0.743	0.748	0.733	0.713	0.704	0.697	0.740	0.737	0.747	0.747	0.735	0.749	0.693
	7	R_L	---	0.977	0.942	0.961	0.810	0.804	0.917	0.951	0.925	0.964	0.942	0.987	0.932	0.954	0.968	0.953
	8	R_{bm}	---	1.990	1.790	1.871	1.944	1.904	1.883	1.948	2.004	1.888	1.801	1.696	1.753	1.787	1.890	2.250
	9	WMRb	---	1.91	1.66	1.49	1.58	1.59	2.33	1.49	1.63	1.61	1.45	1.54	1.55	1.58	1.80	1.81
	10	CL	Km	63.5	124.6	135.3	162.8	193.7	79.3	122.5	146.4	136.7	66.7	65.2	50.3	59.7	55.4	443.2
	11	Si	---	1.228	1.583	1.534	1.52	1.461	1.289	1.273	1.458	1.402	1.347	1.399	1.236	1.439	1.268	1.434
	12	ρ	---	0.697	0.556	0.530	0.507	0.516	0.808	0.539	0.511	0.530	0.540	0.718	0.653	0.561	0.681	0.651
2- Basin Geometry	13	A	Km^2	802.9	1790	1971	4298.8	5472	596.7	2394	3753	2449	442.6	488.3	449.3	583.6	616.8	30179
	14	Pr	Km	197.4	308.8	321.5	506.9	499.4	207.8	348.3	469.6	378.1	169.9	192.5	157.2	170.5	163.8	1385
	15	LB	Km	51.7	78.7	88.2	165.2	132.6	61.5	96.2	100.4	97.5	49.5	46.6	40.7	41.5	43.7	309.1
	16	W	Km	15.53	22.74	22.35	40.14	41.27	9.70	24.89	37.38	25.12	8.94	10.48	11.04	14.06	14.11	97.64
	17	Rc	---	0.259	0.236	0.240	0.210	0.276	0.174	0.248	0.214	0.215	0.193	0.166	0.228	0.252	0.289	0.198
	18	Re	Km	0.619	0.607	0.568	0.691	0.630	0.448	0.574	0.689	0.573	0.480	0.535	0.588	0.657	0.641	0.634
	19	Dt	km^{-1}	7.538	10.952	11.107	15.370	20.026	5.356	12.842	15.134	11.939	4.815	4.722	5.121	6.000	6.569	40.056
	20	Rt	km^{-1}	3.779	5.499	5.580	7.716	10.052	2.695	6.443	7.594	5.990	2.431	2.379	2.583	3.015	3.309	20.111
	21	K	---	3.329	3.460	3.947	2.668	3.213	6.339	3.866	2.686	3.882	5.536	4.447	3.687	2.951	3.096	3.166
	22	Ish	---	0.381	0.367	0.322	0.476	0.395	0.20	0.329	0.473	0.327	0.229	0.286	0.344	0.430	0.410	0.401
	23	SH	km^{-1}	1.966	2.059	2.043	2.181	1.905	2.403	2.009	2.163	2.156	2.279	2.458	2.093	1.991	1.861	2.250
3- Drainage texture	24	(F)	km^{-2}	1.853	1.889	1.812	1.812	1.828	1.865	1.868	1.894	1.843	1.848	1.862	1.792	1.753	1.744	1.838
	25	(D)	km^{-1}	1.440	1.438	1.411	1.408	1.421	1.397	1.421	1.464	1.423	1.421	1.441	1.387	1.368	1.417	1.425
	26	(Di)	km^{-1}	1.287	1.314	1.284	1.287	1.286	1.335	1.315	1.293	1.295	1.301	1.292	1.291	1.281	1.231	1.290
	27	Lo	km^{-1}	0.720	0.719	0.706	0.704	0.711	0.698	0.711	0.732	0.712	0.710	0.721	0.694	0.684	0.709	0.713
	28	FN	km^{-3}	2.668	2.717	2.557	2.553	2.598	2.605	2.655	2.773	2.624	2.626	2.683	2.486	2.398	2.472	2.620

	Serial	Paramet.	unit	Sub-basin of Wadi Allaqi														Total w Allaqi
				W Um Ashira	W. Um Araka--Quleib	W. Haimur	W. Eigat-Nassari	W. Elei-Husheim	W. Murra	W.Seiga-Rod EL-Bil	W. Difeit	W. Oga - Salowit	W. Um Tor	W. Abu Fas	W. Ungat	W. Nuqayt-Um Dawmi	W. Duwaylah	
	29	Fr	---	0.300	0.289	0.253	0.375	0.311	0.158	0.259	0.372	0.258	0.181	0.225	0.271	0.339	0.323	0.316
4- Relief Aspects	30	H_{max}	m	635	894	883	1763	1161	806	1141	1230	879	689	681	615	734	507	1763
	31	H_{min}	m	176	172	179	329	333	247	256	294	314	315	267	225	239	215	153
	32	Rf	m	459	722	704	1434	828	559	885	936	565	374	414	390	495	292	1610
	33	Hm	m	304.3	366	390.1	668.7	559.5	402.5	433.6	491.7	508.7	431.8	406.5	363.5	360.1	338.4	468.1
	34	Rr	---	0.009	0.009	0.008	0.013	0.006	0.009	0.009	0.009	0.006	0.008	0.009	0.010	0.012	0.007	0.005
	35	Sm	degree	4.95	6.07	7.56	8.99	6.61	7.53	6.86	5.29	7.22	5.01	6.05	6.58	7.24	6.31	6.67
	36	Rμ	---	0.661	1.038	0.994	2.020	1.177	0.781	1.258	1.371	0.804	0.531	0.597	0.541	0.677	0.414	2.295
	37	HI	---	0.388	0.367	0.428	0.310	0.377	0.385	0.251	0.268	0.526	0.454	0.508	0.551	0.324	0.732	0.243
	38	DI	---	0.723	0.808	0.797	0.813	0.713	0.694	0.776	0.761	0.643	0.543	0.608	0.634	0.674	0.576	0.913
	39	(E)	m	225	305	285	375	225	165	225	270	235	195	135	135	155	140	315
	40	SI%	---	0.472	0.326	0.281	0.307	0.155	0.277	0.245	0.246	0.229	0.390	0.276	0.358	0.346	0.337	0.095

According to this scale, the calculated hazard degrees in Wadi Gabgaba sub-basins Table 4 show that there are three groups:

1- Slightly hazardous, characterise Tamamah and Bab As-Subu sub-basins.
2- Moderately hazardous, 11 sub-basins represent in this scale (W. Dayyub, W. Bahr Bela Ma, W. Hatab, W. Tawil, W. Abaraga, W. Edeit-Terfawi, W. Tawai, W. Dobi Balat, W. Kuwah-Hidiglib, W. Idirbib, and W. Huwayt sub-basins).
3- Highly hazardous, only one basin belongs to this scale is W. Shiqrib sub-basin.

The calculated hazard degrees at Wadi Allaqi Table 5 it can group the sub-basins based on the previous classification into three categories:

1- Slightly hazardous, two sub-basins represent in this scale (W. Murra and W. Duwaylah sub-basins).
2- Moderately hazardous, 10 sub-basins represent in this scale (W Um Ashira, W. Um Araka-Quleib, W. Haimur, W. Elei-Husheim, W. Seiga-Rod El-Bil, W. Oga-Salowit, W. Um Tor, W. Abu Fas, W. Ungat, W. Nuqayt-Um Domi sub-basins).
3- Highly hazardous, only two sub-basins belong to this scale are W. Eigat-Nassari and W. Difeit.

Table-3. Correlation matrix of morphometric parameters for Wadi Allaqi and Wadi Gabgaba.

Variables	Nμ	Lμ	A	Pr	LB	Rc	Re	Dt	Rt	Ish	(F)	(D)	Lo	FN	Fr	Rf	Rr	Sm	Rμ
Nμ	1.000																		
Lμ	0.998	1.00																	
A	0.998	0.998	1.00																
Pr	0.972	0.97	0.97	1.00															
LB	0.922	0.93	0.93	0.95	1.00														
Rc	-0.21	-0.21	-0.21	-0.37	-0.37	1.00													
Re	0.122	0.11	0.12	0.02	-0.09	0.64	1.00												
Dt	0.961	0.96	0.96	0.91	0.87	0.001	0.25	1.00											
Rt	0.961	0.96	0.96	0.91	0.87	-0.001	0.25	0.998	1.00										
Ish	0.086	0.08	0.08	-0.01	-0.12	0.62	0.99	0.20	0.20	1.00									
(F)	0.169	0.14	0.15	0.15	0.06	-0.04	0.20	0.22	0.22	0.23	1.00								
(D)	0.092	0.14	0.10	0.17	0.16	-0.05	-0.06	0.15	0.15	-0.04	-0.13	1.00							
Lo	0.097	0.15	0.10	0.18	0.16	-0.05	-0.06	0.16	0.15	-0.04	-0.13	0.99	1.00						
FN	0.187	0.21	0.18	0.24	0.17	-0.06	0.08	0.27	0.27	0.12	0.50	0.79	0.79	1.00					
Fr	0.085	0.08	0.08	-0.01	-0.12	0.62	0.99	0.20	0.20	0.998	0.23	-0.04	-0.04	0.11	1.00				
Rf	0.682	0.67	0.68	0.69	0.81	-0.23	0.07	0.68	0.68	0.05	0.12	-0.06	-0.05	0.03	0.05	1.00			
Rr	-0.38	-0.41	-0.39	-0.43	-0.33	0.20	0.35	-0.36	-0.36	0.37	-0.01	-0.46	-0.47	-0.41	0.37	0.24	1.00		
Sm	-0.01	-0.02	0.01	-0.03	0.09	-0.04	-0.15	-0.05	-0.05	-0.18	-0.41	-0.60	-0.60	-0.78	-0.18	0.28	0.38	1.00	
Rμ	0.413	0.40	0.42	0.39	0.54	-0.15	-0.04	0.42	0.42	-0.06	0.05	-0.23	-0.22	-0.16	-0.06	0.86	0.39	0.40	1.00

Table-4. Hazards degree (HD) of Wadi Gabgaba sub-basins in the present study.

W. Gabgaba sub-basins	A	D	F	Ish	SI	Rr	Rμ	Rt	WMRb	sum of HD	Relative HD
Tamamah	1.00	1.94	4.47	2.64	3.59	2.09	1.00	1.27	1.00	18.00	2.25
W. Dayyub	1.23	1.72	3.70	2.79	4.55	2.70	1.95	1.39	1.71	20.50	2.56
Bab As-Subu	1.06	1.00	1.00	2.27	4.45	4.00	2.80	1.00	3.16	19.68	2.46
W. Bahr Bela Ma	1.92	4.66	1.34	2.33	5.00	2.28	3.78	2.42	4.33	26.13	3.27
W. Hatab	2.12	5.00	1.88	1.82	4.21	1.80	3.99	3.08	1.27	23.06	2.88
W. Tawil	3.93	2.61	3.02	3.06	1.97	1.54	3.86	4.47	4.20	24.74	3.09
W. Abaraga	1.58	2.11	2.53	1.39	2.53	2.49	3.93	1.43	4.08	20.48	2.56
W. Edeit-Terfawi	4.41	1.94	3.18	2.24	1.57	1.59	5.00	5.00	4.73	25.25	3.16
W. Tawai	1.85	4.91	1.23	1.00	2.91	1.36	3.88	1.50	5.00	21.79	2.72
W. Dobi Balat	1.94	2.43	4.18	2.55	2.53	2.02	2.82	3.05	2.82	22.40	2.80
W. Kuwah-Hidiglib	1.63	2.27	5.00	2.11	1.00	3.32	4.27	2.08	3.93	23.98	3.00
W. Shiqrib	1.22	2.83	4.78	5.00	1.47	5.00	2.92	1.91	4.62	28.54	3.57
W. Idirbib	4.13	2.64	4.60	1.79	1.55	1.29	4.85	4.86	2.89	24.46	3.06
W. Huwayt	5.00	2.45	3.21	1.71	1.38	1.00	4.86	4.71	1.21	20.52	2.57

Table-5. Hazards degree (HD) of Wadi Allaqi sub-basins in the present study.

Wadi Allaqi sub-basins	A	D	F	Ish	SI	Rr	Rμ	Rt	WMRb	sum of HD	Relative HD
W Um Ashira	1.287	3.979	3.917	3.629	5.000	2.624	1.615	1.704	2.892	25.360	3.170
W. Um Araka-Quleib	2.072	3.905	4.885	3.419	3.158	2.780	2.555	2.626	4.042	27.369	3.421
W. Haimur	2.216	2.806	2.804	2.762	2.590	2.152	2.444	2.669	4.810	23.036	2.880
W. Eigat-Nassari	4.067	2.682	2.820	5.000	2.918	5.000	5.000	3.782	4.412	31.614	3.952
W. Elei-Husheim	5.000	3.216	3.230	3.828	1.000	1.237	2.901	5.000	4.343	24.755	3.094
W. Murra	1.123	2.200	4.238	1.000	2.539	2.735	1.914	1.165	1.000	16.791	2.099
W. Seiga-Rod El-Bil	2.552	3.203	4.323	2.860	2.136	2.793	3.102	3.118	4.813	26.348	3.293
W. Difeit	3.633	5.000	5.000	4.955	2.148	2.858	3.383	3.718	4.183	31.245	3.906
W. Oga-Salowit	2.596	3.302	3.647	2.841	1.934	1.000	1.972	2.883	4.264	21.841	2.730
W. Um Tor	1.000	3.197	3.780	1.422	3.965	1.927	1.293	1.027	5.000	21.611	2.701
W. Abu Fas	1.036	4.043	4.139	2.237	2.527	2.627	1.456	1.000	4.580	22.608	2.826
W. Ungat	1.005	1.812	2.265	3.092	3.562	2.995	1.317	1.106	4.506	20.654	2.582
W. Nuqayt-Um Domi	1.112	1.000	1.226	4.338	3.410	4.230	1.656	1.331	4.409	21.600	2.700
W. Duwaylah	1.139	3.041	1.000	4.045	3.297	1.467	1.000	1.485	3.387	18.722	2.340

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