Watershed delineation and morphometric analysis using remote sensing and GIS mapping techniques in Qena-Safaga-Bir Queh, Central Eastern Desert

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The development of drainage basins to raise aquifer potentiality is considering the major target in Qena-Safaga-Bir Queh (Central Eastern Desert). It is attributed to drought, scarce groundwater resource, expansion of agriculture, growth population, infrastructures, and civilization. Geological, hydrogeological, and morphometric information is used to prepare the drainage development plan and strategy. The morphometric parameters were used to evaluate the hydraulic conductivity of the surficial lithology. The aquifer recharge rate was established according to permeability ranking of the surface geology. DEM, ETM+8, geologic map, and SPSS were used to characterize the hydrological parameters and delineate the watershed. Ten drainage basins were extracted and characterize for the morphometric analysis. The digital geological distribution, of each basin, was determined from geological and remote sensing data. The morphometric parameters (drainage density, constant channel maintenance, length of overland flow, drainage frequency, and drainage texture ratio) indicate the basins related to medium surface rock permeability (weight score 7-12). Multivariate statistical techniques were investigated using 17 morphometric descriptors (variables). The dendrogram analysis (R-mode) was divided into two cluster, which was subdivided into four groups. BirQueh basin is independent basin due to highest drainage area and perimeter. There is great hydrological similarity between sub basin 9 and 10 (wadi Qena). Wadi Safaga is hydrologically similar to sub basin 3, followed by sub basin 4. The principle component analysis contains four factors and represented by 74% of the total variance in the data. It identifies the promising areas in local scale, so that development and agriculture are easier.

Key words: Drainage basins, morphometric parameters, SPSS, central Eastern desert.

INTRODUCTION

The dramatic population increase around River Nile stresses on groundwater and surface water. The groundwater is the alternative water resources, but over exploitation leads to decline in groundwater level, quantity, and quality. The drainage basin investigation identifies the aquifer recharge conditions. The seepage
water relies on geology (hydraulic conductivity). The expose lithology in Qena-Safaga-BirQueh (central Eastern Desert) is mainly covered by hard rocks, which is characterized by low–medium hydraulic conductivity (Figure 1). Elevation, geomorphology, hydrology, geology and hydrogeology represent the main parameters in watershed planning and development. Morphometric parameters estimation reflects the hydrologic nature, hydrogeological conditions of the aquifer, and flood rate. The accurate parameters determination is complex in situ, especially throughout large basins. Instead, GIS and RS application determines the accurate parameters over large areas, compares the geological and hydrogeological parameters, and identifies the best promising areas for aquifer recharge. Digital Elevation Model (DEM) is used to determine the hydrological parameters. The implementation of watershed management is essential to achieve sustainable uses of land and water resources to mitigate the increasing demand (Javed et al., 2009; Rai et al., 2017; Prakash et al., 2019). Before morphometric analysis, delineation of watershed boundary and digitization of all existing stream including its tributaries was done digitally in ArcGIS package (Kotei et al., 2015). Many hydrological features and morphometric behaviors of watershed are established (Magesh et al., 2013; Rastogi and Sharma 1976). GIS and remote sensing with morphometric analysis is most effective, time saving and accurate technique for watershed characterization, planning and management implementation (Benukanth et al., 2019). Management of groundwater, basin and environment is established from morphometric analysis (Magesh et al., 2013). Morphometric and hydrogeological values characterize the groundwater recharge, aquifer aiming, and water collecting (Ewen et al., 2010).
Morphometric application adds water resources for future planning and infrastructures. The drainage basin is distinguished by geological features. Assessment of hydrologic behavior of the drainage basins can evaluate the aquifer recharge potentiality. The Qena-Safaga-Bir Queh areas (central part of Eastern Desert) (Figure 1) is arid region. The study area is new agricultural projects in the desert, which attract the dwellers from the highly populated River Nile areas. The aquifers include crystalline, Nubian, limestone and sandstone, and alluvial (Abdel, 2004). The crystalline aquifer covers the mountains. The Nubian confined aquifer needs much more exploration and exploitation. It is composed of sands and sandstone with intercalated clay and shale. The average water depth and total dissolved solids (TDS) of the aquifers (Gomaa et al., 2013) are illustrated in Figure 2 at Safaga-El Quseir area. The aim of the current paper is to accomplish the numerical correlation between morphometric investigation and hydrogeological data to assess hydraulic conductivity of exposed lithology and aquifer recharge areas.

**RESULTS AND DISCUSSION**

**Drainage basins extraction**

**Red sea basin group**

Wadi Queh is the largest drainage basin (1263 km²) (Figure 4a). The trunk stream flows generally west-east and structurally; it is caused by adhering to Queh shear zone (Badawy, 2008). Wadi Safaga is structurally control (Figure 4b), while Abu Shiqayli has area of 110 km² and the trunk channel is 23.4 km in length (Figure 5a). Wadi El Barud flows from west mountainous to east Red Sea with general lineaments of WNW-ESE and NE-SW (Figure 5b). Gasus basin was area of 142 km² and was the 5th order (Figure 6a).

**Nile basin group (Wadi Qena, sub basins 3, 4, 5, 9, and 10)**

Wadi iQena is one of the longest wadis in the Eastern Desert. It gathers rainfalls and joins to form main stream (270 km course). The wadi extends from north to south with an east–west average width of 40 km. Gheith and Sultan (2002) estimated the probable groundwater recharge rate of Wadi Qena as 49×10⁶ m³. Wadi Qena is subdivided into five sub basins 3, 4, 5, 9, and 10 (Figures 6b to 8). Sub basins 3, 4, and 10 have the 6th order, while sub basins 5 and 9 have the 5th order.
Figure 3. Flow chart for drainage basin extraction.

Table 1. Drainage basin area, length, perimeter, stream number, and bifurcation ratio.

| S/N | Basin   | Drainage Basin area (A; km²) | Basin length (BL; km) | Basin perimeter (P, km) | Number of streams (Nu) of different stream order (u) | Bifurcation ratio Rb (Nu/Nu+1) |
|-----|---------|-------------------------------|------------------------|-------------------------|-----------------------------------------------------|--------------------------------|
| 1   | Bir Queh| 1263.03                       | 71.5                   | 85.75                   | 3375 718 170 33 8 1                                   | 4297 4.70 4.22 5.15 4.125 8 4.42 |
| 2   | Safaga  | 526.94                        | 48.4                   | 78.92                   | 1410 294 72 19 4 1                                   | 1796 4.80 4.08 3.79 4.75 4 3.33 |
| 3   | Sub Basin 3 | 442.28           | 35.8                   | 76.99                   | 1234 264 57 12 4 1                                   | 1568 4.67 4.63 4.75 3 4 3.61 |
| 4   | Sub Basin 4 | 164.50           | 19.5                   | 74.25                   | 478 93 20 6 1 1                                     | 598 5.14 4.65 3.33 6 1 2.82 |
| 5   | Sub Basin 5 | 160.75           | 22.6                   | 62.63                   | 459 97 22 5 1                                     | 583 4.73 4.41 4.40 5 4.55 |
| 6   | Gasus   | 142.07                        | 26.4                   | 64.08                   | 408 86 21 5 1                                     | 520 4.74 4.10 4.20 5 4.55 |
| 7   | El Barud| 134.72                        | 30.7                   | 65.95                   | 386 80 18 3 1                                     | 487 4.83 4.44 6.00 3 4.35 |
| 8   | Sub Basin 9  | 110.29           | 23.4                   | 42.73                   | 320 75 18 5 2 1                                   | 419 4.27 4.17 3.60 2.5 2 2.81 |
| 9   | Abu Shaqayli | 109.41           | 23.4                   | 38.40                   | 316 66 16 5 1                                     | 403 4.79 4.13 3.20 5 4.78 |
| 10  | Sub Basin 10 | 103.14           | 23.4                   | 36.52                   | 277 66 17 5 1                                     | 366 4.20 3.88 3.40 5 1 2.50 |
|     | Average  | 315.71                        | 32.51                   | 62.6211                 | 866.3 183.9 43.1 9.8 2.4 0.6 1104                 |                                |
Table 2. Selected hydrological parameters weights. No. 1: Basin No. 1 was in Table 1

| Bifurcation ratio | Controlling factor of drainage pattern | 1st order | 2nd order | 3rd order | 4th order | 5th order |
|-------------------|----------------------------------------|-----------|-----------|-----------|-----------|-----------|
| Rb Range          | < 3                                    | Natural   |           |           |           |           |
|                   | 3–5                                    | Geomorphic|           |           |           |           |
|                   | > 5                                    | Structural|           |           |           |           |

| Stream Length (Lu) | Nature of stream | Range | Average | Surface rock-permeability | Run-off | Infiltration rate | Basin | Weight |
|--------------------|------------------|-------|---------|---------------------------|---------|------------------|-------|--------|
| Larger number of shorter stream length | Low | High | Low | 1st, 2nd, and 3rd orders | 1 |
| Medium number of medium stream length | Medium | Medium | Medium | 4th order | 2 |
| Smaller number of longer stream length | High | Low | High | 5th and 6th orders | 3 |

| Drainage density (Dd) km/km² | Range | Average | Surface rock-permeability | Run-off | Infiltration rate | Basin | Weight |
|------------------------------|-------|---------|---------------------------|---------|------------------|-------|--------|
| < 1.5                        | Low   | High   | Low | 1st, 2nd, and 3rd orders | 1 |
| 1.5–2.5                      | Medium | Medium | Medium | No. 1-7 and 9-10 | 2 |
| > 2.5                        | High  | Low    | High | No. 8 | 1 |

| Constant channel maintenance, C (km²/km) | Range | Average | Surface rock-permeability | Run-off | Infiltration rate | Basin | Weight |
|------------------------------------------|-------|---------|---------------------------|---------|------------------|-------|--------|
| < 0.3                                    | Low   | Steep  | Low | 1st, 2nd, and 3rd orders | 1 |
| 0.3-0.5                                  | Medium | Moderate | Medium | No. 1-10 | 2 |
| > 0.5                                    | High  | Gentle | High | No. 8 | 1 |

| Length of overland flow (Lg) (km²/km) | Range | Average | Surface rock-permeability | Run-off | Infiltration rate | Basin | Weight |
|---------------------------------------|-------|---------|---------------------------|---------|------------------|-------|--------|
| < 0.2                                 | Ground slope and flow-path | High | Low | 1 |
| 0.2-0.25                              | Moderate slope and moderate flow-path | Medium | Medium | No. 1-10 | 2 |
| > 0.25                                | Gentle slope and long flow-path | Low | High | 3 |

| Stream frequency (Fs) (per km²) | Range | Average | Surface rock-permeability | Run-off | Infiltration rate | Basin | Weight |
|--------------------------------|-------|---------|---------------------------|---------|------------------|-------|--------|
| < 2                            | Gentle slope and high permeable | Low    | High | 3 |
| 2–3                            | Moderate slope and medium permeable | Medium | Medium | 2 |
Table 2. Selected hydrological parameters weights. No. 1: Basin No. 1 was in Table 1

| Drainage texture (T) (per km) | > 3 | 4.31 | Steep slope and low permeable | High | Low | No. 1-10 |
|-----------------------------|-----|------|-------------------------------|------|-----|----------|
| Range                       | Average | Surface rock permeability | Infiltration rate |      |     | No. 1-10 |
| < 4                         | 1.71 | High | High                          |      |     | 3        |
| 4-10                        | 6.94 | Medium | Medium                       |      |     | 2        |
| > 10                        | 16.43 | Low | Low                           |      |     | 1        |

Table 3. Stream number and stream length ratio.

| Basin No. | Drainage Basin | Total stream lengths Lu (km) in different u | Average Lu (km) in different u (Lu/Nu) | Stream length ratio RI (Lu/Lu-1) |
|-----------|----------------|---------------------------------------------|----------------------------------------|----------------------------------|
|           |                | 1   | 2   | 3   | 4   | 5   | 6   | ∑ Lu | 1  | 2   | 3   | 4   | 5   | 6   | 2/1 | 3/2 | 4/3 | 5/4 | 6/5 |
|           |                |     |     |     |     |     |     |      | 1   | 2   | 3   | 4   | 5   | 6   |     |     |     |     |     |
| 1         | Bir Queh       | 1621 | 733 | 381 | 171 | 82  | 72  | 3060 | 0.48| 1.02| 2.24| 5.18| 10.25| 72  | 2.13| 1.12| 2.31| 1.98| 7.02|
| 2         | Safaga         | 667  | 291 | 147.5| 74  | 27  | 47.5| 1254 | 0.47| 0.99| 2.05| 3.89| 6.75  | 47.5| 2.09| 2.08| 1.90| 1.73| 7.04|
| 3         | Sub Basin 3    | 565  | 245 | 120 | 72  | 39  | 15  | 1056 | 0.46| 0.93| 2.11| 6.00| 9.75  | 15  | 2.03| 2.06| 2.85| 1.63| 1.54|
| 4         | Sub Basin 4    | 215  | 101 | 53  | 23  | 6.6 | 12  | 410.6| 0.45| 1.09| 2.65| 3.83| 6.6   | 12  | 2.41| 2.68| 1.45| 1.72| 1.82|
| 5         | Sub Basin 5    | 201  | 106 | 44  | 23  | 20  |     | 394  | 0.44| 1.09| 2.00| 4.60| 20    |     | 2.50| 2.16| 2.30| 4.35|     |
| 6         | Gasus          | 179  | 87  | 37  | 19  | 21  |     | 343  | 0.44| 1.01| 1.76| 3.80| 21    |     | 2.31| 1.62| 2.16| 5.53|     |
| 7         | El Barud       | 183  | 79  | 38  | 19  | 15  |     | 334  | 0.47| 0.99| 2.11| 6.33| 15    |     | 2.08| 1.93| 3.00| 2.37|     |
| 8         | Abu Shaqayli   | 150  | 66  | 32  | 16  | 4.6 | 17  | 285.6| 0.47| 0.88| 1.78| 3.20| 2.3   | 17  | 1.88| 1.76| 1.80| 0.72| 7.39|
| 9         | Sub Basin 9    | 134  | 65  | 23  | 16  | 19  |     | 257  | 0.42| 0.98| 1.44| 3.20| 19    |     | 2.32| 1.46| 2.23| 5.94|     |
| 10        | Sub Basin 10   | 126  | 52  | 34  | 18  | 4   | 6   | 240  | 0.45| 0.79| 2.00| 3.60| 4     | 6   | 1.73| 2.27| 1.80| 1.11| 1.50|
| Average   |               | 404.10| 182.50| 90.95| 45.10| 23.82| 16.95| 763.40| 0.46| 0.98| 2.01| 4.36| 11.47 | 16.95| 2.15| 1.91| 2.18| 2.71| 2.63|

**Geology**

The investigated area is composed of crystalline and sedimentary rocks (Figure 1). The Precambrian basement complex (crystalline rocks) runs parallel to the Red Sea graben and consisted essentially of metamorphic and igneous rocks (Said, 1962, 1990; El- Ramly, 1972). The Lower Cretaceous (Nubian sandstone) is composed of sandstone, shale and clay. It overlies the basement complex and overlain by the impervious shaley layer (Upper Cretaceous). The Post-Nubian is differentiated into carbonate, Neogene and alluvial deposits. The supervised classification of the geological map was accomplished (Figure 1). The fraction percent of each lithology in the study area and in each drainage basin was estimated and discussed. The older granite and gabbroic rocks are the highest concentration in Qena-Safaga-Bir Queh area, followed by ophiolitic serpentinite, Nubian sandstone, and Dokhan volcanic, while the lowest is chalky limestone (Figure 9a) Bir Queh basin is the longest lineaments lengths (652 km); followed by Safaga (352 km), whereas the shortest is Abu Shiqayli (44 km) (Figure 9b). Wadi Queh is covered mainly by meta-volcanic followed by felsite and older granite/or gabbroic with sandstone and crystalline carbonate due coast (Figure 10a). Chalky limestone mountains (Gebel Duwei) were in the
Table 4. Hydrological parameters of the basins.

| Basin   | Drainage density, Dd: | Constant of channel, C: | Length of overland, Lg: | Stream frequency, Fs: | Drainage texture, T: |
|---------|-----------------------|-------------------------|-------------------------|----------------------|---------------------|
| S/N     | ΣLu/A (km²/km²)       | maintenance, C:         | flow, Lg:               | ΣNu/A (per km²)      | Nu/P                |
|         | 1/Dd (km²²/km)        | 1/2Dd (km²²/km)         |                         |                      |                     |
| 1       | Bir Queh              | 2.42                    | 0.41                    | 0.21                 | 3.41                | 17.94               |
| 2       | Safaga                | 2.4                     | 0.41                    | 0.21                 | 3.42                | 12.5                |
| 3       | Sub Basin 3           | 2.4                     | 0.42                    | 0.21                 | 3.6                 | 11.4                |
| 4       | Sub Basin 4           | 2.5                     | 0.4                     | 0.21                 | 3.7                 | 10                  |
| 5       | Sub Basin 5           | 2.4                     | 0.4                     | 0.21                 | 3.6                 | 6.8                 |
| 6       | Gasus                 | 2.4                     | 0.4                     | 0.21                 | 4.7                 | 8.4                 |
| 7       | El Barud              | 2.5                     | 0.4                     | 0.2                  | 3.6                 | 6.3                 |
| 8       | Abu Shaqayli          | 2.55                    | 0.4                     | 0.2                  | 3.8                 | 5.7                 |
| 9       | Sub Basin 9           | 2.3                     | 0.43                    | 0.22                 | 3.71                | 6.4                 |
| 10      | Sub Basin 10          | 2.3                     | 0.43                    | 0.22                 | 3.6                 | 5.7                 |
| Average |                       | 2.417                   | 0.41                    | 0.21                 | 3.714               | 9.114               |

| Basin   | Circularity ratio, Rc: | Elongation ratio, Re: | Relief ratio (RR): | Slope average (SA): |
|---------|------------------------|-----------------------|--------------------|---------------------|
| S/N     | 4πA/P²                 | (2/BL).A/m²⁵           | Diff. elevation/BL | BL/ basin relief (H) |
| 1       | Bir Queh               | 0.28                  | 0.56               | 0.01517             | 66.4                |
| 2       | Safaga                 | 0.32                  | 0.54               | 0.02225             | 45                  |
| 3       | Sub Basin 3            | 0.29                  | 0.66               | 0.0301              | 33.2                |
| 4       | Sub Basin 4            | 0.58                  | 0.74               | 0.0552              | 18.1                |
| 5       | Sub Basin 5            | 0.27                  | 0.63               | 0.0477              | 21                  |
| 6       | Gasus                  | 0.29                  | 0.51               | 0.0408              | 24.5                |
| 7       | El Barud               | 0.29                  | 0.43               | 0.0351              | 28.5                |
| 8       | Abu Shaqayli           | 0.25                  | 0.51               | 0.046               | 21.7                |
| 9       | Sub Basin 9            | 0.34                  | 0.54               | 0.049               | 20.4                |
| 10      | Sub Basin 10           | 0.32                  | 0.75               | 0.0704              | 14.2                |
| Average |                        | 0.323                 | 0.587              | 0.041172            | 29.3                |

The drainage density (Dd) ranged from 0 to 4.8 km²/km² (Figure 4b). The highest LD (2.4-4.8 km²/km²) and lowest Dd (0.154 km²/km²) of the previous geology represent the best promising areas for groundwater storage (Figure 4b).

Table 4. Hydrological parameters of the basins.

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Southeastern part. The undifferentiated meta-volcanic, meta-volcanic, and ophiolitic serpentines were characterized by the highest lineaments density (LD) (Figure 4a). The drainage density (Dd) ranged from 0-1.83 km²/km² (Figure 4a). The lowest Dd (0-0.91) and highest LD (0.91-1.8 km²/km²) areas are considered the best promising zones for aquifer recharge. The main exposed rocks of wadiSaftaga are older granite/or gabbroic, meta-volcanic undifferentiated, meta-gabbro, and meta-diorite, nearly in equal concentration (Figure 4b). It contains low concentration of sandstone through Red Sea coast and patches of chalky limestone. The Dd varied from 18-494 km²/km², while the LD ranged from 0-4.8 km²/km² (Figure 4b). The highest LD (2.4-4.8 km²/km²) and lowest Dd (0-154 km²/km²) of the previous geology represent the best promising areas for groundwater storage (Figure 4b).

Abu Shaqayli, El Barud, and Gasus have low LD compared to Bir Queh and Saftaga (Figures 5 to 6b). Abu Shaqayli contains high concentration of undifferentiated Quaternary and Nubian sandstone deposits due west and meta-volcanic in the east (Figure 10c). The main exposed rocks in El Barud basin are older granite; gabbroic, followed by undifferentiated Quaternary deposits with low areas covered by sandstone and felsite in the coast (Figure 10d). WadiGasus is represented mainly by older granite/or gabbroic, while the Dokhan volcanic and felsite are in equal proportions (Figure 10c). It includes low concentration of crystalline carbonate and sandstone in the coast. Sub basin 3 (Wadi Qena) mainly was exposed by Nubian sandstone, followed by Quaternary and meta-volcanic deposits in equal concentrations (Figure 11a). The Dd ranged from 27-496 km²/km², whereas the LD varied from 0.2-4 km²/km² (Figure 6b). The Dd (27-231 km²/km²) and LD (1.2-2.4 km²/km²) were chosen for good hydrogeological conditions. Sub basin 4 is mainly composed of Quaternary, sandstone with clay stone, and Nile silt in nearly equal proportion in the western part, while the hammamatlastic was in the eastern part (Figure 11b). The geological conditions with Dd (28-211
Figure 4. Extracted of Bir Queh (a) and Safaga (b) basins.

Figure 5. Extracted of Abu Shiqayli (a) and El Barud (b) basins.
southeastern part. The undifferentiated meta-volcanic, meta-volcanic, and ophiolitic serpentines were characterized by the highest lineaments density (LD) (Figure 4a). The drainage density (Dd) ranged from 0.183 km/km² (Figure 4a). The lowest Dd (0.091) and highest LD (0.91-1.8 km/km²) and LD (1.8-3.6 km/km²) were the best aquifer recharge areas (Figure 6b). Sub basin 5 includes mainly Quaternary deposits and low concentration of older granite/or gabbroic (Figure 11c). The best promising geology is the Quaternary deposits with Dd (44-226 km/km²) and LD (1.7-3.4 km/km²) (Figure 7b). Sub basin 9 contains felsite, meta-volcanic, and Quaternary sediments (Figure 11d). Meta-volcanic and felsite sediments with Dd (57-218 km/km²) and LD (1.7-3.5) were chosen to locate the best aquifer recharge (Figure 8a). Sub basin 10 is represented by older granite/or gabbroic and meta-volcanic (Figure 11e). The Dd (40-234.4 km/km²) and LD (1.6-3.2 km/km²) were the good hydrogeological conditions in the previous geology (Figure 8b). The centroid of drainage areas as centers of gravity, the length of the longest flow path in a selected set of drainage areas (e.g. any polygon feature class), and main flow path are computed in Figure 12a. The Basin length function allows generating a cost path line from the inlet point to the outlet point of a basin (Figure 12b-c) traveling through a cost surface that has minimum values toward the center and maximum values at the boundary.

**Morphometric parameters**

**Stream number (Nu) and order (u)**

The comparison of drainage networks geometry is carried out by stream order (Strahler 1952). The Gasus, El Barud, and Wadi iQena (sub basin 5 and 9) have the 5th order, while the rest basins have the 6th order (Table 1). The discharge rate increases in latter basins than those in the former basins. The higher order streams are less permeable and infiltration than those in lower orders (Gajbhiye et al., 2015).

The total number of streams (ΣNu) varies from 366 (sub basin 10) to 4297 (Bir Queh basin) (Table 1). The change in order and length of streams is due to slope gradient (Figure 13), geomorphology, and tectonic impact. The basin lengths are subdivided into two categories, the first is 22.6 – 30.7 km, while the second is 35.8 to 71.5 km (Table 1). These parameters were governed by the physiographic difference and structural condition of the watershed (Nikhil Raj and Azeez, 2012; Biswas, 2016). The consistent decrease in N, against u (Figure 14a) revealed the presence of erosional landform throughout the watershed (Avijit, 2019).

**Bifurcation ratio (Rb)**

High Rb shows high overland flow while low Rb reflects high infiltration rate and fewer channels (Thomas et al., 2012). If Rb is 3-5, the geological structures play a minor role, while if Rb is > 5; it is structurally control (Strahler 1957). The average value of Rb of all the basins is <5, confirming geomorphological control. However, Bir Queh (5th order), sub basin 4 (1st and 4th orders), sub basin 5 (4th order), sub basin 9 (4th order), and sub basin 10 (4th order), Gasus (4th order), and El Barud (3rd order) have Rb greater than 5; it indicates structural control (Table 2).

**Stream length (Lu) and basin area (A)**

The basin area and perimeter increase from sub basin 10 (103 km², 36.5 km) to BirQueh (1263 km², 85.7 km) (Table 1). The total stream length of ten basins is 7626 km from 10128 of the study area. The total stream length (ΣLu) is minimum in sub basin 10 (240 km) and maximum in Bir Queh (3060 km) (Table 3). The maximum average of Lu (404.1 km) was first order, while the minimum average was sixth order (Table 3). The average Lu decreases from 4th order (45 km) toward 5th (24 km) and 6th (17 km) orders (Table 3). The difference in Lu for first-sixth orders attributed to variation in relief over which the streams occur (Raju et al., 1995). On the other hand, a smaller number of relatively longer stream lengths are observed in the 5th and 6th order streams than those in the 1st, 2nd, and 3rd orders streams. Therefore, the lithology underlain by 5th and 6th orders are high hydraulic conductivity, with higher infiltration than the rock formations drained under the 1st, 2nd, and 3rd orders streams, which are associated with low hydraulic conductivity and medium seepage (Table 2). The average Lu/Nu ranges from 0.5 for 1st order to 16.9 for 6th order (Table 3). The inverse relationship was obvious between average Lu and stream order (Figure 14b), which satisfy Horton (1945)'s. Stream lengths increase with the stream number (Figure 14c). The largest drainage area (Da) was Wadi Queh (1263 km²), while the lowest was Wadi Qena (sub basin 10) (103 km²). Basin area directly affects the peak and average runoff magnitudes. If the drainage basin size is small, the rainfall reaches the main channel more rapidly than those in larger basin. Sub basin 9 and 10 of Wadi Qena were the most dangerous for flooding, because of the lowest drainage area.

**Stream length ratio (RI)**

It represents the relative permeability of the geology and relationship with the surface flow discharge (Al-Saady et al., 2016). The mean RI of 5th and 6th orders are the highest (2.6-2.7) through the rest orders (Table 3), reflect gentle slope and high hydraulic conductivity than those in lower orders.
Figure 6. Extracted of Gasus (a) and sub basin 3 (b).

Figure 7. Extracted of sub basins 4 and 5.
**Drainage density (Dd)**

It relates to structure, lithology, geomorphology, and topography. The Dd ranges from 2.3-2.55 km/km² (Table 4), which are convergent values due to similar geology (mainly hard rocks). It indicates the underlying geology is permeable (Dd< 5) (Smith, 1950; Strahler, 1957). Most of the drainage basins (Table 2) have moderately permeable strata, with medium run-off and infiltration. Abu Shiqayli (drainage no. 8) has Dd of 2.55 km/km², which include low permeability strata, with more run off and less infiltration.

**Length of overland flow (Lg)**

Lg describes the length of flow of water over the ground before it becomes concentrated in incised stream channels or permanent drainage channels (Prasad 2008). It ranges from 0.2 to 0.22 km (convergent values). The ten basins fall between 0.20 and 0.25 km²/km of moderate ground slopes, where the flow-paths, run-off and infiltration are moderate (Table 2).

**Constant of channel maintenance, C**

It determines the minimum limiting area required for developing a drainage channel. It ranged from 0.4 to 0.43 (convergent values), with average 0.41 km² that is required to support each linear kilometer of stream channels. Sub basins 3, 9, and 10 (Qena) have C values higher than 0.41 km², reflect large area required to maintain 1 km stream channel. Sub basins 4, 5 (Qena), Gasus, El Barud, and Abu Shiqayli have lower C than 0.41 km². Both cases fall within the range of 0.30 to 0.50 of C values, which clarify moderate hydraulic conductivity (Table 2).

**Stream frequency (Fs)**

It is influenced by hydraulic conductivity, seepage rate, and topography (Rekha et al. 2011). The Fs is convergent (3.41-3.8 streams/km²), excluding wadiGasus (4.7 streams per km²) with average 3.714 km². This indicates the development of about three streams in an area of 1 km² in the basin. The high Fs values (>3 per km²) are observed in all basins, indicating the occurrence of steep ground slopes, with lower permeability rocks, which facilitates greater run-off and less infiltration (Table 2).
Figure 9. Geological percentage (a) and lineaments lengths of the study area (b).
According to the El-Shamy (1992)'s model, flash flood hazard maps of sub-basins have been produced by comparing the hazard degree resulting from bifurcation ratio versus drainage frequency and bifurcation ration versus drainage density (Figure 15). Al-Saady et al. (2016) classified the study area based on El-Shamy zones. The basin No. 1, 2, 6, 8, and 9 occupy moderate risk, while No. 10 was in high risk, and the rest were in low risk (Figure 15).

**Drainage texture ratio \((T)\)**

The drainage texture \((T)\) is a measure of closeness of the channel spacing, depending on lithology, infiltration capability and relief features of a particular terrain (Gutema et al., 2017). It is very coarse (< 2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (> 8) Smith (1950). The ratio ranges between 5.7 km for Wadi Qena (sub basin 10) and 17.9 km for Wadi Queh and the mean
Figure 11. Geological distribution in sub basins 3, 4, 5, 9, and 10 (wadi Qena).

The texture ratio of the whole basins is about 9.1 km. The drainage basins nos. 8 (Abu Shakyli) and Wadi Qena (sub basin 10) are medium. Fine textures include Wadi Qena (sub basin 5), El Barud, and Wadi Qena (sub basin 9), while Wadi Queh, Safaga, Qena, Wadi Qena (sub basin 4), and Gasus are very fine textures (Table 4). Table 2 clarifies basins no. 1-3 are low infiltration, while the rest are medium.

Circularity ratio (Rc)

It expresses the drainage basin shape. It equals to 1 when the basin shape is perfect circle, decreases to 0.79 when the basin is a square, and continues to decrease to the extent to which the basin becomes elongated (Zavoianu, 1985). The value of Rc for the basins, ranges from 0.29 to 0.58 (Table 4); it is attributable to the
Figure 12. main flow path and basin lengths.

Figure 13. Slope map of the study area.
Figure 14. Average stream order vs Nu (a), Lu (b), and Lu vs Nu (c).
differences in the geomorphological features. The average value of $R_c$ is 0.32, which is less than one. This clearly indicates that the mega basin is not circular in shape.

**Elongation ratio ($R_e$)**

Strahler (1964) states the ratio ranges between 0.6 and 1.0 for a wide variety of climatic and geologic types. $R_e$ is circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5) (Pareta and Pareta, 2012). Elliptical basins are El Barud (0.43), while the rest are elongate to less (0.51-0.75). The infiltration rate was increased in El Barud basin rather than the rest basins. The elongate to less elongate basins cover mainly the Precambrian (basement) and chalky limestone rocks.

**Slope average ($S_A$)**

Leakage and runoff relationship was estimated by slope; the slope should analyze in any region. Infiltration capacity is inversely related to the slope (Avijit, 2019). It ranges between 14.2 for Wadi iQena (sub basin 10) and 66.4 for Wadi Queh. The total slope average of the whole basins is about 29.3 (Table 4). The slope plays an

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**Figure 15.** Bifurcation ratio ($R_b$) vs $F_s$ and $D_d$. 

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A: Low risk; B: Moderate risk; and C: High risk

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The bifurcation ratio ($R_b$) vs $F_s$ and $D_d$.
**Table 5.** Classification of drainage basins.

| Basin No. | Basin name    | Dd | C  | Lg  | Fs | T  | Total weight score |
|-----------|---------------|----|----|-----|----|----|--------------------|
| 1         | Bir Queh      | 2  | 2  | 2   | 1  | 1  | 8                  |
| 2         | Safaga        | 2  | 2  | 2   | 1  | 1  | 8                  |
| 3         | Sub Basin 3   | 2  | 2  | 2   | 1  | 1  | 8                  |
| 4         | Sub Basin 4   | 2  | 2  | 2   | 1  | 2  | 9                  |
| 5         | Sub Basin 5   | 2  | 2  | 2   | 1  | 2  | 9                  |
| 6         | Gasus         | 2  | 2  | 2   | 1  | 2  | 9                  |
| 7         | El Barud      | 2  | 2  | 2   | 1  | 2  | 9                  |
| 8         | Abu Shaqayli  | 2  | 2  | 2   | 1  | 2  | 9                  |
| 9         | Sub Basin 9   | 2  | 2  | 2   | 1  | 2  | 9                  |
| 10        | Sub Basin 10  | 1  | 2  | 2   | 1  | 2  | 8                  |

1: low permeable zone, 2: medium permeable zone, 3: high permeable zone

**Classification rules**

| Range of total weight score | Classification of numerical scheme in respect (Subba 2009) of surface rock-permeability |
|-----------------------------|----------------------------------------------------------------------------------------|
| < 6                         | Low surface rock-permeability zone                                                      |
| 7 to 12                     | Medium surface rock-permeability zone                                                   |
| > 13                        | High surface rock-permeability zone                                                     |

Important role for estimating flood hazardous where steep slopes could lead to severe flash floods (Patton and Baker, 1976).

**Relief ratio (RR)**

It is a dimensionless ratio that measures the overall steepness of a drainage basin and indicates the intensity of erosion processes operating on slopes of the basin (Strahler, 1964). As said by Schumm (1956) and determined by Ajaykumar et al. (2019), the correlation between hydrological characteristics and the relief aspects is accomplished. The relief ratio ranges between 0.0301 for Wad iQena (sub basin 3) to 0.07 for Wad iQena (sub basin 10). Great similarity is deduced owing to homogeneity of climatic conditions, rock formations, and geologic structure. According to Table 5, all the basins belong to medium surface rock permeability (weight score 7-12).

**Multivariate statistical analyses**

The descriptive investigation of hydrological parameter is tabulated in Table 6. The Slope average strongly correlated with texture ratio, shape index, stream number, basin area, basin perimeter, and basin length (Table 6). It indicates the impact of basin length, area, and perimeter. The basin area strongly correlated with relief ratio, slope average, shape index, total stream length, and stream number, while moderately correlated with basin ratio (Table 6). The mountainous areas (hard rocks) contributed to this significance correlation. The bifurcation ratio moderately correlated with total stream length, stream number, basin area, basin perimeter, and basin length (Table 6). The rock resistance types, topography, and geology contributed partially in bifurcation ratio. The constant channel maintenance, circularity ratio, and drainage frequency have no correlation with hydrological parameters; reflect independents of these parameters. The regression application between basin areas in X-axis and slope average, basin length, total stream length, and basin length in Y-axis are illustrated in Figure 16. They have direct proportional regression relations with basin areas. The dendrogram analysis (hydrological similarity among basins), based on 17 hydrological parameters, divided into two clusters (cluster I and II) (Figure 17a). Cluster I subdivided into two groups, group A include circularity ratio, relief ratio, basin elongation, basin frequency, length of overland flow, and constant channel maintenance. It clarifies the impact of relief ratio, basin frequency, and length of overland flow on the basin shape. Group B contains drainage density and drainage frequency, reflect the stream lengths and numbers have coincidence trend. The group C represents the perimeter and bifurcation ratio; indicate the outer boundary of the drainage basin impact on stream number in all orders. Group D characterize the rest hydrological parameters (Figure 17a). It is called geology group.

Three main clusters and one independent basin are identified by Q mode (Figure 17b). Cluster I has high similarity between the sub basin 9 and 10 (Qena). The
### Table 6. Descriptive statistics and correlation.

#### Descriptive statistics

| Code | Hydrological parameter     | N  | Minimum | Maximum | Mean  | Std. Deviation |
|------|-----------------------------|----|---------|---------|-------|----------------|
| Dd   | Drainage density           | 10 | 2.3     | 2.55    | 2.42  | 0.08           |
| RR   | Relief ratio               | 10 | 0.015   | 0.07    | 0.04  | 0.02           |
| SA   | Slope average              | 10 | 14.2    | 66.4    | 29.3  | 15.71          |
| T    | Texture ratio              | 10 | 5.7     | 17.94   | 9.11  | 3.94           |
| BF   | Basin form                 | 10 | 0.14    | 0.44    | 0.28  | 0.1            |
| Rb   | Bifurcation ratio          | 10 | 3       | 5.25    | 4.23  | 0.62           |
| Re   | Basin elongation           | 10 | 0.43    | 0.75    | 0.59  | 0.1            |
| CR   | Constant channel maintenance| 10 | 0.4     | 0.43    | 0.41  | 0.01           |
| Lg   | Length overland flow       | 10 | 0.2     | 0.22    | 0.21  | 0.01           |
| Fs   | Drainage frequency         | 10 | 3.41    | 4.7     | 3.71  | 0.37           |
| Rc   | Circularity ratio          | 10 | 0.25    | 0.58    | 0.32  | 0.09           |
| SI   | Shape index                | 10 | 5.6     | 22.6    | 10.5  | 5.44           |
| Lu   | Total stream length        | 10 | 240     | 3060    | 762.6 | 861.23         |
| Nu   | Stream number              | 10 | 367     | 4305    | 1106  | 1233.58        |
| A    | Basin area                 | 10 | 103.14  | 1263.03 | 315.71 | 364.81         |
| P    | Basin perimeter            | 10 | 36.524  | 85.748  | 62.62 | 17.7           |
| BL   | Basin length               | 10 | 19.5    | 71.5    | 32.51 | 16.13          |

#### Correlations

| Code | Hydrological parameter     | Dd | RR | SA | T  | BF | Rb | Re | CR | Lg | Fs | Rc | SI | Lu | Nu | A | P | BL |
|------|-----------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|----|
| Dd   | Drainage density           |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |    |
| RR   | Relief ratio               | -0.23 |    |    |    |    |    |    |    |    |    |    |    |    |   |   |    |
| SA   | Slope average              |    | -0.896 |    |    |    |    |    |    |    |    |    |    |    |   |   |    |
| T    | Texture ratio              |    |    | 0.908 |    |    |    |    |    |    |    |    |    |    |   |   |    |
| BF   | Basin form                 |    |    |    | -0.3 | 0.55 | -0.32 | 0.01 |    |    |    |    |    |    |   |   |    |
| Rb   | Bifurcation ratio          |    |    |    | -0.18 | -0.62 | 0.637 | 0.61 | -0.25 |    |    |    |    |    |   |   |    |
| Re   | Basin elongation           |    |    |    |    | -0.31 | 0.54 | -0.3 | 0.04 | 0.998 | -0.25 |    |    |    |   |   |    |
| CR   | Constant channel maintenance|    |    |    |    |    | -0.818 | 0.24 | -0.06 | -0.04 | 0.35 | -0.14 | 0.36 |    |   |   |    |
| Lg   | Length overland flow       |    |    |    |    |    |    | -0.918 | 0.39 | -0.17 | 0 | 0.54 | 0.06 | 0.56 | 0.802 |   |   |    |
| Fs   | Drainage frequency         |    |    |    |    |    |    |    | 0.02 | 0.21 | -0.36 | -0.3 | -0.22 | -0.07 | -0.22 | -0.29 | -0.04 |   |   |    |
| Rc   | Circularity ratio          |    |    |    |    |    |    |    |    | 0.13 | 0.34 | -0.27 | 0.06 | 0.55 | -0.09 | 0.54 | -0.07 | 0.21 | -0.05 |   |   |    |
| SI   | Shape index                |    |    |    |    |    |    |    |    |    | -0.07 | -0.659 | 0.851 | 0.951 | 0.2 | 0.52 | 0.22 | 0.12 | 0.1 | -0.46 | -0.01 |   |   |    |
| Lu   | Total stream length        |    |    |    |    |    |    |    |    |    |    | 0 | -0.765 | 0.959 | 0.943 | -0.09 | 0.6 | -0.07 | 0.03 | -0.02 | -0.4 | -0.17 | 0.937 |   |   |    |
| Nu   | Stream number              |    |    |    |    |    |    |    |    |    |    |    | 0.01 | -0.768 | 0.959 | 0.944 | -0.09 | 0.6 | -0.07 | 0.04 | -0.02 | -0.4 | -0.17 | 0.941 | 1 |   |   |
| A    | Basin area                 |    |    |    |    |    |    |    |    |    |    |    |    | -0.01 | -0.766 | 0.96 | 0.943 | -0.09 | 0.6 | -0.07 | 0.04 | -0.01 | -0.41 | -0.17 | 0.939 | 1 | 1 |    |
| P    | Basin perimeter            |    |    |    |    |    |    |    |    |    |    |    |    |    | 0.31 | -0.764 | 0.716 | 0.82 | -0.05 | 0.662 | -0.05 | -0.42 | -0.32 | -0.19 | 0.16 | 0.73 | 0.675 | 0.677 | 0.674 |   |   |    |
| BL   | Basin length               |    |    |    |    |    |    |    |    |    |    |    |    |    |    | -0.02 | -0.835 | 0.989 | 0.897 | -0.25 | 0.6 | -0.24 | 0.04 | -0.08 | -0.4 | -0.28 | 0.865 | 0.967 | 0.967 | 0.969 | 0.655 |   |   |    |
Figure 16. Basin area vs slope average, basin length, Lu, and P.

geological area distribution was more or less equal except chalky limestone (Tett), crystalline carbonate (Tms), and sandstone (Tpls); they have areal distribution in sub basin 10 higher than those in sub basin 9 (Figure 18a). Felsite (Vf) has area distribution in sub basin 9 higher than those in sub basin 9 (Figure 18a). Cluster II includes similarity among Gasus, sub basin 5, Abu Shiqayli, and El Barud basins. The main differences in geological area were chalky limestone (Tett), Nubian sandstone (Kut), and wadi deposits (Qw), while the rest areal geology was little difference fluctuation (Figure 18b). Cluster III contains high similarity between Safaga
and sub basin 3, followed by sub basin 4. The area geographical distribution was greatly differ except the undifferentiated Quaternary (Q) and wadi deposits (Qw), which are more or less equal distribution (Figure 18c). The independent basin was BirQueh, which has the highest basin area. The main basin area was hard rocks,
followed by wadi deposits, and the lowest area was Nubian sandstone (Turonian) (Figure 18d). The principle component analysis is differentiated into four factors with eigen value higher than 1 (Figure 19). The 1st factor includes slope average, texture ratio, shape index, total stream lengths, stream number, basin area, perimeter, and basin length, they have positively loading. It is the main association hydrological parameters (50% variance). These parameters influence hydrological and environmental design of the basins (Subyani et al., 2012).
Figure 19. Principle component analysis of hydrological parameters.

Factor 2 includes parameters derived from each other. Factor 3 has positive loading among basin frequency, basin elongation, and circularity ratio; it is the basin shape factor. The fourth factor has negative loading with
bifurcation ratio and drainage frequency; it indicates the stream number in each order.

**Conclusion**

The morphometric investigation was applied to calculate relief and areal aspects of ten sub basins. The study used RS (satellite images) and GIS techniques to be more precise and economic for drainage basin delineation and extraction. GIS of these basins are high accuracy. The digital based approach provide easier, more accurate, and more quantitative way to test morphometric features and to identify variations within large scale. It promotes the water resources management and future planning. The Qena-Safaga-Bir Queh is new project to increase the agricultural outcomes and move the dwellers outside the River Nile. The groundwater resources are very rare, infiltrating recharge water to reach the groundwater body depends on the surface rock-permeability. The latter is generally low, especially in the hard rock terrain, which represents most of the exposed rocks. Wadi Queh is the largest drainage basin followed by Safaga, Gasus; El Barud; and Abu Shaqayli. Wadi Queh covered mainly by meta-volcanic followed by felsite and older granite/or gabbroic. Abu Shaqayli contains Dokhan volcanic, Quaternary, and felsite deposits. The basin length differs from 19.5 km for Wad iQena (sub basin 4) to 71.5 km for Wadi Queh. Gasus basin and Wad iQena (sub basin 5) have the 5th order, while the rest basins have the 6th order. Elliptical basins are El Barud, while the rest are elongate to less. Basins occupy the moderate groundwater potential and probability for flooding except Wad iQena (sub basin 10). The Red Sea basins are fine to very fine texture. The Red Sea basins are elongate to less. The Red Sea basins are El Barud, while the rest are elongate to less. Basins occupy the moderate groundwater potential and probability for flooding except Wad iQena (sub basin 10). The Red Sea basins are fine to very fine texture. Eighteen categories (rock types) are identified by reflectance to construct the digital geological map.

**CONFLICT OF INTERESTS**

The author has not declared any conflict of interests.

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