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# Using morphometric analysis for delineating groundwater potential zones of wadi Qena basin, Eastern Desert, Egypt.

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**ABSTRACT**

This study is an attempt to use the morphometric analysis of the wadi Qena watershed to predict the groundwater potential zones in the basin. The drainage network was extracted from DEM with 30 m resolution. The valley was divided into 24 sub basins, and the morphometric analysis was performed on these basins using ARCGIS 10.3 version. The stream orders range from first to sixth, and the drainage patterns are dendritic to sub dendritic in the sedimentary rocks and parallel to trellis at the basement and hard rocks. The maps of drainage density, stream frequency, elongation ratio, Constant of Channel Maintenance, drainage texture, and length of overland flow have been prepared as a layer using ARCGIS software; each layer was reclassified into 3 classes in terms of their influence on infiltration and groundwater recharge. Then these layers were combined according to their weights using a raster calculator in ARCGIS software, finally, that groundwater potential map has been produced.

## 1.INTRODUCTION

Wadi Qena is considered one of the most promising valleys in the Eastern desert of Egypt for reclamation and development. Due to the scarcity of water resources in the valley and the high cost of traditional methods in searching of groundwater, using GIS and remote sensing data has become one of the most effective methods in the initial studies to detect potential groundwater zones in the arid basins. The study of the morphometric characteristics of the basins is of great importance, as they are related to the water resources of those basins. Morphometry is defined as the measurement and the mathematical assay of the configuration of the earth's surface, shape, and the dimension of its landforms [1]. In the present study, we used some of the morphometric parameters of the Wadi Qena watershed based on their relative influence on infiltration to prospect the groundwater potential zones of the basin by using the integration of remote sensing data and GIS teqniques.

## 2. Study area

Wadi Qena is located in the Eastern desert of Egypt between latitude 26° 10` to 28° 5` N and longitude 32° 31` to32° 45'E. (Fig. 1). Wadi Qena has its deltaic mouth at the town of Qena; its course extends in a north-south direction to its source at latitude 28° 5` N. The channel of the wadi occupies the floor of a greater valley. 'It is bounded on the west by cliffs of the limestone plateau and by red sea mountains at the east. Toward the south, between red sea peaks and the valley, lies a broad plain with brown tabular outliers of Nubia sandstone capped by later sediments [2].

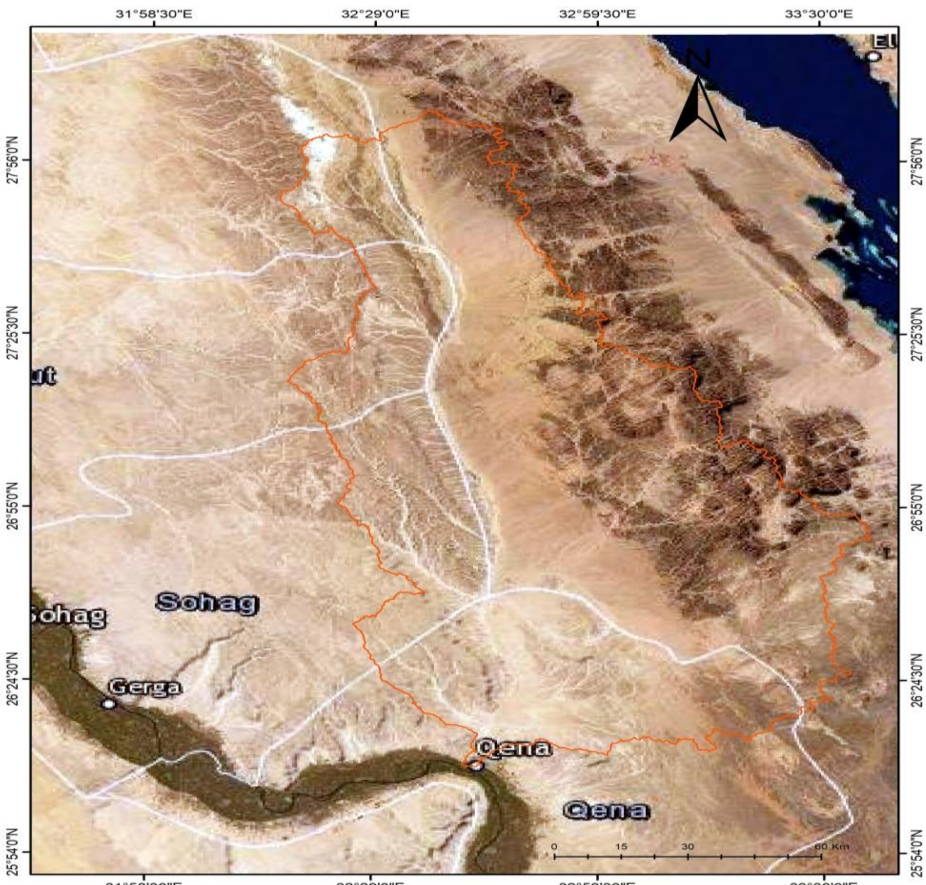


Figure 1. Location map of Wadi Qena Basin.

## 3. RESULTS And DISCUSSION

The morphometric analysis of the wadi Qena watershed has been obtained by using DEM of 30 m resolution based on stander method and laws of Horton [3&4], Schumm [5], Miller [6] and Strahler [7&8] (Table 1). The results of all parameters were presented in Table 2.

Table 1. The morphometric parameters and their mathematical formula.

| Morphometric parameters | Formula | Reference |
|---|---|---|
| Stream order (Su) | ARCGIS | Strahler (1964) |
| Stream length (Lu) | The lengths of all streams Lu= L1+L2+L3---+Ln | Horton (1945) |
| Stream NO. (Nu) | (Nu)= N1+N2+----+Nu | Horton (1945) |
| Bifurcation ratio (Rb) | Rb=Nu/Nu+1 | Schumn(1956) |
| Basin length (Lb) | Measure tool in ARCGIS | Grehory and walling (1973) |
| Area (A) (km)2 | (A) ARCGIS | Suhumm(1956) |
| Perimeter (P) | P | Suhumm(1956) |
| Drainage density (Dd) | Dd= Σ Lu/A | Horton(1945) |
| Drainage texture (Dt) | Dt=Σ Nu/P | Horton(1945) |
| Form factor(Rf) | Rf= A/Lp2 | Horton (1932) |
| Stream frequency (Fs) | Fs=Σ Nu/A | Horton (1945) |
| Elongation ratio (Re) | Re= 2√(A/π)/Lp | Suhumm(1956) |
| Constant of channel maintenance © | C= 1/Dd | Miller (1953) |
| Length of overland flow (Lf) | Lf=1/2Dd | Horton (1945) |
| Relief ratio (Rr) | Rr=H/Lp, H the total relief of the basin | Suhumm(1956) |

### 3-1 Linear parameters

The streams network of wadi Qena was extracted based on strahler's method (1964) and the streams were classified into orders (u) according to [9] and [10] wadi Qena is as $6^{th}$ order wadi (Fig 2). The stream numbers (Nu) and stream lengths (Lu) were obtained according to [4] by using ARCGIS software. The smaller lengths of streams may be indicated in areas with fine textures and larger slopes while the longer streams indicated to gently slope. A dendritic drainage pattern was noted on the limestone plateau that are underlain by homogenous rocks, While the major drainages at the sedimentary sequence along the main Wadi course are of parallel pattern and the small tributaries join the main stream channel as trellis. However, the basement rocks show irregular drainages [11].

The bifurcation ratio also concluded [5], bifurcation ratio is defined as the ratio of the number of a given order to the number of streams in the next higher order. According to [4] bifurcation ratio varies from a minimum of 2 in flat drainage basins to 3-4 in highly dissected drainage basins or mountainous areas. Its ranges from 2.8 at sub-basin (23) to 5 at sub-basin (20) (Fig. 5).

### 3-2 Areal aspects

The sub-basins areas and perimeter are the basic areal parameters in the quantitative morphometric, and they are calculated by using ARC map10.3. Basin length is defined as the longest length between the farthest point on the circumference of the basin to the point of confluence [12]. It's computed by the measure tool in ArcGIS software. The areal parameters considered for this study are drainage density, drainage texture, stream frequency, elongation ratio, form factor and constant channel maintenance.

### 3-2-1 Drainage density (Dd)

It is measured as the total lengths of streams of all orders in the basin divided by the basin's area. Horton (1932) defined it as an important indicator of the landform elements in stream eroded topography. The lower values of (Dd) may be indicated permeable rocks, low relief, and dense vegetation, while the higher values indicate impermeable rocks and steep slopes areas. The drainage density for the sub-basins of Wadi Qena ranged from 0.51km/km$^2$ to 0.77 km/km$^2$(Fig3).

### 3-2-2Stream frequency (Fs)

Horton (1945) defined The stream frequency (Fs) as the whole number of streams of all orders per unit area. The values of (Fs) for Wadi Qena sub- basins ranges from 0.121 to 0.184 per km2 (Fig 3) and (Table 2). the higher values of Fs indicated to lower permeability sediments, higher runoff, and lower infiltration, while the lower values indicate to gentle relief, higher rock permeability, lower runoff, and more chances of infiltration, and that represented prospective sites for groundwater potential.

### 3-2-3 Texture of drainage (Dt)

According to Horton [4], the drainage texture is defined as the number of stream segments of all orders in a basin (Nu) divided by the basin perimeter. It depends on the lithology of the ground; the higher values indicate a fine-grained texture, lower permeability deposits and lower infiltration however, the lower values indicate a coarse texture that indicates higher permeability deposits, greater infiltration and less run off. According to Smith [13] drainage texture had been classified into coarse (<6.4 km$^{-1}$), intermediate (6.4-16 km$^{-1}$), and fine (>16 km$^{-1}$), the drainage texture values of all sub-basin is less than 2 (Fig4) and that means the sub-basins falls under coarse drainage texture.

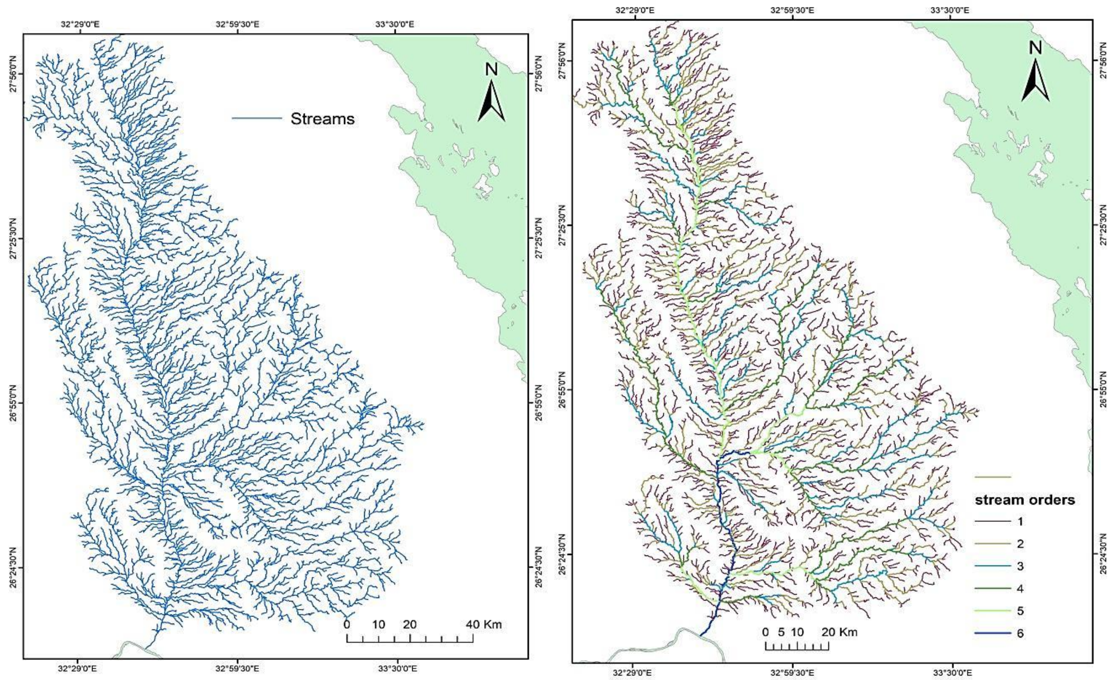


Figure2. stream network and stream orders of Wadi Qena.

Table 2. Morphometric parameters of Wadi Qena.

| Basin | Su | Lu | A(km2) | Lb(km) | P(km) | Dd | Fs | Dt | C | Lf | Rf | Re | Rr | Rb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 720 | 995.3 | 48.6 | 259 | 0.774 | 0.158 | 0.88 | 1.3 | 0.65 | 0.42 | 0.73 | 12.2 | 3.3 |
| 2 | 4 | 452.27 | 822.5 | 51.3 | 256.2 | 0.549 | 0.141 | 0.68 | 1.8 | 0.91 | 0.31 | 0.63 | 8.9 | 4.5 |
| 3 | 5 | 393.84 | 584.5 | 18 | 222.4 | 0.673 | 0.142 | 0.51 | 1.5 | 0.74 | 1.8 | 1.5 | 26.7 | 3.3 |
| 4 | 4 | 195 | 337.9 | 31.2 | 163.6 | 0.577 | 0.133 | 0.41 | 1.7 | 0.87 | 0.35 | 0.66 | 31.7 | 3.4 |
| 5 | 5 | 126.2 | 197.3 | 18.2 | 127.4 | 0.64 | 0.152 | 0.35 | 1.6 | 0.78 | 0.6 | 0.87 | 18 | 2.9 |
| 6 | 4 | 185.75 | 315 | 26.6 | 135.4 | 0.59 | 0.152 | 0.54 | 1.7 | 0.85 | 0.45 | 0.75 | 17.5 | 3.5 |
| 7 | 5 | 379.6 | 583.4 | 27.6 | 213.2 | 0.65 | 0.152 | 0.6 | 1.5 | 0.77 | 0.77 | 0.98 | 17 | 3.3 |
| 8 | 4 | 254 | 411.5 | 43 | 192.5 | 0.617 | 0.121 | 0.4 | 1.6 | 0.81 | 0.22 | 0.53 | 17.9 | 3.6 |
| 9 | 5 | 723.3 | 1074.9 | 42 | 264.5 | 0.673 | 0.17 | 1.02 | 1.5 | 0.74 | 0.61 | 0.88 | 11.1 | 4.4 |
| 10 | 6 | 795.3 | 1372.5 | 92 | 412.8 | 0.579 | 0.148 | 0.72 | 1.7 | 0.86 | 0.16 | 0.45 | 6.1 | 3.9 |
| 11 | 4 | 478 | 817.6 | 65.4 | 308.8 | 0.585 | 0.14 | 0.58 | 1.7 | 0.85 | 0.19 | 0.49 | 14.6 | 4.5 |
| 12 | 4 | 442.7 | 768.6 | 53.5 | 260.7 | 0.576 | 0.145 | 0.64 | 1.7 | 0.87 | 0.27 | 0.58 | 28.6 | 4.4 |
| 13 | 4 | 249.3 | 485.9 | 41.6 | 191.1 | 0.513 | 0.167 | 0.61 | 1.9 | 0.97 | 0.28 | 0.59 | 36.3 | 4.1 |
| 14 | 6 | 270.6 | 457.3 | 47.4 | 267.2 | 0.592 | 0.161 | 0.43 | 1.7 | 0.84 | 0.2 | 0.5 | 9.9 | 3 |
| 15 | 5 | 95.2 | 155.8 | 37 | 161.5 | 0.611 | 0.141 | 0.2 | 1.6 | 0.82 | 0.11 | 0.38 | 9.2 | 2.9 |
| 16 | 4 | 1000.8 | 1779.5 | 72.6 | 341.8 | 0.562 | 0.149 | 1.22 | 1.8 | 0.89 | 0.34 | 0.65 | 22 | 4.7 |
| 17 | 4 | 59.8 | 90.6 | 23.4 | 97.3 | 0.66 | 0.133 | 0.17 | 1.5 | 0.76 | 0.17 | 0.45 | 5.1 | 2.2 |
| 18 | 5 | 277.9 | 427.9 | 35.4 | 163.8 | 0.649 | 0.155 | 0.59 | 1.5 | 0.77 | 0.34 | 0.65 | 20.5 | 2.5 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 6 | 230.3 | 355.6 | 42.5 | 174.6 | 0.648 | 0.152 | 0.48 | 1.5 | 0.77 | 0.2 | 0.5 | 10.3 | 3 |
| 20 | 6 | 392.7 | 602.4 | 36.6 | 181.4 | 0.652 | 0.184 | 0.87 | 1.5 | 0.77 | 0.45 | 0.75 | 13.3 | 5 |
| 21 | 5 | 746.6 | 1439.2 | 58.6 | 362.2 | 0.519 | 0.141 | 0.84 | 1.9 | 0.96 | 0.42 | 0.73 | 14 | 3.6 |
| 22 | 6 | 350.9 | 648.5 | 49.1 | 230.1 | 0.541 | 0.166 | 0.67 | 1.8 | 0.92 | 0.27 | 0.58 | 10.1 | 3.3 |
| 23 | 5 | 201.4 | 326.2 | 32.2 | 146.3 | 0.617 | 0.165 | 0.54 | 1.6 | 0.81 | 0.31 | 0.63 | 15.6 | 2.8 |
| 24 | 6 | 310.7 | 491.5 | 27.5 | 245.3 | 0.632 | 0.183 | 0.52 | 1.6 | 0.79 | 0.65 | 0.9 | 35.9 | 2.9 |

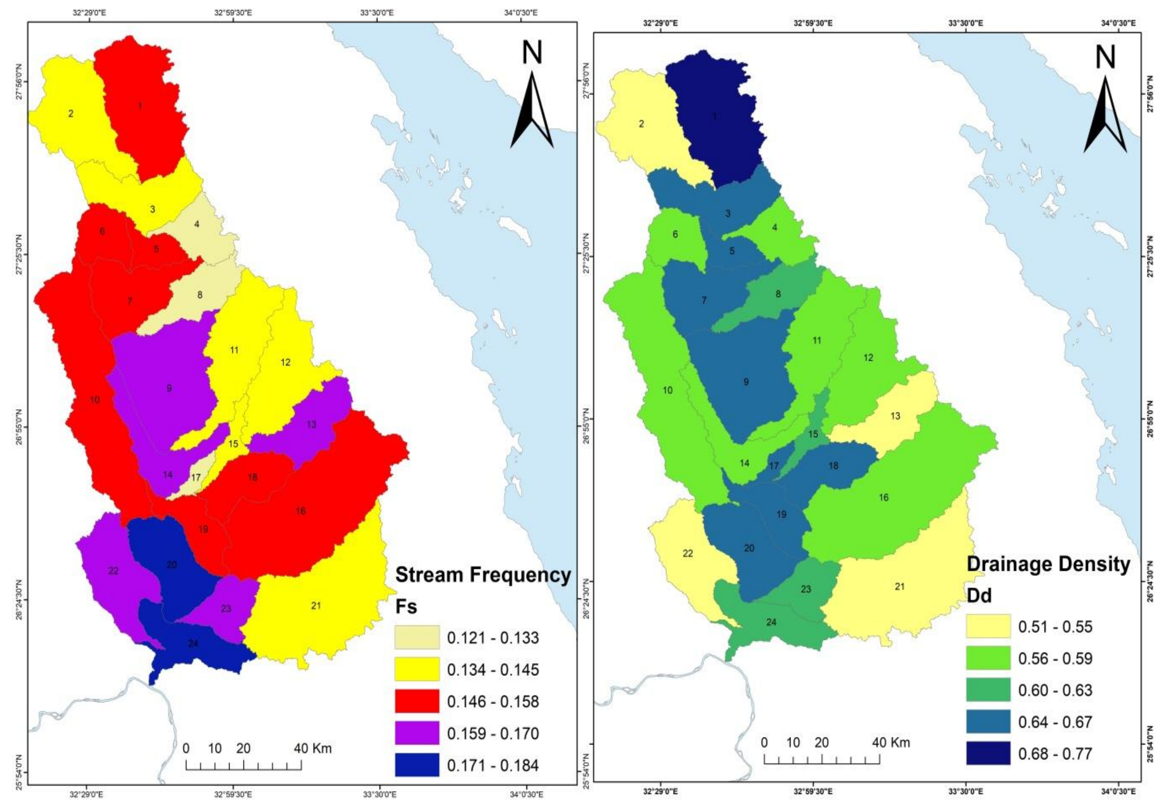


Figure3. Drainage density and stream frequency of wadi Qena.

## 3-2-4 length of over land flow

The length of over land flow was described by Horton as the length of water flow on the ground surface before it confined into definite channels (Horton, 1945). and expressed it as equal to half of the of drainage density (D). In the present study length of overland flow ranges from 0.65 at sub-basin (1) to 0.97at basin (13) (Fig 5a). The higher values of (Lf) reflect the occurrence of long flow paths, gentle slopes, fewer runoff, and more infiltration.

## 3-2-5 Constant of channel maintenance (C)

Schumm (1956) had defined it as the inverse of the drainage density. The higher values of constant (C) refers to higher permeability rocks and higher infiltration. The values of the constant (C) of the wadi Qena sub-basin range from 1.3 to 1.9 Fig(5c).

### 3-2-6 form factor (Rf)

Is the ratio of the basin area to square of basin length [4]. It is used as a measureable expression of the basin shape form. The lower values of the form factor indicate to elongated basins with low peak flow for longer durations, while the higher values mean a circular shape with major peak flows of short durations (Fig4).

### 3-2-7 Elongation ratio

This ratio shows the extent of the basin's elongation and its proximity to the rectangular shape. Its defined as the ratio between the diameter of the circle of the same area as the drainage basin to the maximum length of the basin [5]. It's give indications about the hydrology of the basin and it ranged from 0to 1. the lower values indicate elongated basins and higher values refer to circular shape sub-basins(Fig5d). The variations of the elongated shapes of the basins are due to the guiding effect of structures [14].

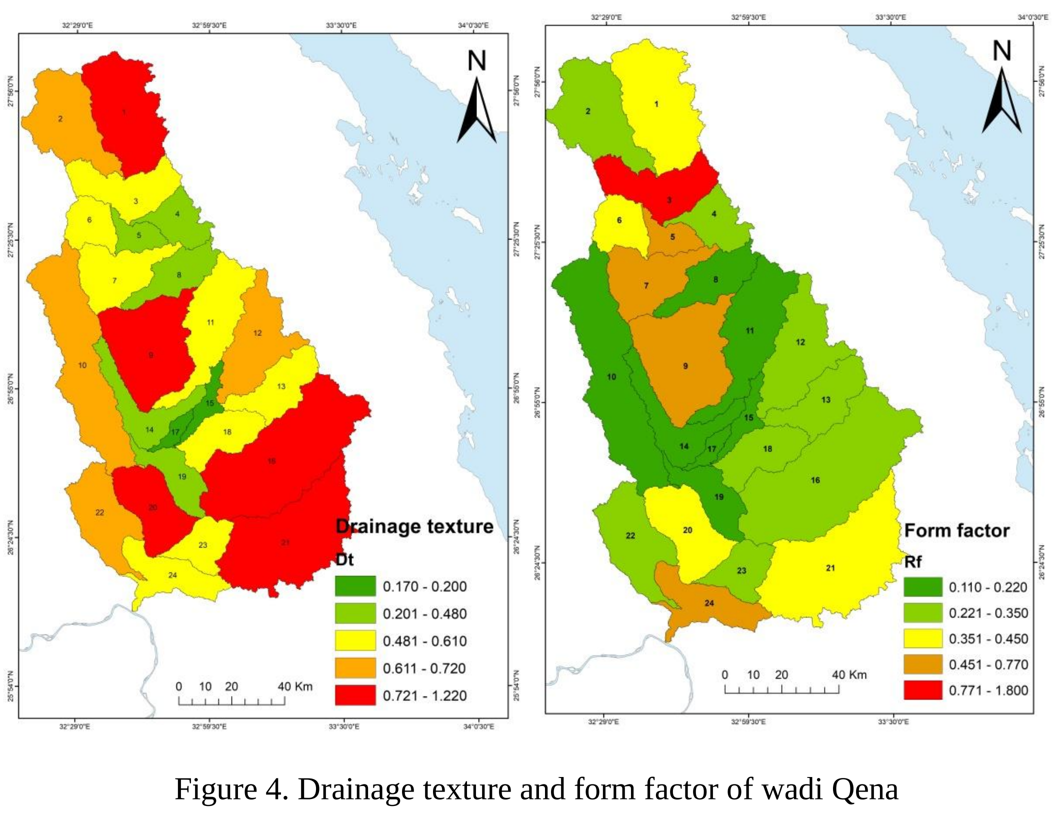


Figure 4. Drainage texture and form factor of wadi Qena

## 4- Groundwater potential map

The groundwater potential map of wadi Qena was produced using ARCGIS software. The raster layers of drainage density, stream frequency, constant of channel maintenance, elongation ratio, length of overland flow, and drainage texture of all sub-basins were reclassified into 3 classes in terms of their impact on groundwater potentiality (Table 3). Ranks from 1 to 3 that representing lower, intermediate and higher groundwater potential were used. based on these ranks, assigning a weight to each raster layer (Table 4), were integrated by using the raster calculator of ARCGIS program to highlight the areas with higher infiltration or recharge. This potential map was classified into five categories; very high, high, intermediate, low and very low groundwater potential (Fig. 6).

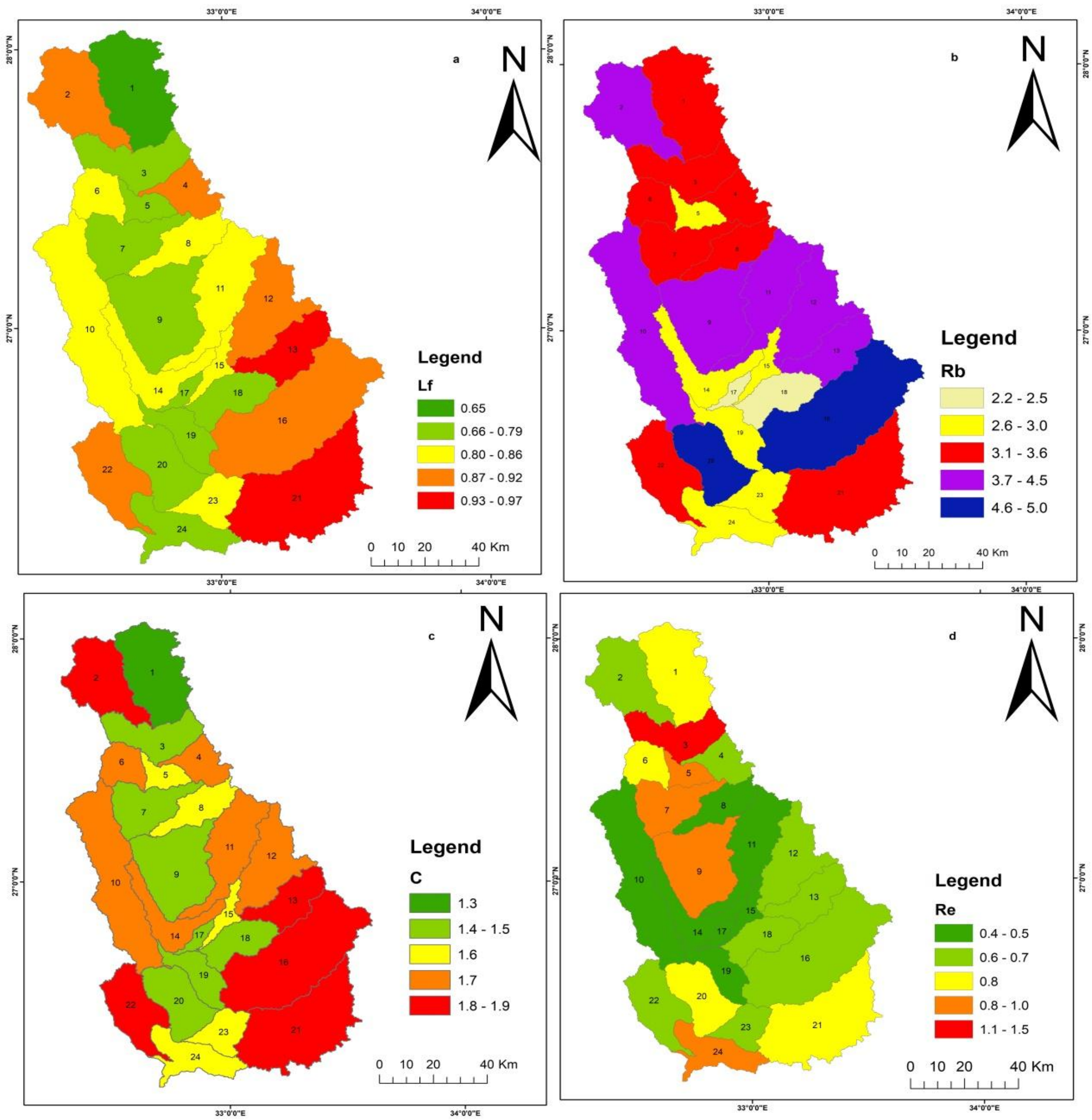

Figure5. (a)Length of overland flow (Lf), (b)Mean Bifurcation ratio, (c) Constant of channel Maintenance(C) and (d) Elongation ratio(Re).

Table3. Morphometric parameter with ranking method

| Parameter | Classes | Rank | Capacity to infiltration |
|---|---|---|---|
| Dd | 0.513 - 0.562 | 3 | high |
| | 0.563 - 0.617 | 2 | moderate |
| | 0.618 - 0.774 | 1 | low |
| Fs | 0.121 - 0.142 | 3 | high |
| | 0.143 - 0.161 | 2 | moderate |
| | 0.162 - 0.184 | 1 | low |
| Lf | 0.650 - 0.790 | 1 | low |
| | 0.791 - 0.870 | 2 | moderate |
| | 0.871 - 0.970 | 3 | high |
| C | 1.300 - 1.500 | 1 | low |
| | 1.501 - 1.700 | 2 | moderate |
| | 1.701 - 1.900 | 3 | high |
| Dt | 0.17 - 0.43 | 3 | high |
| | 0.44 - 0.72 | 2 | moderate |
| | 0.73 - 1.22 | 1 | low |
| Re | 0.4 - 0.5 | 3 | high |
| | 0.6 - 0.8 | 2 | moderate |
| | 0.8 - 1.5 | 1 | low |

Table4. Morphometric parameters with their Weights and compact factor.

| Basin _N | Dd | Dt | Fs | Lf | C | Re | Total Weight Score | **compact factor** |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 2 | 1 | 1 | 2 | 8 | 1.33 |
| 2 | 3 | 2 | 3 | 3 | 3 | 2 | 16 | 2.66 |
| 3 | 1 | 2 | 3 | 1 | 1 | 1 | 9 | 1.5 |
| 4 | 2 | 3 | 3 | 2 | 3 | 2 | 15 | 2.5 |
| 5 | 1 | 3 | 2 | 1 | 2 | 1 | 10 | 1.66 |
| 6 | 2 | 2 | 2 | 2 | 2 | 2 | 12 | 2 |
| 7 | 1 | 2 | 2 | 1 | 1 | 1 | 8 | 1.33 |
| 8 | 2 | 3 | 3 | 2 | 2 | 3 | 15 | 2.5 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 1 |
| 10 | 2 | 2 | 2 | 2 | 2 | 3 | 13 | 2.16 |
| 11 | 2 | 2 | 3 | 2 | 2 | 3 | 14 | 2.33 |
| 12 | 2 | 2 | 2 | 2 | 2 | 2 | 12 | 2 |
| 13 | 3 | 2 | 1 | 3 | 2 | 2 | 13 | 2.16 |
| 14 | 2 | 2 | 2 | 2 | 2 | 3 | 13 | 2.16 |
| 15 | 2 | 3 | 3 | 2 | 2 | 3 | 15 | 2.5 |
| 16 | 3 | 1 | 2 | 3 | 3 | 2 | 14 | 2.33 |
| 17 | 1 | 3 | 3 | 1 | 1 | 3 | 12 | 2 |
| 18 | 1 | 2 | 2 | 1 | 1 | 2 | 9 | 1.5 |
| 19 | 1 | 2 | 2 | 1 | 1 | 3 | 10 | 1.66 |
| 20 | 1 | 1 | 1 | 1 | 1 | 2 | 7 | 1.16 |
| 21 | 3 | 1 | 3 | 3 | 3 | 2 | 15 | 2.5 |
| 22 | 3 | 2 | 1 | 3 | 3 | 2 | 14 | 2.33 |
| 23 | 2 | 2 | 1 | 2 | 2 | 2 | 11 | 1.83 |
| 24 | 1 | 2 | 1 | 1 | 2 | 1 | 8 | 1.33 |

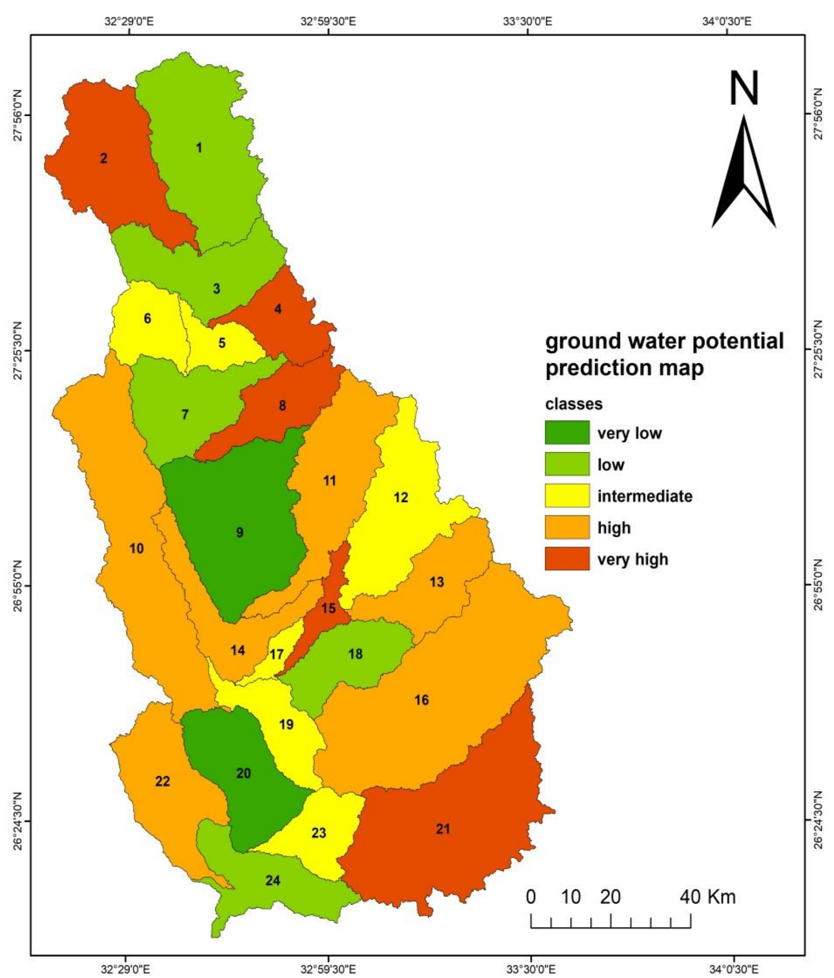


Figure 6. Groundwater potential map of wadi Qena.

## CONCLUSION

Wadi Qena is one of the most important and promising valleys in Eastern Desert of Egypt, so the sustainable development of groundwater resources in the valley is required. In this study, we have used the morphometric analysis of some important parameters that may be have a great influence on the infiltration of the rainwater to predict the recharge and the groundwater potential zones in the valley. The parameters such as drainage density, texture, stream frequency, and elongation ratio found to be had an inverse relationship with recharge of groundwater; higher value of these factors indicates lower groundwater potential, and the parameters like length of overland flow and constant of channel maintenance found to be had a direct relationship with the infiltration and recharge, higher values refer to high recharge and higher groundwater potential. The sub-basins classified into five categories based on their weights, very high, high, intermediate, low and very low for groundwater potential.

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