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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

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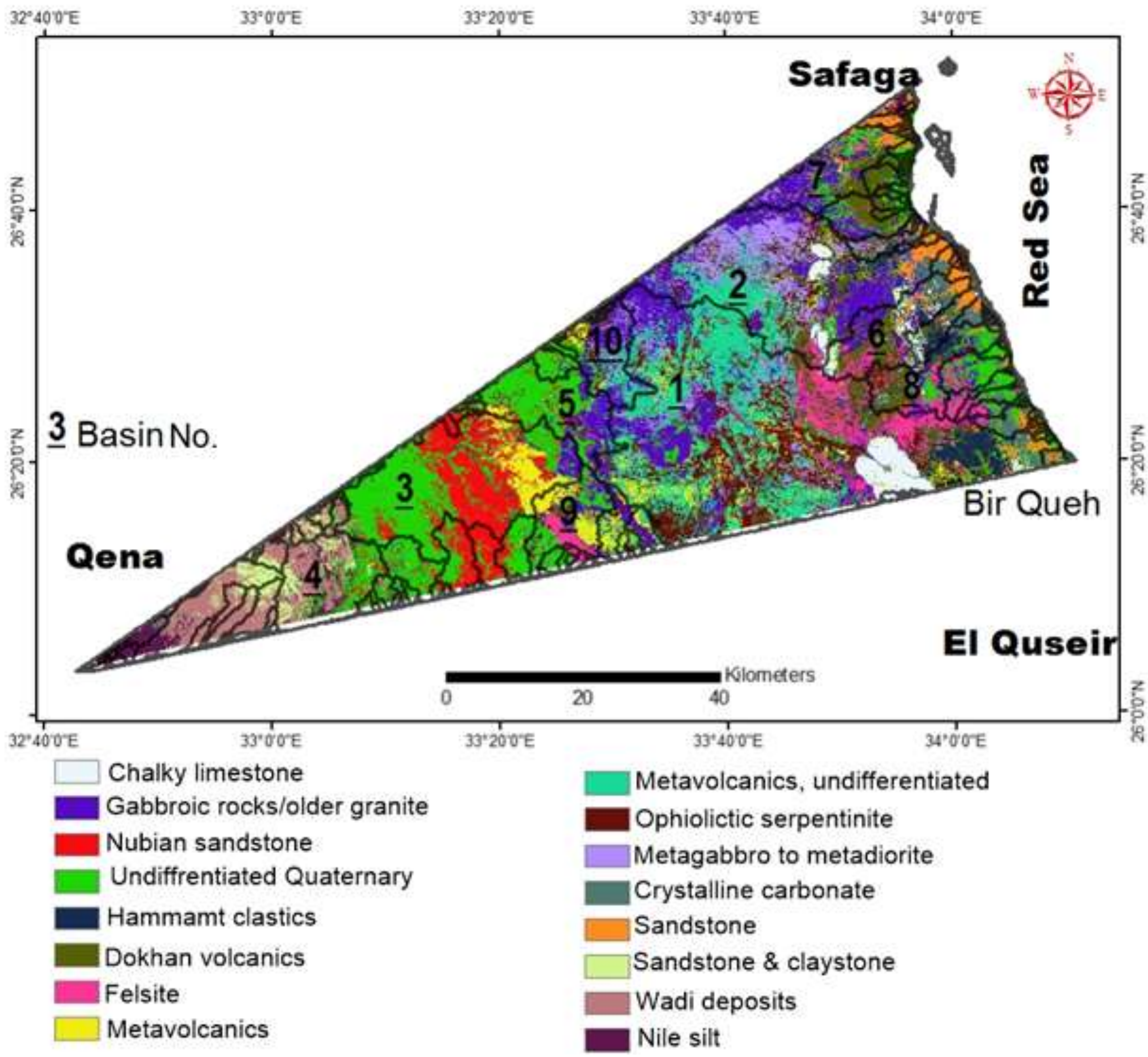


Figure 1. Base and classified geological map.

water relies on geology (hydraulic conductivtiy). 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 (Benukantha 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).

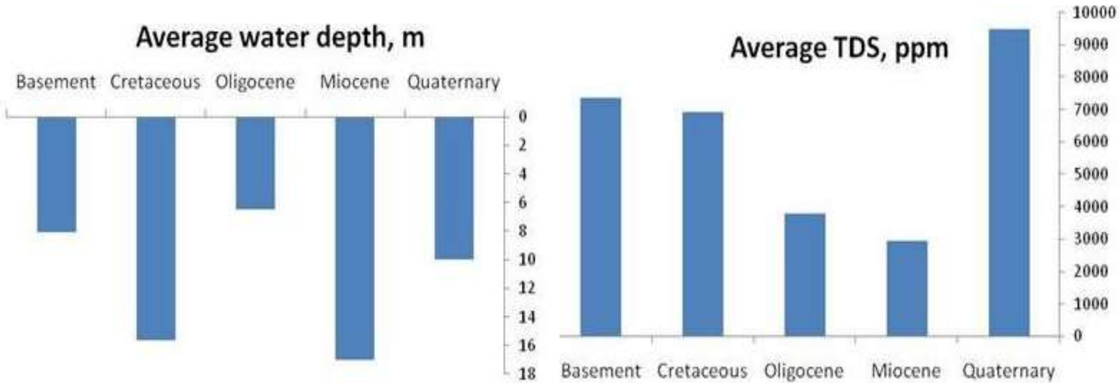


Figure 2. Average water depth and TDS of the aquifers atSafaga-El Quseir area.

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.

METHODOLOGY

The morphometric parameters of watershed were determined using DEM (SRTM) with 30 m resolution. Envi 5.1, Erdas 2014, Global Mapper 16, and ARCMAP 10.2 were applied. Among the morphometric variables that were determined were stream number and order, bifurcation ratio (Rb), stream length, basin area, stream length ratio, drainage density, constant of channel maintenance, length of overland flow, stream frequency, texture ratio, circularity ratio, elongation ratio, and relief analysis. A detailed flowchart of watershed extraction methodology is shown in Figure 3. The morphometric parameters are determined according to formulae in Tables 1 to 4. The geological map (EGPC/Conoco 1987), scale of 1:250,000 are scanned and geo-referenced according to coordinates of satellite image and digitized different rock units. The digitized different geology is valuable data for the supervised image classification accuracy assessment. Enhanced Thematic Mapper (ETM+8) Landsat satellite images were acquired in January (2003) to extract land cover classes. Three satellite images were mosaicked. The available ETM+ imagery was corrected for wavelengths, quick atmospheric, UTM projection WSG84, and contrast stretching. The principle component image (PCI Geomatica software) delineates the lineaments. Multivariate statistical techniques include Q-mode, R-mode hierarchical (Judd, 1980; Rummel, 1970; Berry, 1995; Guler et al., 2002), and principal component analysis (PCA). For understanding the hydrological parameters, the multivariate statistical investigation was applied (Drever, 1997; Alther, 1979). The hierarchical cluster methods (HCA; StatSoft, Inc. 1995) were used to determine the catchment areas classification (Z-scores) (Ward, 1963).

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 km^2 and was the 5^{th} order (Figure 6a).

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

Wad 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 49×10^6 m^3. 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 6^{th} order, while sub basins 5 and 9 have the 5^{th} order.

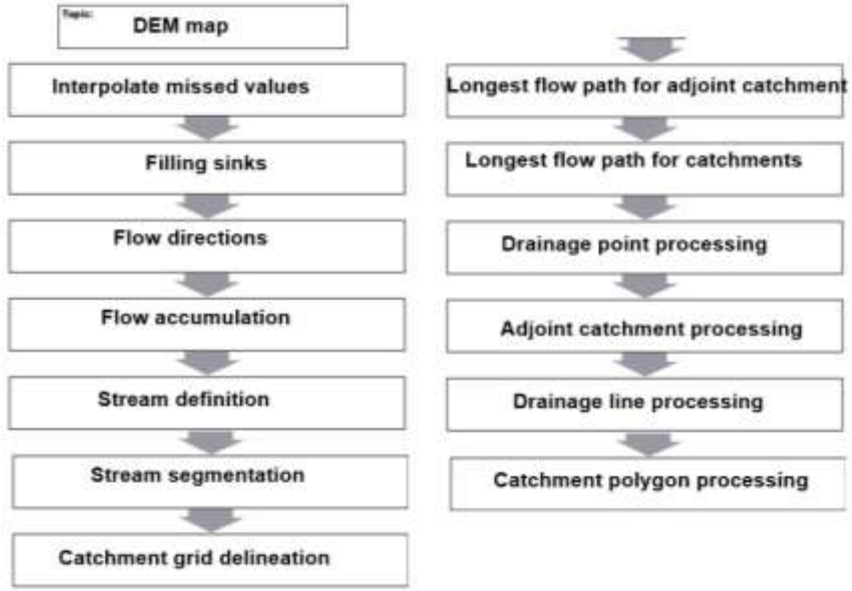


Figure 3. Flow chart for drainage basin extraction.

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

Basin S/N	Drainge Basin	Basin area (A; km^2)	Basin length (BL; km)	Basin perimeter (P, km)	Number of streams (Nu) of different stream order (u)							Bifurcation ratio Rb (Nu/Nu+1)					
					1	2	3	4	5	6	∑ Nu	1/2	2/3	3/4	4/5	5/6	Av.
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	Abu Shaqayli	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	Sub Basin 9	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	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					Drainage basins			
Rb Range			**1st order**	**2nd order**	**3rd order**	**4th order**	**5th order**		
< 3	Natural						No. 4, 8, and 10		
3--5	Geomorphic		No. 1-3 and 5-10	No. 1-10	No. 2-6 and 8-10	No. 1-3, and 8	No. 2 and 3		
> 5	Structural		No. 4		No. 1 and 7	No. 4-6 and 9-10	No. 1		
Stream Length (Lu)									
Nature of stream					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		Surface rock-permeability	Run-off	Infiltration rate		
			< 1.5		High	Low	High		3
			1.5-2.5		Medium	Medium	Medium	No. 1-7 and 9-10	2
			> 2.5		Low	High	Low	No. 8	1
Constant channel maintenance, C			Range	Average	Surface rock-	Ground slope	Infiltration rate		
(km²/km)					permeability				
			< 0.3	0.28	Low	Steep	Low		1
			0.3-0.5	0.47	Medium	Moderate	Medium	No. 1-10	2
			> 0.5	0.88	High	Gentle	High		3
Length of overland flow (Lg)		Range	Average			Run-off	Infiltration rate		
(km²/km)									
		< 0.2	0.15	Ground slope and flow-path		High	Low		1
		0.2-0.25	0.24	Moderate slope and moderate flow-path		Medium	Medium	No. 1-10	2
		> 0.25	0.45	Gentle slope and long flow-path		Low	High		3
Stream frequency (Fs)		Range	Average	Ground slope and surface		Run-off	Infiltration rate		
(per km²)				rock-permeability					
		< 2	1.4	Gentle slope and high permeable		Low	High		**3**
		2--3	2.76	Moderate slope and medium permeable		Medium	Medium		**2**

Table 2. Selected hydrological parameters weights. No. 1: Basin No. 1 was in Table 1

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

Table 3. Stream number and stream length ratio.

		Total stream lengths Lu (km) in different u							**Average Lu (km) in different u (Lu/Nu)**						**Stream length ratio Rl (Lu/Lu-1)**				
Basin No.	**Drainage Basin**	**1**	**2**	**3**	**4**	**5**	**6**	**∑ Lu**	**1**	**2**	**3**	**4**	**5**	**6**	**2/1**	**3/2**	**4/3**	**5/4**	**6/5**
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 Pre-Cambrian 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, Neogeone 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 serpentine, 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 S/N	Drainage Basin	Drainage density, Dd: ∑Lu/A (km/km^2)	Constant of channel maintenance, C: 1/Dd (km^2/km)	Length of overland flow, Lg: 1/2Dd (km^2/km)	Stream frequency, Fs: ∑Nu/A (per km^2)	Drainage texture ratio, T: Nu/P
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 S/N	Drainage Basin	Circularity ratio, Rc: 4πA/P^2	Elongation ratio, Re (2/BL).(A/π)$^{0.5}$	Relief ratio (RR): Diff. elevation/BL	Slope average (SA): 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

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 km/km^2 (Figure 4a). The lowest Dd (0-0.91) and highest LD (0.91-1.8 km/km^2) areas are considered the best promising zones for aquifer recharge. The main exposed rocks of wadiSafaga 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 km/km^2, while the LD ranged from 0-4.8 km/km^2 (Figure 4b). The highest LD (2.4-4.8 km/km^2) and lowest Dd (0-154 km/km^2) of the previous geology represent the best promising areas for groundwater storage (Figure 4b).

Abu Shiqayli, El Barud, and Gasus have low LD compared to Bir Queh and Safaga (Figures 5 to 6b). Abu Shiqayli 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 10e). It includes low concentration of crystalline carbonate and sandstone in the coast. Sub basin 3 (Wad iQena) mainly was exposed by Nubian sandstone, followed by Quaternary and meta-volcanic deposits in equal concentrations (Figure 11a). The Dd ranged from 27-496 km/km^2, whereas the LD varied from 0-2.4 km/km^2 (Figure 6b). The Dd (27-231 km/km^2) and LD (1.2-2.4 km/km^2) 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 hammamatclastic was in the eastern part (Figure 11b). The geological conditions with Dd (28-211

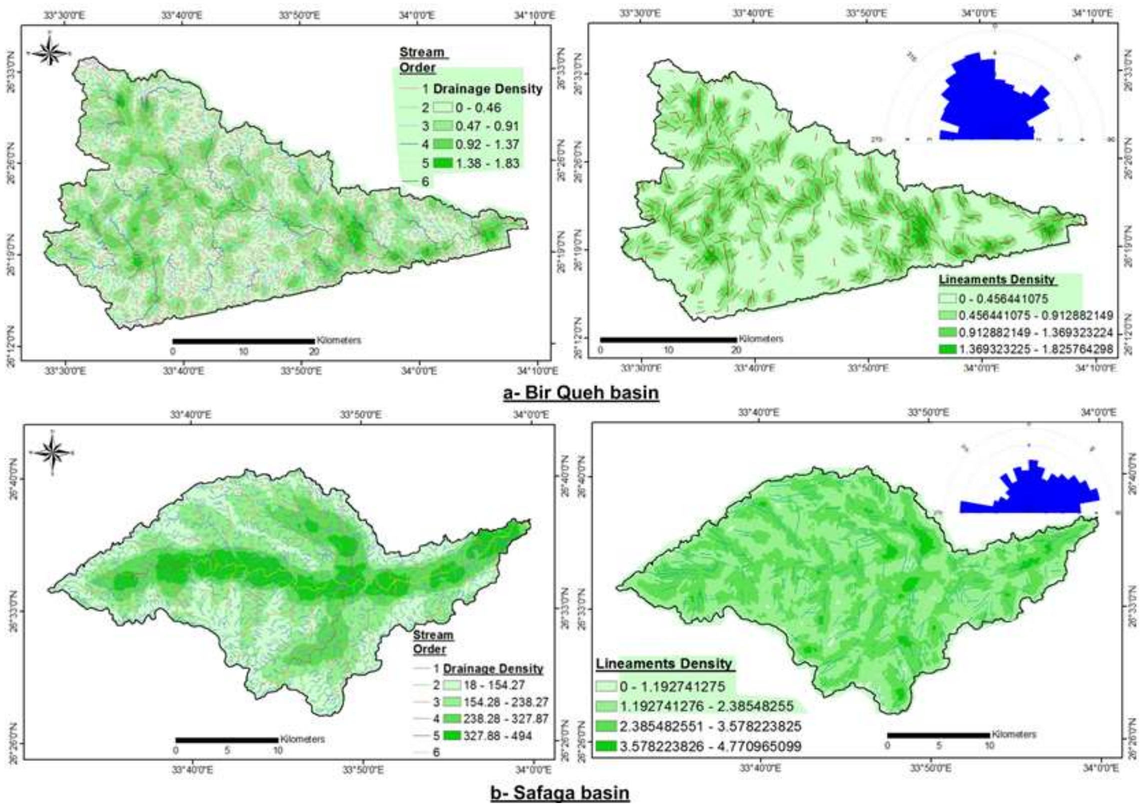


Figure 4. Extracted of Bir Queh (a) and Safaga (b) basins.

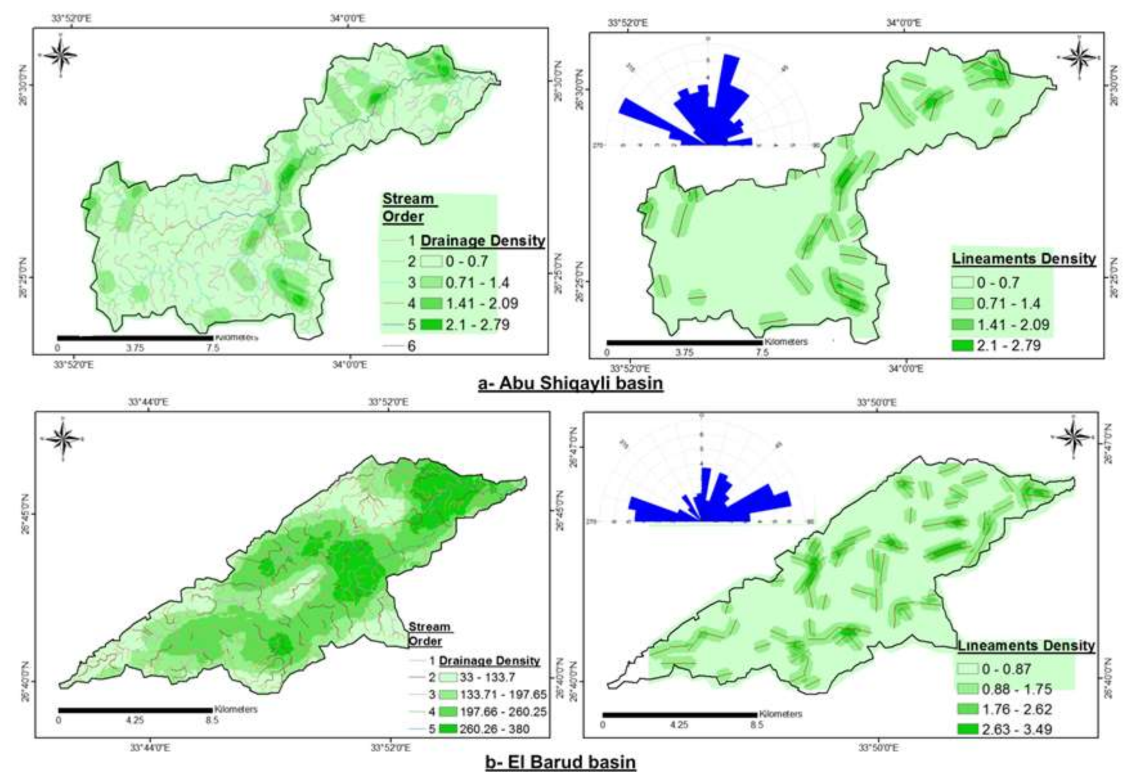


Figure 5. Extracted of Abu Shiqayli (a) and El Barud (b) basins.

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 0-1.83 km/km^2 (Figure 4a). The lowest Dd (0-0.91) and highest LD (0.91-1.8 km/km^2) and LD (1.8-3.6 km/km^2) 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/km^2) and LD (1.7-3.4 km/km^2) (Figure 7b). Sub basin 9 contains felsite, meta-volcanic, and Quaternary sediments (Figure 11d). Meta-volcanic and felsite sediments with Dd (57-218 km/km^2) 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/km^2) and LD (1.6-3.2 km/km^2) 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 Wad 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 (∑Nu) 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_u 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 km^2, 36.5 km) to BirQueh (1263 km^2, 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 (∑Lu) 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 km^2), while the lowest was Wadi Qena (sub basin 10) (103 km^2). Basin area directly affects the peak and average runoff magnitudes. If the drainage basin size is small, the rainwater 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 (Rl)

It represents the relative permeability of the geology and relationship with the surface flow discharge (Al-Saady et al., 2016).The mean Rl 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.

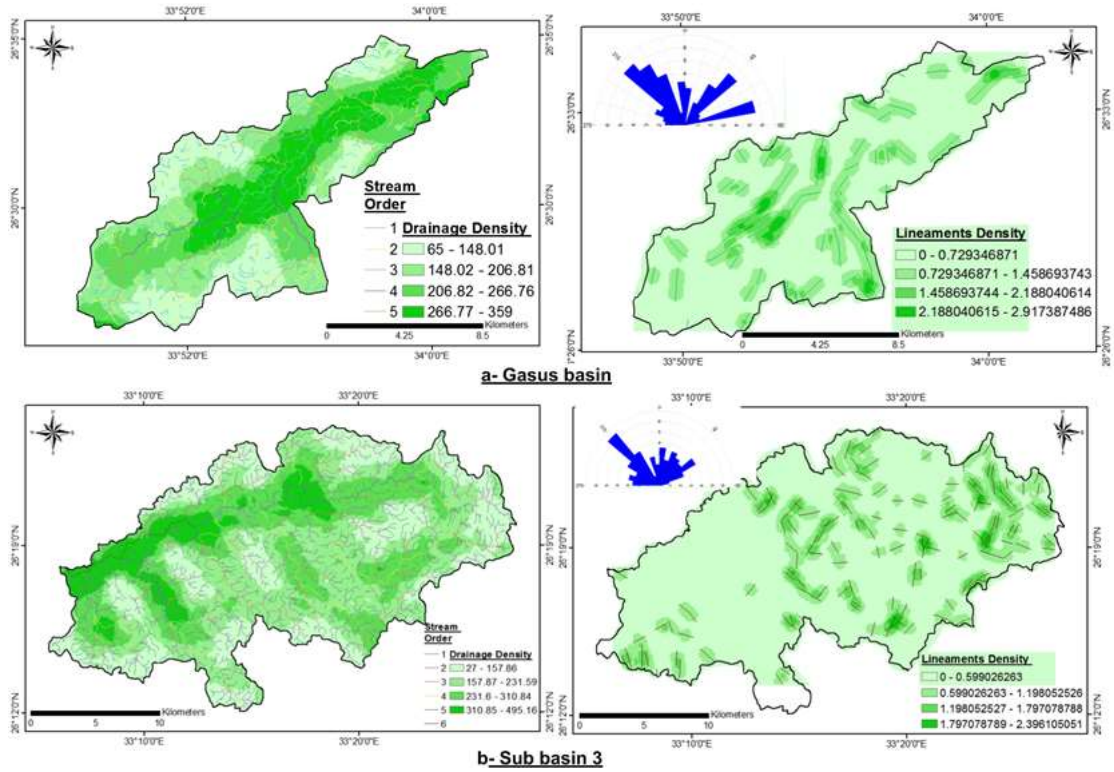


Figure 6. Extracted of Gasus (a) and sub basin 3 (b).

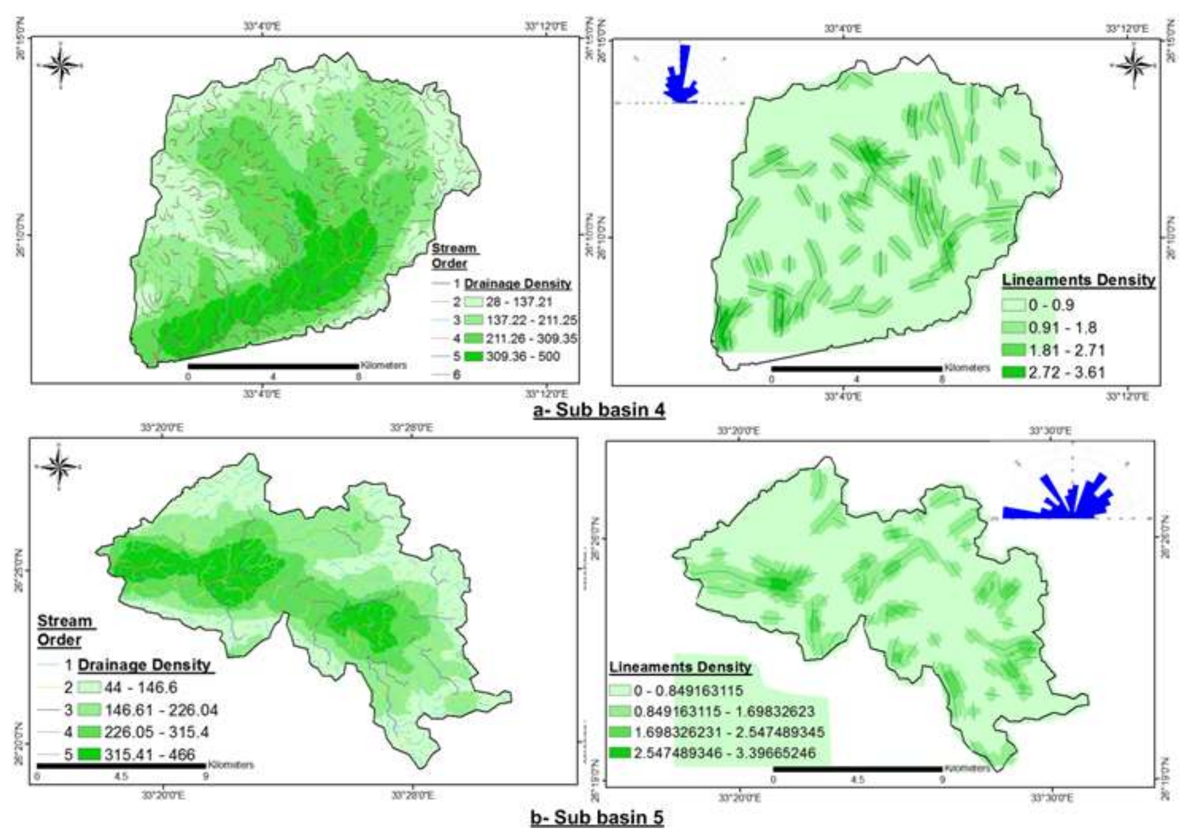


Figure 7. Extracted of sub basins 4 and 5.

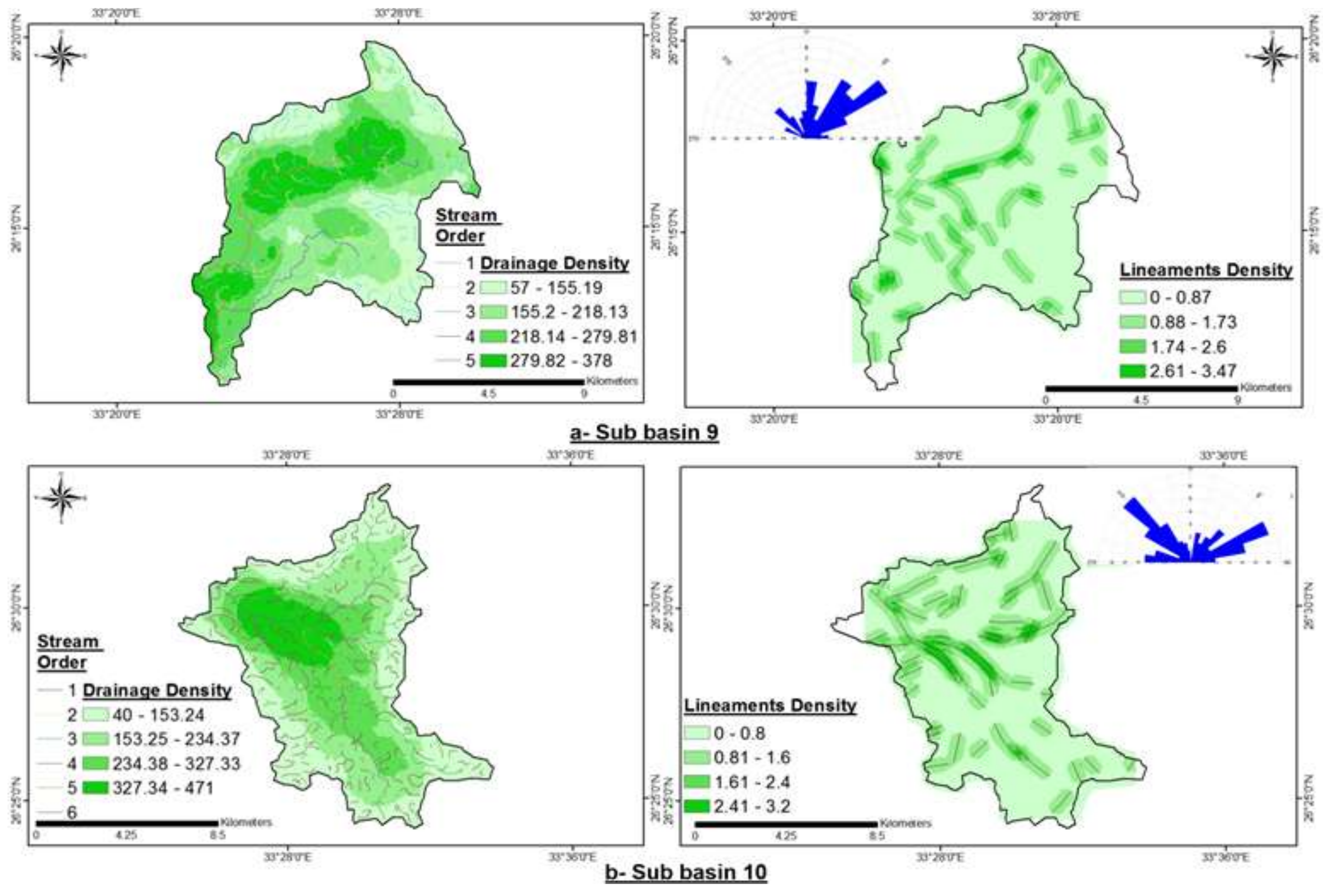


Figure 8. Extracted of sub basins 9 and 10.

Drainage density (Dd)

It relates to structure, lithology, geomorphology, and topography. The Dd ranges from 2.3-2.55 km/km^2 (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.

Constant of channel maintenance, C

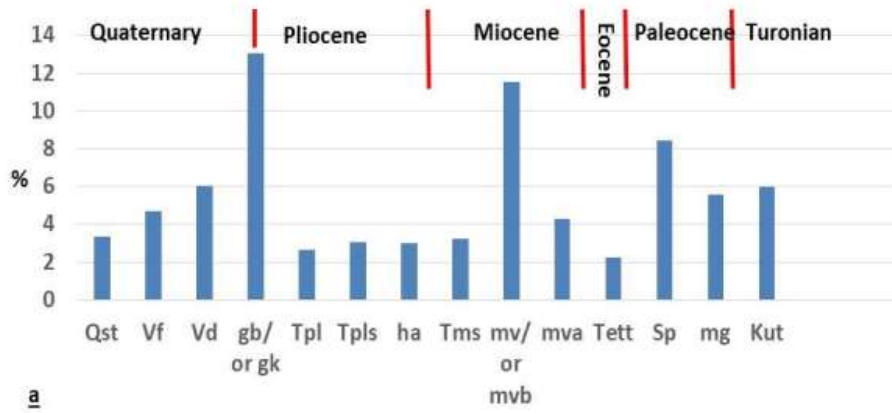
It determines the minimum limiting area required for developing a drainage channel. It ranged from 0.4 to 0.43 (convergent values), with average 0.41 km^2 that is required to support each linear kilometer of stream channels. Sub basins 3, 9, and 10 (Qena) have C values higher than 0.41 km^2, reflect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

Length of overland flow (Lg)

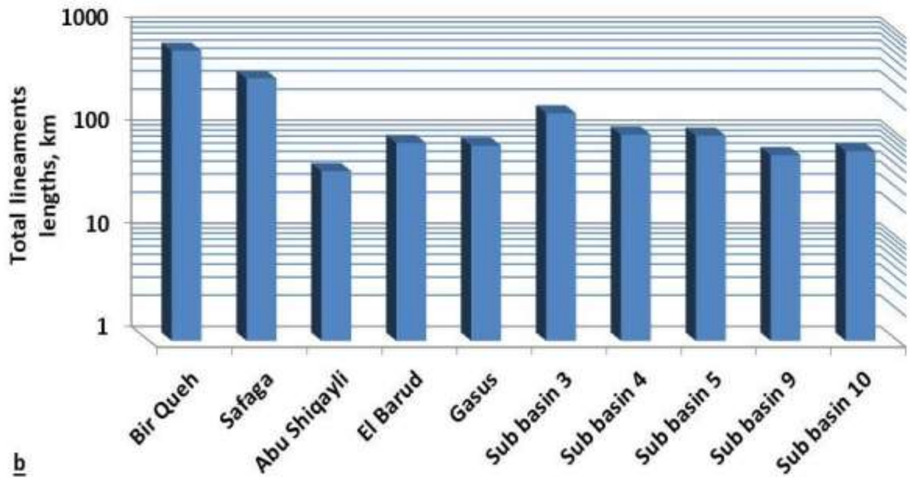
Lg describes the length of flow of water over the ground before it becomes concentrated in incised stream channels or permanent drainage channels (Prasad 2008). It ranges from 0.2 to 0.22 km (convergent values). The ten basins fall between 0.20 and 0.25 km^2/km of moderate ground slopes, where the flow-paths, run-off and infiltration are moderate (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/km^2), excluding wadiGasus (4.7 streams per km^2) with average 3.714 km^2. 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).



a



b

Q	Undiffrentiated Quaternary	
Qw	Wadi deposits	
Qst	Nile silt	
Vf	Felsite	**Quaternary**
Vd	Dokhan volcanics	
gk	Older granite	
gb	Gabbroic rocks	
Tpl	Sandstone & claystone	
Tpls	Sandstone	**Pliocene**
ha	Hammamt clastics	
Tms	Crystalline carbonate	
ms	Metasediments	**Miocene**
mv	Metavolcanics, undifferentiated	
mva	Metavolcanics	
Tett	Chalky limestone	**Eocene**
Sp	Ophiolictic serpentinite	
mg	Metagabbro to metadiorite	**Paleocene**
Kut	Nubian Sandstone	**Turonian**

c

Figure 9. Geological percentage (a) and lineaments lengths of the stud area (b).

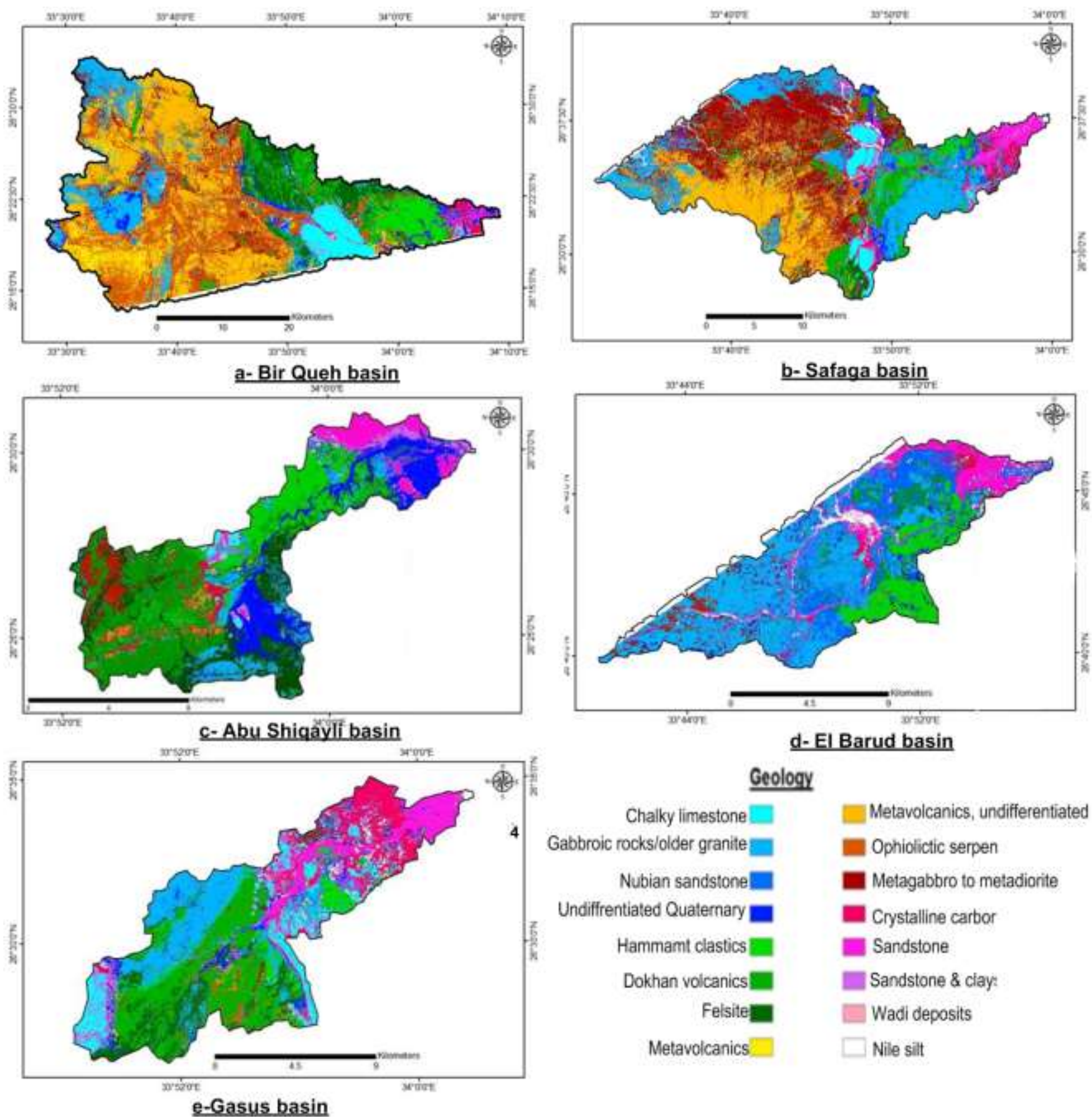


Figure 10. Geological distribution in Bir Queh, Safaga, Abu Shiqayli, El Barud, and gasus drainage basins.

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 Wad iQena (sub basin 10) and 17.9 km for Wadi Queh and the mean

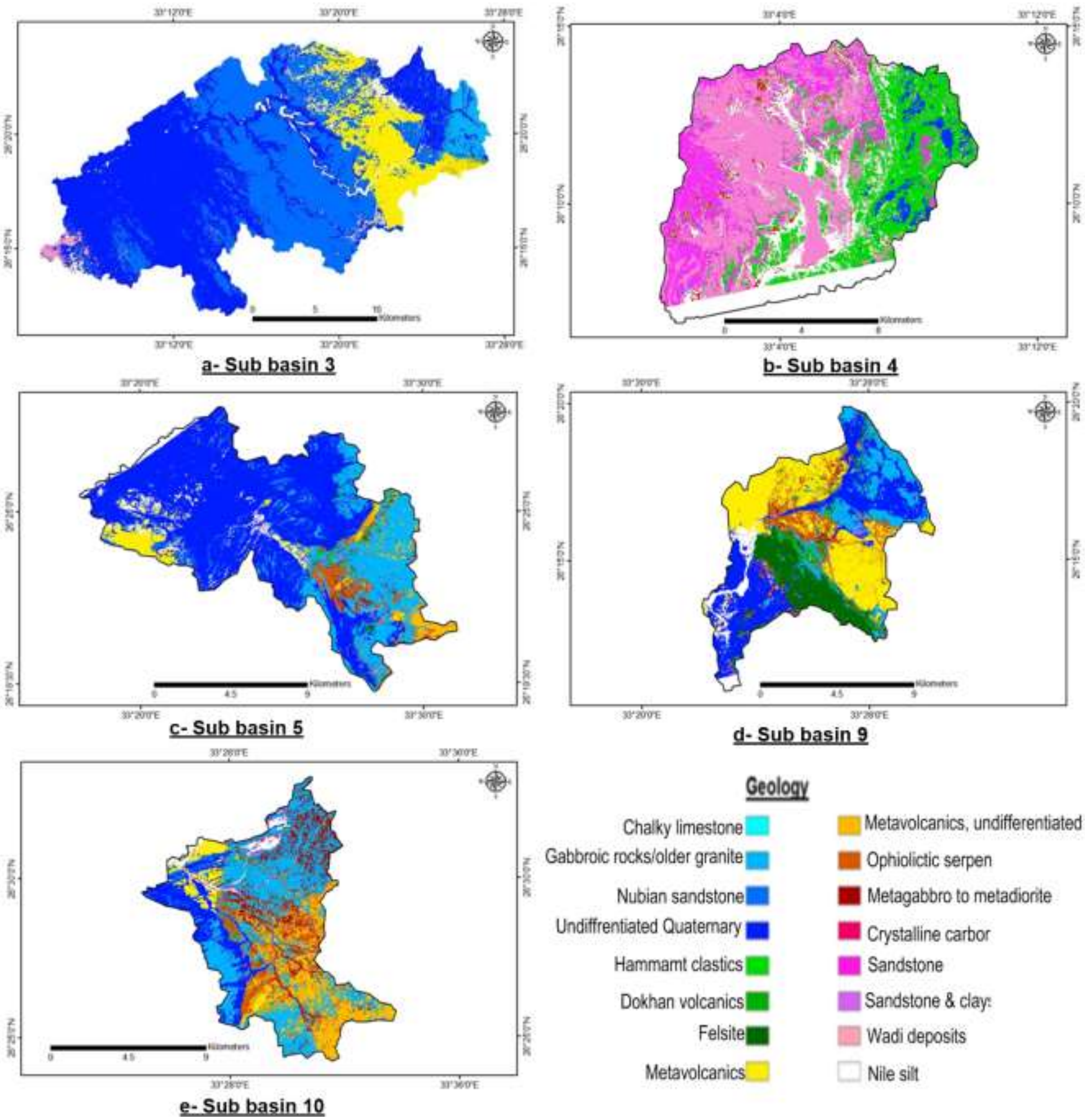


Figure 11. Geological distribution in sub basins 3, 4, 5, 9, and 10 (wadi Qena).

texture ratio of the whole basins is about 9.1 km. The drainage basins nos. 8 (Abu Shakyli) and Wad iQena (sub basin 10) are medium. Fine textures include Wad iQena (sub basin 5), El Barud, and Wad iQena (sub basin 9), while Wadi Queh, Safaga, Qena, Wad iQena (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

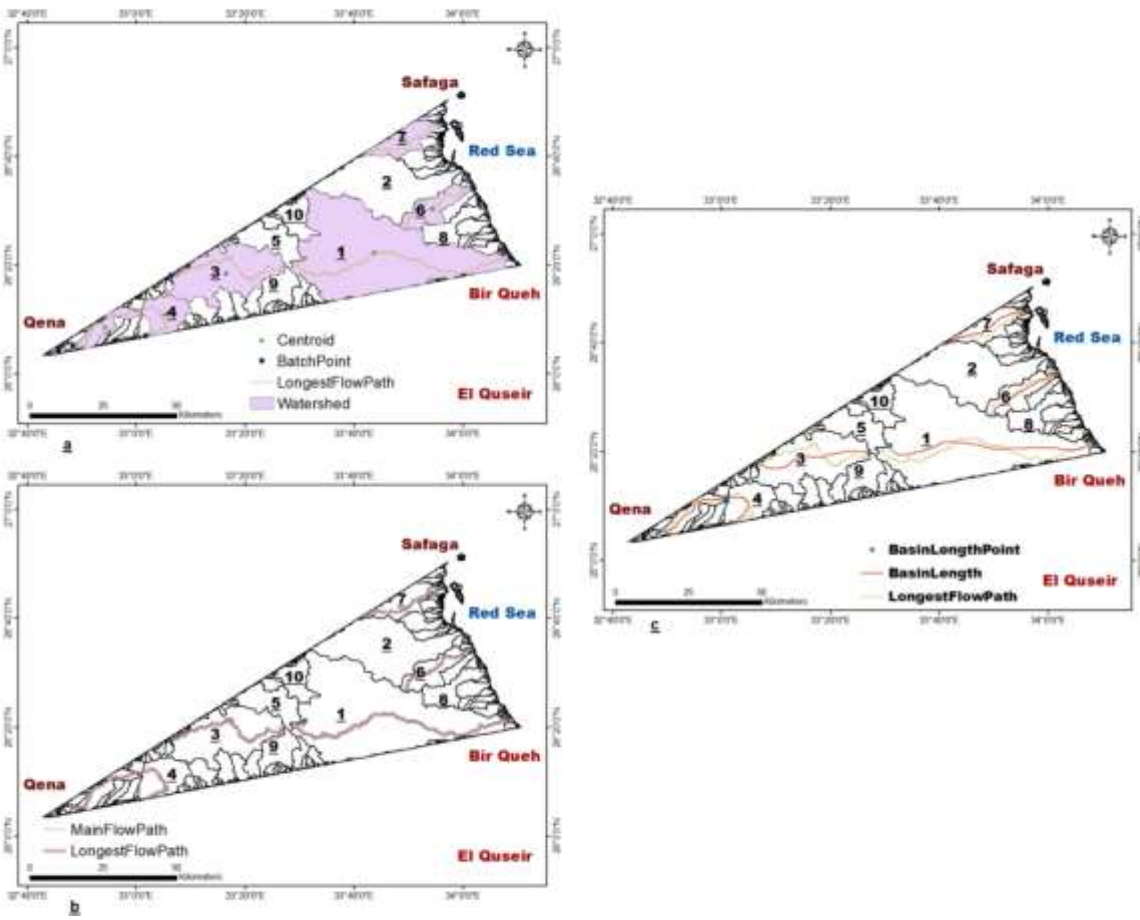


Figure 12. main flow path and basin lengths.

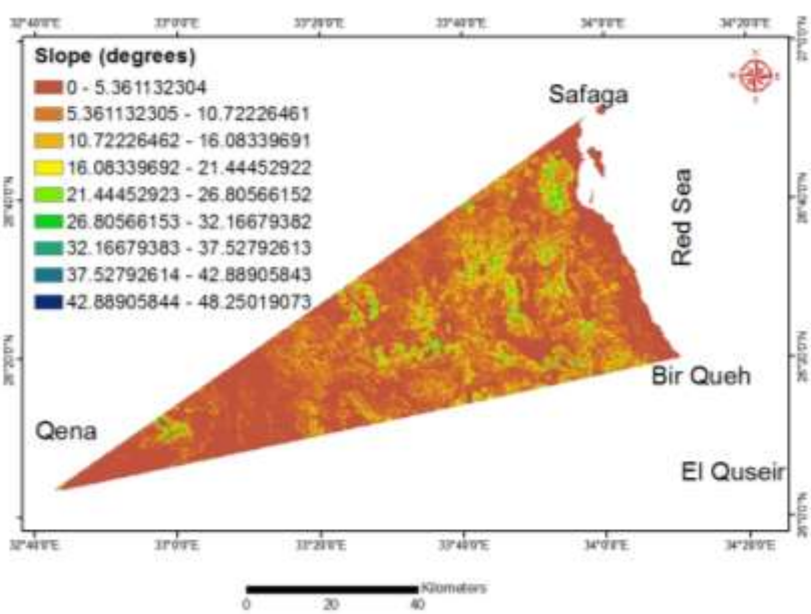


Figure 13. Slope map of the study area.

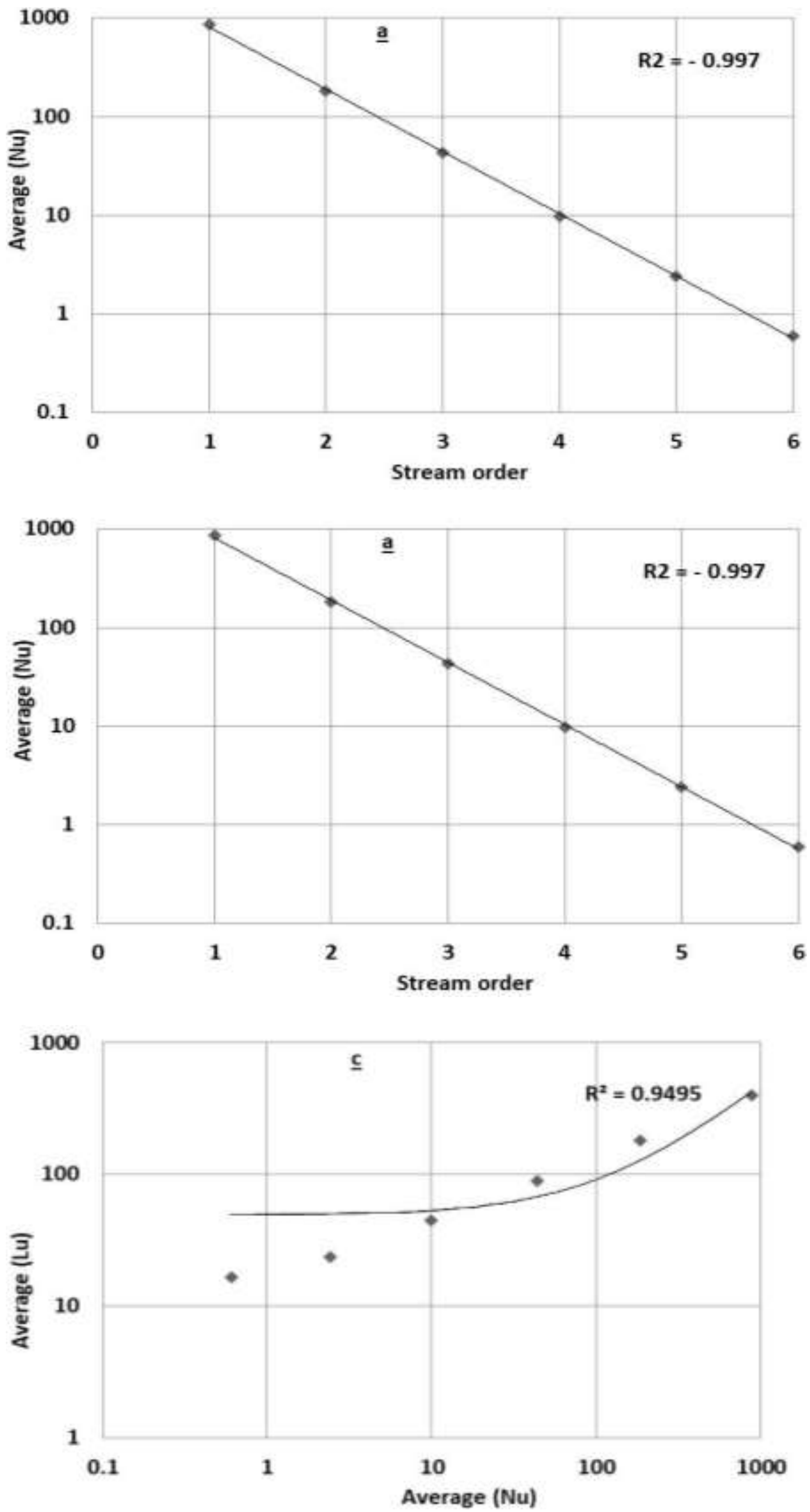


Figure 14. Average stream order vs Nu (a), Lu (b), and Lu vs Nu (c).

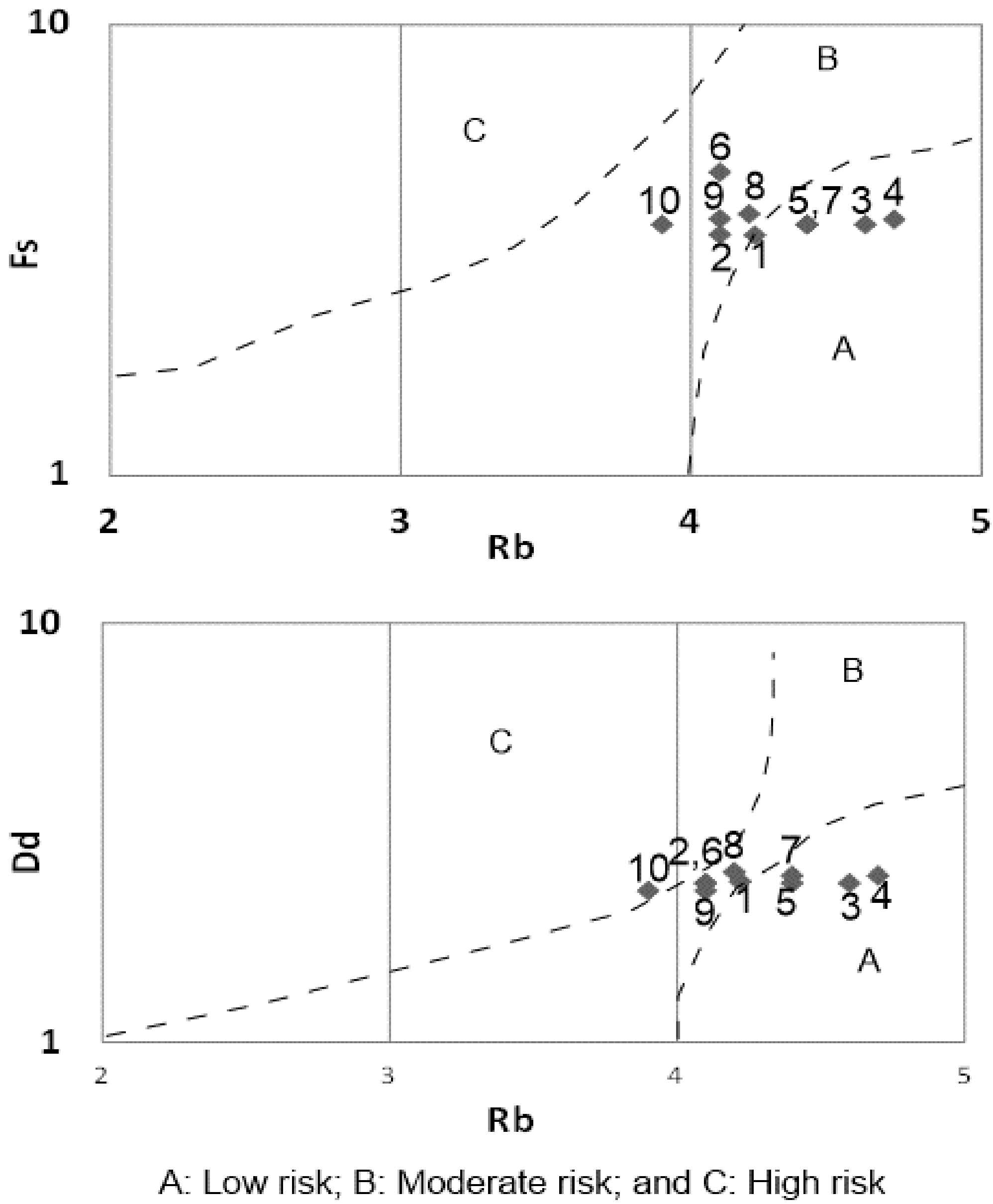


Figure 15. Bifurcation ratio (Rb) vs Fs and Dd.

differences in the geomorphological features. The average value of Rc is 0.32, which is less than one. This clearly indicates that the mega basin is not circular in shape.

Elongation ratio (Re)

Strahler (1964) states the ratio ranges between 0.6 and 1.0 for a wide variety of climatic and geologic types. Re 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 (SA)

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 Wad 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

Table 5. Classification of drainage basins.

		Morphometric characteristics with respect to their weights					
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	881.23
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	0.07	-0.896															
T	Texture ratio	0.03	-0.767	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	

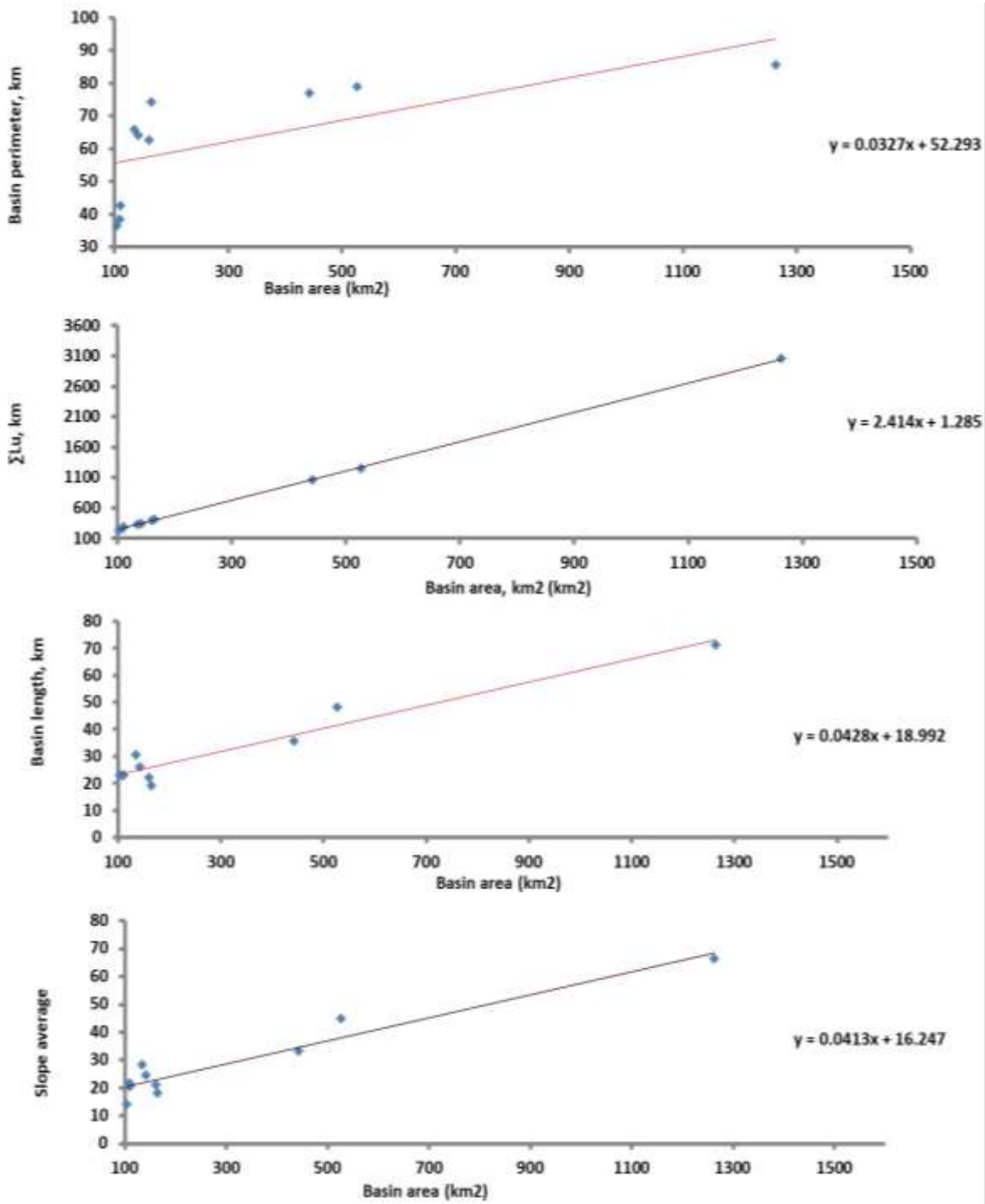


Figure 16. Basin area vs slope average, basin length, Lu, and P.

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

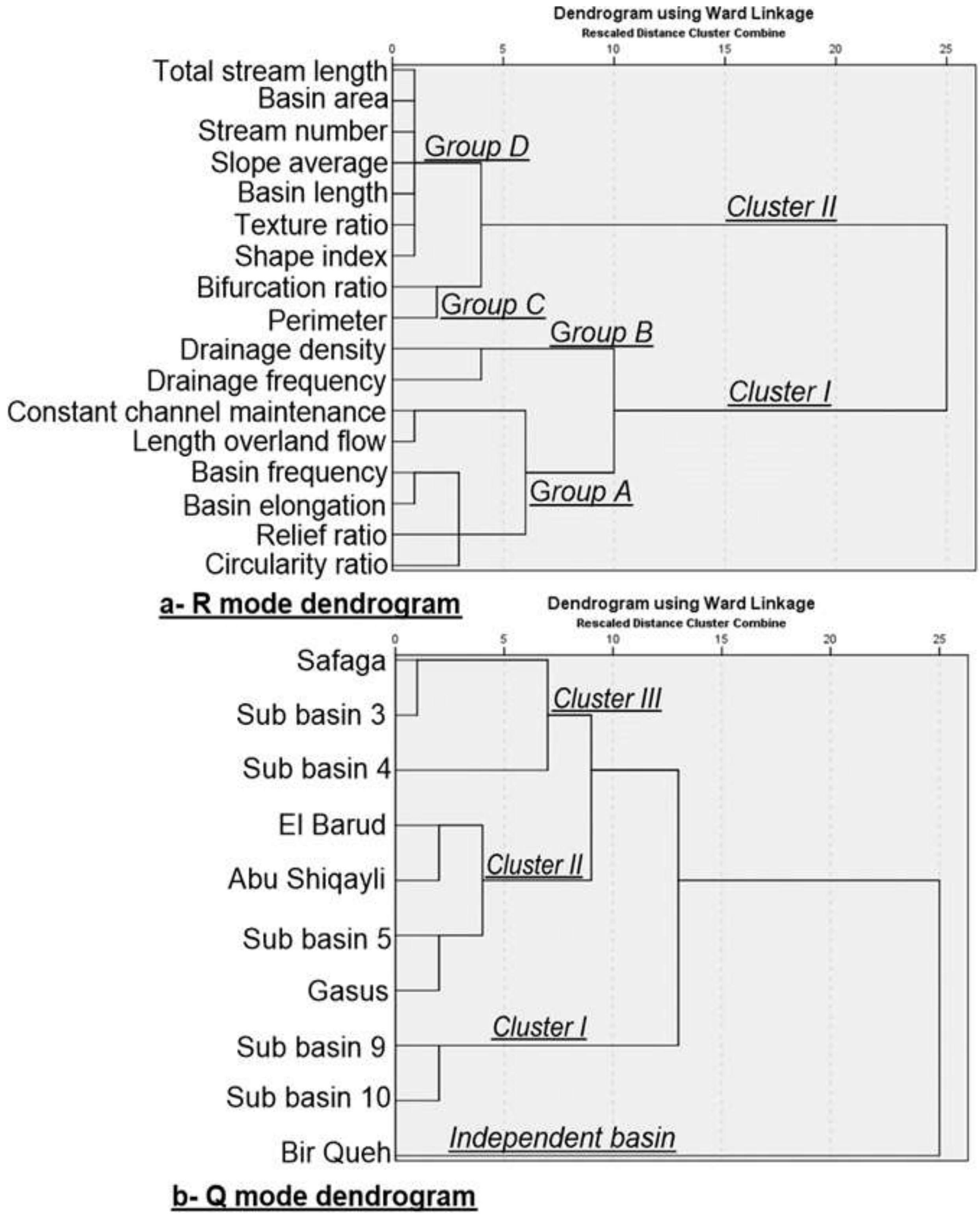


Figure 17. Dendrogram investigation by R (a) and Q (b) modes.

and sub basin 3, followed by sub basin 4. The area geological 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,

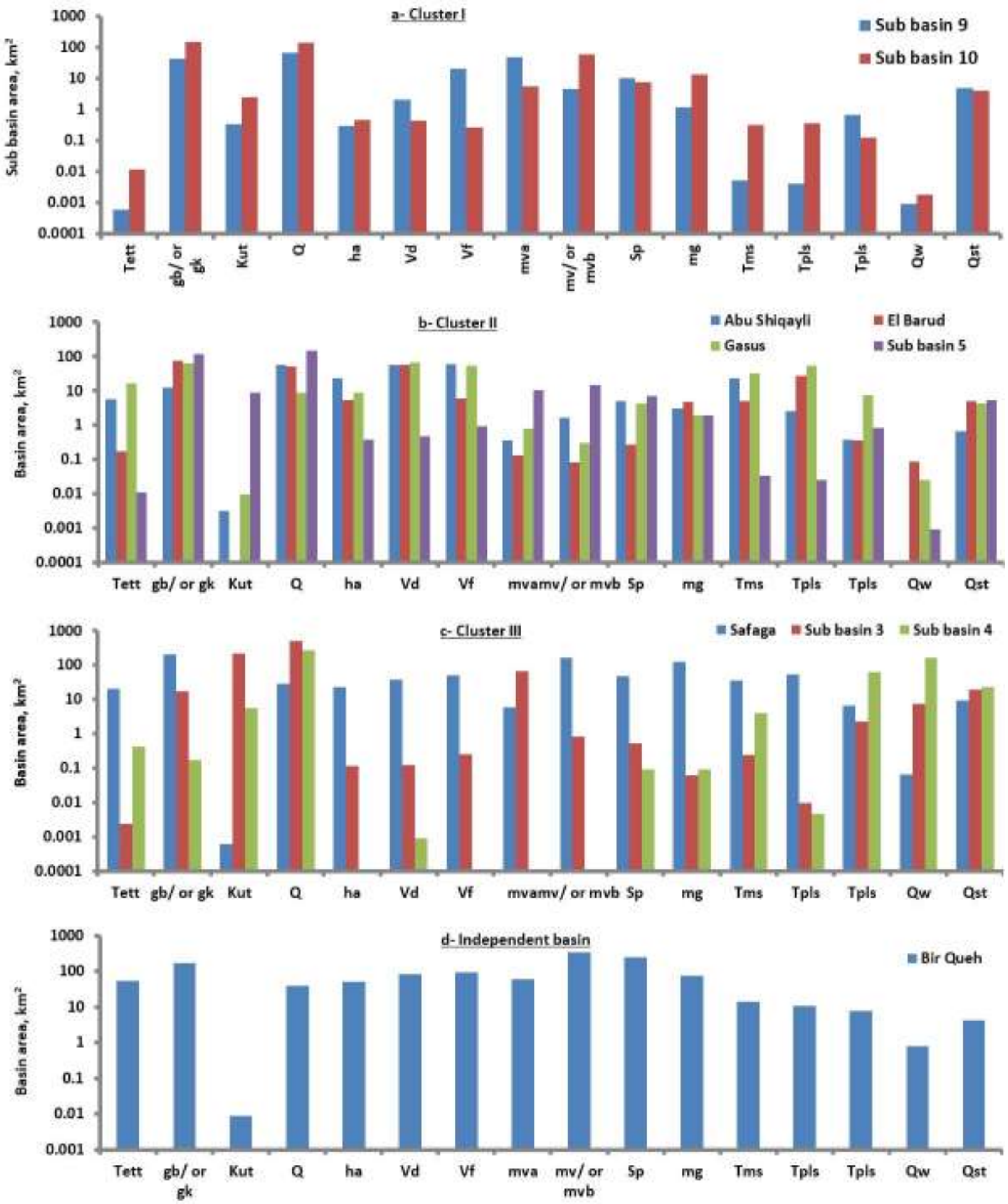


Figure 18. Areal distribution of geology in drainage basins.

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).

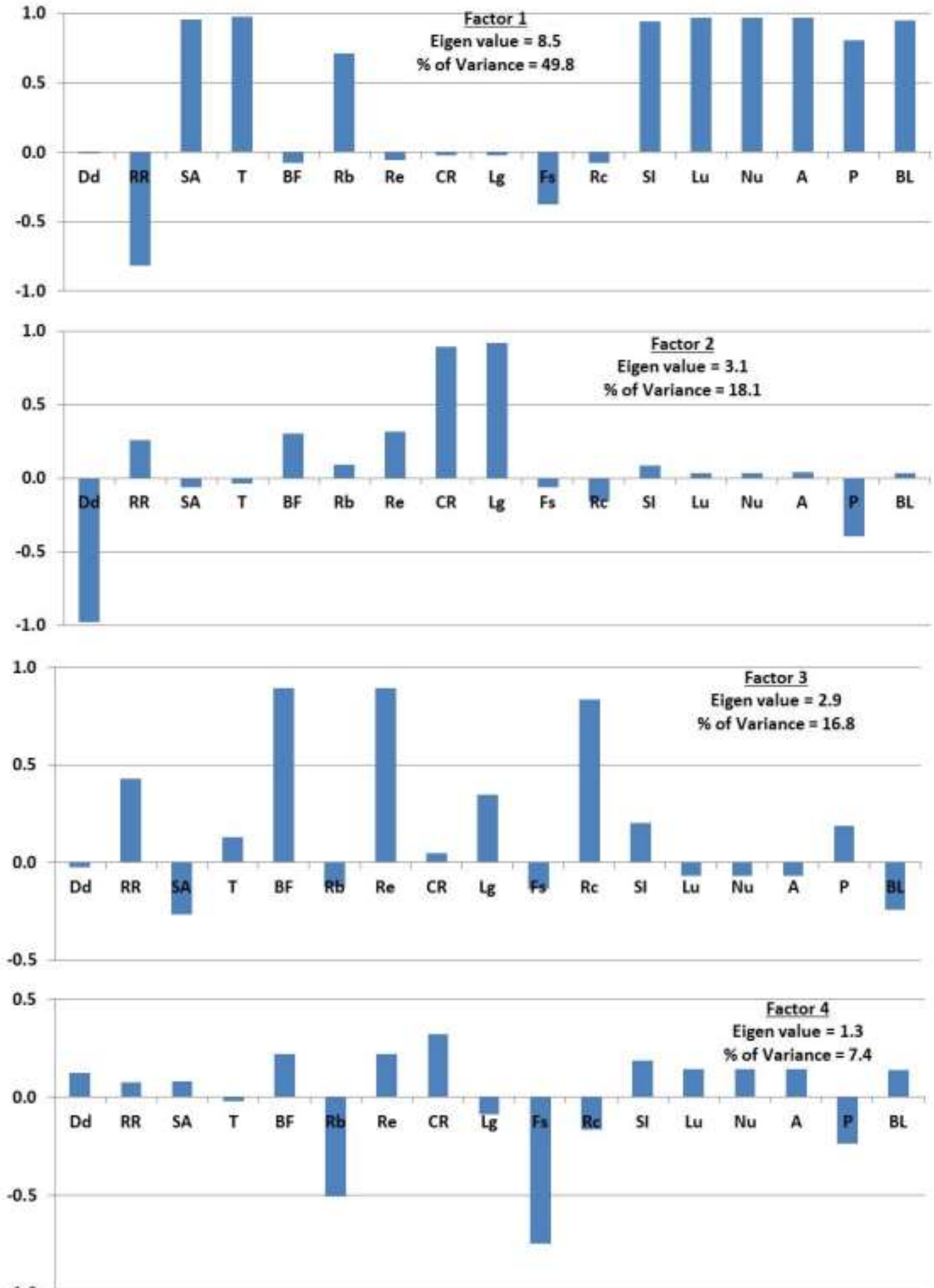


Figure 19. Principle component analysis of hydrological parameters.

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 drainge 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 5^{th} order, while the rest basins have the 6^{th} 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. 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.

REFERENCES

Abdel MA (2004). Overview of the geomorphological and hydrogeological characteristics of the Eastern Desert of Egypt. Hydrogeology Journal 13:416-425.

Ajaykumar KK, Tasadoq HJ, Sanjay SK, Bhavana NU, Rabindranath NS (2019). Identification of erosion prone areas using modified morphometric prioritization method and sediment production rate: a remote sensing and GIS approach. Geomatics, Natural Hazards and Risk 10(1):986-1006.

Al-Saady YI, Qusay A, Balsam SA, Arsalan AO (2016). Drainage network extraction and morphometric analysis using remote sensing and GIS mapping techniques (Lesser Zab River Basin, Iraq and Iran). Environmental and Earth Science 75:1243.

Alther A (1979). A simplified statistical sequence applied to routine water quality analysis: a case history. Ground Water 17:556-561.

Avijit M (2019). The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings. Applied Water Science 10:33.

Badawy M (2008). Applications of Remote Sensing and Geographic Information Systems In Geomorphological Studies. Safaga-El Quseir Area,, Red Sea Coast,, Egypt As An Example. M. Sci. Thesis, Universitat Mainz, 302p.

Benukantha D, Nagaraju MSS, Sahu N, Nasre RA, Mohekar DS, Srivastava R, Singh SK (2019).Morphometric Analysis for Planning Soil and Water Conservation Measures Using Geospatial Technique. International Journal of Current Microbiology and Applied Science 8(01):2719-2728.

Berry K (1995). Spatial reasoning for effective GIS.GIS World Books, Fort Collins EGPC/Conoco, 1987. Photogeological interpretation map, scale (1:100,000). CORALI, Cairo.

Biswas SS (2016). Analysis of GIS Based Morphometric Parameters and Hydrological Changes in Parbati River Basin, Himachal Pradesh, India. Journal of Geography and Natural Disaster 6:175.

DreverIJ (1997). The geochemistry of natural waters. Inc., New Jersey, 436p.

El Ramly IM (1972). Final report on geomorphology, hydrology planning for groundwater resources and reclamation in lake Nasser region and its environs. Cen and Des Inst, Cairo 603p.

EL Shamy IZ (1992). Towards the water management in Sinai Peninsula. Proc. 3rd Conference Geol. Sinai Development, Ismailia, pp. 63-70.

Ewen J, Parkin G, O'Connell P (2010). SHETRAN: distributed riverbasin flow and transport modeling system. Journal of Hydrology Engineering 10:307-314.

Gajbhiye S, Mishra SK, Pandey A (2015). Prioritizing erosion-prone area through morphometric analysis: an RS and GIS perspective. Applied Water Science 4:51-61.

Gheith H, Sultan M (2002). Construction of a hydrologic model for estimating wadi runoff and groundwater recharge in the Eastern Desert, Egypt. Journal of Hydrology 263:36-55.

Gomaa MD, Meraj NM, Khaled AA (2013). Assessment of several flood estimation methodologies in Makkah metropolitan area, Saudi Arabia. Arab Journal of Geoscience 6(4):985-993.

Guler G, Geophrey D, McCray J (2002).Evaluation of graphical and multivariate statistical methods for classification of water chemistry data. Hydrogeology Journal 10:455-474.

Gutema D, Kassa T, and Sifan AK (2017). Morphometric Analysis to Identify Erosion Prone Areas on The Upper Blue Nile Using Gis (Case Study of DidessaAndJema Sub-Basin, Ethiopia). International Research Journal of Engineering and Technology 04(08).

Javed A, Khanday MY, Ahmed R (2009). Prioritization of Sub-Watersheds Based on Morphometric and Land Use Analysis Using Remote Sensing and GIS Techniques. Journal of the Indian Society of Remote Sensing 37:261.

Horton RE (1945). Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. Geological Society of America bulletin 56:275-370.

Judd G (1980). The use of cluster analysis in the derivation of geotechnical classification. Bulletin of the Association of Engineering Geology 17:193-211.

Kotei R, Agyare WA, Kyei-Baffour N, Atakora ET (2015).Morphometric Analysis of the Sumanpa River CatchmentatMampong-Ashanti in Ghana. ARPN Journal of Earth Sciences 4(2).

Magesh N, Jitheshlal K, Chandrasekar N, Jini K (2013). Geographical information system based morphometric analysis of Bharathapuzha river basin, Kerala, India. Applied Water Science 3:467-477.

Patton P, Baker V (1976). Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls. Water Resources Research 12:941-952.

Prakash K, Rawat D, Singh S (2019). Morphometric analysis using SRTM and GIS in synergy with depiction: a case study of the Karmanasa River basin, North central India. Applied Water Science 9:13.

Pareta K, Pareta U (2012).Quantitative geomorphological analysis of a watershed of Ravi River Basin, H. P. India. International Journal of Remote Sensing GIS 1:41-56.

Prasad G (2008). Environmental geomorphology.Discovery Publishing House, New Delhi.

Nikhil Raj PP, Azeez PA (2012).Morphometric Analysis of a Tropical Medium River System: A Case from Bharathapuzha River Southern India. Open Journal of Modern Hydrology 2:91-98.
Rai PK, Mishra VN, Mohan K, (2017). A Study of Morphometric Evaluation of the Son Basin, India Using Geospatial Approach, Remote Sensing Applications: Society and Environment 7:9-20.
Raju NJ, Reddy TVK, Nayudu PT, Reddy GJ (1995). Morphometric analysis of the Upper Gunjanaeru River Basin, Cuddapah District, Andhra Pradesh. Natural Geography Journal India 41:145-153.
Rastogi RA, Sharma TC (1976). Quantitative analysis of drainage basin characteristics. Journal of Soil Water Conservation India 26:18-25. Rummel J (1970). Applied factor analysis. Northwestern University Press, Evanston.
Said R (1962).The Geology of Egypt.Elesvier Publication, Amsterdam.
Said R (1990). The Geology of Egypt. A.A.Balkema/Rotterdam/Brookfield, 734 pp.
Schumm SA (1956). The Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletins 67:597–646.
Smith KG (1950). Standards for grading texture of erosional topography. American Journal of Science 248:655-688.
Strahler AN (1952). Hypsometric (area-altitude) analysis of erosional topography. Bulletin of Geology Society of America 63:1117-1142.
Strahler AN (1957). Quantitative analysis of watershed geomorphology. Transactions American Geophysical Union 38(6):913-920.
Strahler AN (1964). Quantitative geomorphology of drainage basin and channel networks. In: Chow VT (ed) Handbook of applied hydrology.McGraw Hill, New York, pp. 39-76.
Thomas J, Joseph S, Thrivikramji K, Abe G, Kannan N (2012). Morphometrical analysis of two tropical mountain river basins of contrasting environmental settings, the southern Western Ghats, India. Environmental Earth Science 66:2353-2366.
Ward H (1963). Hierarchical grouping to optimize an objective function. Journal of American Statistics Association 69:236-244.
Zavoianu I (1985). Morphometry of drainage basins (developments in water science). Elsevier, Amsterdam.