ISSN 2229-5518

GIS Based Morphometric Analysis of Wadi el-Arish Watershed Sinai, Egypt-Using ASTER (DEM) Data

Hamdeno Abdel Kader al-Awady

ABSTRACT— Projected Digital Elevation Model (ASTER-DEM-30m) and Geographical Information Systems (GIS) techniques were prepared and used to evaluate the morphometric aspects of Wadi el-Arish watershed. Results of morphometric parameters such as linear (one dimension), areal (two dimensions) and relief (three dimensions) aspects revealed that the drainage area of Wadi el-Arish watershed occupy an area of about 23,765 sq.km. According to Strahler ordering, the investigated drainage watershed has seven stream orders with dendritic drainage pattern and homogeneous nature. Five sub-watersheds namely (Wadi el-Hasana, Wadi el-Bruk, Wadi el-Roak, Wadi Aqabah and Wadi Abu Qurayah) are reached to the sixth stream orders; they were selected for a detailed morphometric study. Morphometric analysis indicates that the Wadi el-Arish watershed and sub-watersheds tend to be elongated and the basin drainage density was considered to be low as well as stream frequency and bifurcation ratio indicating the surface runoff has low to moderate potential during the normal precipitation events. On the other hand, Wadi el-Arish watershed as a whole and sub-watersheds are characterized by high to moderate relief. Furthermore, the hypsometric integral (HI) indicates that the watershed of Wadi el-Arish is in monadnock or old stage, indicating the basin is fully stabilized. Accordingly, the basin's area has a good groundwater prospect can be used to agricultural activity. The present study may be useful in water resources management for sustainable development.

Keywords— Digital Elevation Model (DEM), Geographical Information systems, Morphometric Analysis, Morphometric parameters, Sinai, Stream's orders, Wadi el-Arish watershed

---

1. INTRODUCTION

DRAINAGE basin or watershed is a basic unit in morphometric analysis because all the hydrologic and geomorphic processes occur within the watershed where denudation and aggradation processes are most explicitly manifested. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [1], [2]. A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks [3], [4], [5]. Most previous morphometric analyses were based on arbitrary areas or individual channel segments. Using watershed as a basic unit in morphometric analysis is the most logical choice. A watershed or drainage basin is the surface area drained by a part or the totality of one or several given water courses and can be taken as a basic erosional landscape element where land and water resources interact in a perceptible manner. In fact, the modern approach of quantitative analysis of drainage basin morphology was given inputs by Horton (1945)[3] the first pioneer in this field. Horton's laws were subsequently modified and developed by several geomorphologists, most notably by Strahler [6],[7],[8],[9], Schumm [10], Scheidegger [11], Shreve [12], and Gregory [13]. Subsequently a number of books have further propagated the Morphometric analysis.

The morphometric analysis is done successfully through measurement of linear, aerial, and relief of the watershed [3], [9], [21], [23]. A widely acknowledged principle of morphometry is that drainage basin morphology reflects various geological and geomorphological processes over time, as indicated by various morphometric studies [3], [6], [9], [12, 14], [15]. It is well established that the influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. The Digital Elevation Model (DEM) of the study area was generated to extract the morphometric parameters such as drainage basin area, drainage density, drainage order, relief and other network characteristics. The geographic and geomorphic characteristics of a drainage basin are important for hydrological investigations involving the assessment of surface water and groundwater potential.

The present study aims to study the morphometric characteristics of Wadi el-Arish watershed and its sub-watersheds using RS & GIS techniques and also to provide basic information and maps that can be used for assessing groundwater potential, basin management and environmental assessment in the investigated area.

• *Hamdeno Abdel Kader el-Awady is currently Prof. of physical Geography & GIS in Department of Geography and GIS, Alexandria University, Alexandria, Egypt.*

ISSN 2229-5518

2. STUDY AREA

Wadi el-Arish Watershed is considered the largest drainage basin in Sinai Peninsula, where it is located between latitudes 29°00`18``- 31°08`52``N and longitudes 33°04`31``- 34°45`45``E (Fig.1) covering an area of about 23765 km². More than 91% (21669 km²) of its area lies in Sinai, while the rest area (2096 km²) is located in el-Naqb Desert. Wadi el-Arish drains the central highlands of Sinai, its upstream tributaries originate from el-Teeh and el-Egma plateaus. The longest water path is 276 km, starting from el-Teeh Plateau at a level of 1632 m above sea level and ending at el-Arish City at zero level. This Wadi passes through different geological and morphological units, its upper tributaries drain from the mountainous region of extreme steep slopes in the south, then runs in meandering nature through the area of sedimentary rocks with moderate slopes in the middle, and finally ends at extensive sand dune and sand sheet fields near el-Arish City in the north.

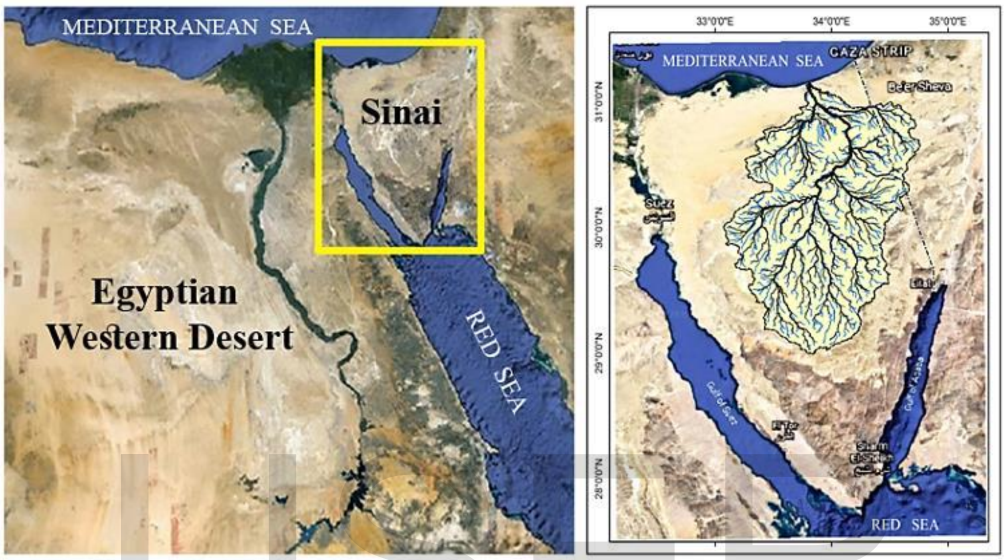

Fig. 1: Location of Wadi el-Arish watershed.

2.1. Geomorphologic and Geologic Setting

Three main geomorphic units are distinguished in Wadi el-Arish watershed namely (Central Plateaus, Hilly Area and Northern Coastal Plains) each of which has different geological characteristics [16], [17]. From the south to the north are:

The elevated plateaus (el-Teeh and el-Egma) are located in central portion of Sinai and in the southern upstream portion of Wadi el-Arish watershed, they cover an area of about 13000 sq.km. The maximum ground elevation of these plateaus attains about 1626 m above mean sea level (a.m.s.l), while the minimum level reaches 523 m (a.m.s.l). The bedrock is predominantly composed of horizontally bedded Middle and Lower Cretaceous sandstones and Eocene limestone. Wadi el-Arish and its tributaries cut deep and narrow gorges in the Eocene and Cretaceous formations (Fig. 2).

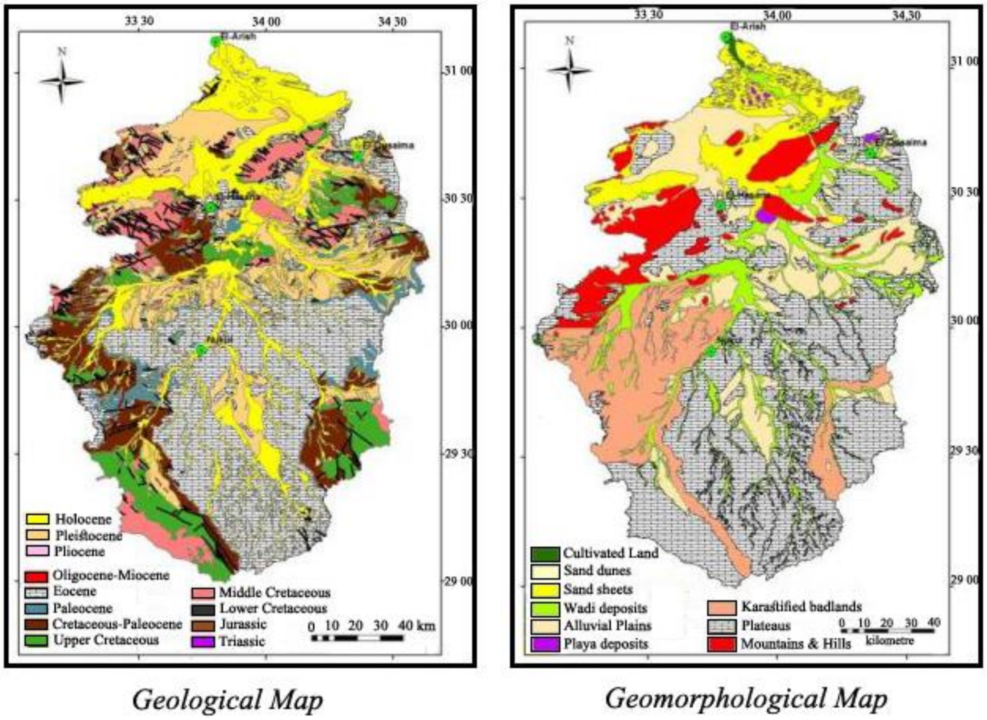

Figure 2: Geologic and Geomorphologic Maps of Wadi el-Arish watershed (Modified after Geological survey of Egypt, 1994 [41],and Abdel Ghaffar, et al., 2015)[18]

The hilly area occupies the northeastern portion of Sinai as well as the central portion of Wadi el-Arish watershed. It covers an area of about 17,000 sq.km. It is characterized by isolated hills as Gebel El Magharah (750m), Gebel Yelleq (1087m), Gebel El Halal (892m) and others. These hills are formed of elongated doubly plunging dome-like anticlines arranged in northeast-southwest direction (Syrian Arc trend). The strata that form the anticlines are predominantly Cretaceous limestone, dolomite marl and sandstone. Outliers of Eocene chalk and limestone occur in the synclinal lowlands between the anticlines.

The northern coastal plain (downstream part of Wadi El Arish) is gently undulated and is marked by intensive Quaternary deposits, distributed in wadi's courses and they are occupied vast areas in the northern coastal plain around el-Arish City. The Pleistocene deposits consist mainly of fanglomerate and alluvial deposits, while the Holocene ones consist mainly of playa, sand dune and sand sheet deposits.

It is observed that the rock units constituting these landforms are dissected by major and minor faults and fractures. Three main structure trends are commonly distributed in the Wadi el-Arish Basin; namely: Gulf of Suez trend (NNW), Aqaba trend (NE) and Syrian Arc trend (ENE). As well as from the north an east-west trending shear zone of a major slip fault with up to 2.5 km displacement called Raqabet El Naam fault.

2.2. Climatic Setting

More than twenty meteorological stations in and adjacent to Sinai Peninsula were considered to perform the temperature and rainfall as well as runoff calculation models. Temperature and rainfall data indicated that Wadi el-Arish is a dry basin in nature, where the average summer temperature varies between 25°C and 29°C, reaching a maximum of 43°C. The average long-term winter temperature is 10°C to 11°C with a minimum of 3°C. These variations are expected because of the differences in position, elevation, and distance from the coast and the environment around the stations [19]. In general, the temperature increases from north to south and from east to west. The summer daily temperatures are relatively constant whereas they fluctuate in winter hence, warm and nice days are quickly followed by cold cloudy ones with potential of short rainfall events with high intensity that may result in flash floods.

On the other hand, the main annual rainfall increases northwards and westwards, where it ranges from 22 mm (el-Teeh Plateau in the south) to 40 mm (Gebel el-Maghara in the north). The main annual rainfall increases steadily to the Northwards and northeastwards of Gebel el-Maghara and Gebel el-Halal, reaching 58 mm at Abu Aweigila and about 100 mm at el-Arish City. Wadi el-Arish rainfall is mainly precipitated from November to March. Heavy rainfall has been repeated in many days during winter season under the effect of atmospheric depressions.

3. MATERIALS AND METHODS

The ASTER DEM-30m spatial resolution of Wadi el-Arish watershed re-projected and transformed to the regional projection (WGS-1984, UTM Zone 36 N) as output coordinate system. The watershed of Wadi el-Arish is automatically extracted from the ASTER DEM data using various Geo-Processing Techniques of Arc GIS-10.3. The DEM and the pour point are the two input parameters required for the extraction purpose. A pour point is a user-supplied point to the pixels of highest flow accumulation[20]. Drainage network of the investigated watershed is also extracted from DEM data using available Geo-processing and Hydrologic options of Arc GIS-10.3. Such as fill, flow direction, flow accumulation, raster calculation, depending on (flow accumulation > 1500 & watershed < 0), then stream link, stream to feature (drainage network), stream order and zonal statistics as table. The output of this method is a basis for creating a stream/ drainage network grid with stream order based on Strahler's system (1964)[9]. The output of the drainage network is smoothened using a smooth line tool.

Three major morphometric aspects are grouped and utilized namely: basin geometry and form, Drainage network and relief basin. Some aspects of which such as basin area, basin length, mean basin width, basin perimeter, stream order, stream number, stream length, and mean stream length were extracted from Digital Elevation Model (DEM) and calculated using spatial analyst tools of ArcGIS-10.3 software. Other aspects such as elongation ratio, circularity ratio, form factor, bifurcation ratio, stream frequency, drainage density, basin relief, relief ratio, relative relief, ruggedness ratio and hypsometric integral were computed and evaluated with established mathematical equations (Table.1).

Stream ordering has been generated using Strahler (1964)[9] system. The morphometric linear aspects were studied using the methods of Horton (1945)[3], Strahler (1964)[9], Chorley (1967)[21], the areal aspects using those of Schumm (1956)[10], Strahler (1958, 1964) [8], [9], Miller (1953)[22], and Horton (1932)[23], and the relief aspects employing the techniques of Horton (1945)[3], Melton (1957)[24], Schumm (1954) [25], Strahler (1952)[6], and Pareta (2004) [26].

TABLE 1

PARAMETERS AND METHODS INCLUDED IN MORPHOMETRIC ANALYSIS OF WADI EL- ARISH WATERSHED - COMPARATIVE CHARACTERISTICS

Parameter	Formulae	Reference	M. results
A. Basin Geometry and form			
1. Basin Area (sq.km)	GIS Software Analysis	Schumm (1956)[10]	23765 sq.km
2. Basin Length (km)	GIS Software Analysis	Schumm (1956) [10]	276 km
3. M. Basin Width (km)	$Wb = A / L_b$	Horton (1932) [23]	86 km
4. Basin Perimeter(km)	GIS Software Analysis	Schumm (1956)[10]	1060 km
5. Elongation Ratio (Re)	$(2/L_b)\sqrt{(A/\pi)}$	Schumm (1956)[10]	0.63
6. Circularity Ratio (Rc)	$Rc = {}^{4\pi A}/_{P^2}$	Miller (1953) [22]	0.27
7. Form Factor (Rf)	$Rf = A / {L_b}^2$	Horton (1932) [23]	0.31
B. Drainage Network			
8. Stream Order (Su)	Hierarchical Rank	Strahler (1952) [6]	1-7
9. Stream Number (Nu)	$N_u = N_1 + N_2 +\cdot\cdot N_n$	Horton (1945)[3]	7447
10. Stream Length (Lu)	$L_u = L_1 + L_2 +\cdot\cdot L_n$	Strahler (1964) [9]	19401.99 km
11. M. St. Length (Lum)	$L_{um} = L_u/N_u$	Horton (1945)[3]	1.85-159.8 km
12. Bifurcation Ratio (Rb)	$Rb = N_u/N_u + 1$	Strahler (1964) [9]	3.12-6.71
13. Stream Frequency (Fs)	Fs = Nu / A	Horton (1932)[23]	0.313 sq.km
14. Drainage Density (Dd)	Dd = Lu / A	Horton (1932) [23]	0.816 sq.km
C. Relief Aspects			
15. Basin Relief (H)	H = Z - z	Strahler (1952)	1632 m
16. Relief Ratio (Rh1)	Rhl = H / Lb	Schumm (1956)[10]	5.91 m/km
17. Relative Relief (Rhp)	Rhp = H * 100 / P	Melton (1957) [24]	153.96%
18. Rugg. Number (Rn)	Rn = Dd * (H / 1000)	Strahler (1952) [9]	1.33
19. Hypsometric Integral (HI)	In Text	Pike and Wilson (1971) [39]	0.31

4. RESULTS AND DISCUSSION

The morphometric analysis of Wadi el-Arish watershed and its sub-watersheds was carried out using data of Landsat-ETM+ with 30m spatial resolution and ASTER-DEM with 30m spatial resolution. Results of different morphometric parameters are listed in Tables 2-5.

4.1 Basin Geometry and Form

The most significant geometric and formal aspects of drainage basins are: basin area (A), basin length (Lb), Mean basin width (Mwb) and basin perimeter (P). As well as elongation ratio (Re), circularity ratio (Rc) and form factor (Rf). Some were extracted using spatial analyst tools of Arc GIS 10.3, and others were calculated depending on conventional methods and functions.

ISSN 2229-5518

4.1.1 Basin Area (A)

Although basin area by itself is an important independent variable, it has also been employed to manifest a variety of other parameters, each of which has a particular significance in basin geomorphology, especially in regard to the collection of rainfall and concentration of runoff [27]. Basin area was computed using ArcGIS-10.3 software. Wadi el-Arish Watershed has an area of about 23,765 sq.km, while the area of sub-basins ranges from 2,517 sq.km to 6,381 sq.km, with an average of 3,782.8 sq.km (Table 2). Wadi Aqabah has the lowest basin area, while Wadi el-Roak has the highest basin area. Schumm (1956)[10] established an interesting relation between the total watershed areas and the total stream lengths, which are supported by the contributing areas.

TABLE 2

GEOMETRIC AND FORMAL ASPECTS OF WADI EL-ARISH BASIN AND SUB-BASINS

	Basin	Basin's geometry				Basin's form		
		A (km2)	Lb (km)	Mwb (km)	P (km)	Re	Rc	Rf
	Wadi el-Arish Basin	23765	276	86	1060	0.63	0.27	0.31
Sub-basins	el-Hasana	3606	91	40	359	0.74	0.35	0.44
	el-Bruk	3326	102	33	369	0.64	0.31	0.32
	el-Roak	6381	136	47	499	0.66	0.32	0.34
	Aqabah	2517	96	26	350	0.59	0.26	0.27
	Abu Qurayah	3084	73	42	350	0.86	0.32	0.58
	average	3782.8	99.6	37.6	385.4	0.70	0.31	0.39

4.1.2 Basin Length (Lb)

Basin length has defined in different ways, for example, Schumm (1956)[10] defined the basin length as the longest dimension of the basin parallel to the principal drainage line. Gregory and Walling (1968)[13] defined the basin length as the longest in the basin in which are end being the mouth. Gardiner (1975)[28] defined the basin length as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter. According to the definition of Schumm (1956)[10] the length of Wadi el-Arish Basin is 276 km and the investigated sub-basin lengths range from 73 km to 136 km, with an average of 99.6 km (Table 2). In general, the basin area and the basin length both are proportional and they show almost positive relationship.

4.1.3 Mean Basin Width (Mwb)

The basin's width affects the precipitation level and flooding flow [29]. The measured mean width (A/Lb) of Wadi el-Arish watershed is 86 km and the width of investigated sub-watersheds ranges from 26 km to 47 km, with an average of 37.6 km (Table 2). Although, some sub-watersheds (Aqabah and el-Bruk) are narrow, others (el-Roak, Abu Quryah and el-Hasana) in comparison are wider, lead to increasing the volume of infiltration and evaporation, especially at the flat and gentle slope surfaces.

4.1.4 Basin Perimeter (P)

Basin perimeter which is the outer boundary of the watershed that enclosed its area, has measured using ArcGIS-10.3 software. Perimeter of Wadi el-Arish watershed is 1060 km, and its sub-watershed perimeters range from 350 km to 499 km, with an average of 385 km (Table 2). In general, the geometric characteristics of drainage basins are considered as significant affected aspects especially in the precipitation level, infiltration, and evaporation as well as surface runoff.

4.1.5 Elongation Ratio (Re)

Elongation ratio is a very significant index in the analysis of watershed's shape which helps to give an idea about the hydrological character of a watershed. Schumm (1956)[10] defined the elongation ratio (Re) as the ratio of a circle's diameter of the same area as the basin to the maximum basin length. The varying slopes of drainage basin can be classified with the help of the index of elongation ratio, i.e. circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (< 0.5). Regions with low elongation ratio values are susceptible to more erosion whereas regions with high values correspond to high infiltration capacity and low runoff. The elongation ratio of Wadi el-Arish watershed is 0.63, indicating that the watershed is elongated and has high infiltration capacity as well as low runoff. The Re Values of the sub-watersheds range from 0.59 to 0.86 with an average of 0.70 (Table 2). Some of sub-watersheds (el-Bruk, el-roak and Aqabah) are elongated and have high infiltration capacity and low runoff; however the others (el-Hasana and Abu Qurayah) ate less elongated and have moderate infiltration capacity as well as runoff. Many authors have noted that the flow of water in elongated basins is distributed over a longer period than either in less elongated or circular ones.

4.1.6 Circularity Ratio (Rc)

Miller (1953) [22] defined a dimensionless circularity ratio (Rc) as the ratio of basin area to the area of a circle having the same perimeter as the basin and it is pretentious by the lithological character of the watershed. He has described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The Rc value of the watershed as a whole is 0.27, while it ranges in sub-watersheds from 0.26 to 0.35 with an average of 0.31 (Table 2) indicating that the watershed of Wadi el-Arish and its sub-watersheds are tending to elongated in shape, low discharge of runoff and highly permeability of the subsoil condition.

4.1.7 Form Factor (Rf)

Horton (1945)[3] stated form factor as the ratio of the area of the basin and square of the basin length. Strahler (1964) [9] noted that the shape of a drainage basin may conceivably affect stream discharge characteristics. The value of form factor would always be greater than 0.78 for a perfectly circular basin. Basins of low value of form factor are more elongated, less intense rainfall simultaneously and also have lower peak runoff of longer duration over its entire area than an area of equal size with a large form factor [30]. Accordingly, the Rf of Wadi el-Arish watershed as a whole is 0.31 indicating that the watershed is an elongated and experience low peak flows for long duration. The Rf of the sub-basins ranges from 0.27 (Wadi Aqabah) to 0.58 (Wadi Abu Qurayah) with an average of 0.39 indicating that they are elongated in shape and have attenuated discharge periods.

4.2 Drainage Network

The most significant linear aspects of drainage network are: stream order, bifurcation ratio, stream frequency and drainage density. Some were extracted using spatial analyst tools of Arc GIS 10.3, and others were calculated depending on conventional methods and functions.

4.2.1 Stream Order (Su)

There are available different systems of ordering stream networks [3], [6], [12, 31]. In Strahler's system, a segment with no tributaries is designated as a first-order stream. Where two first-order segments join they form a second-order segment; two second-order segments join to form a third-order segment, and so on. Any segment may be joined by a channel of lower order without causing an increase in its order. Only where two segments of equal magnitude join are an increase in order required. The trunk stream is the stream segment of highest order [27]. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964) [9] using GIS software. Details of stream order of Wadi el-Arish drainage network is shown in the Table 3. The main channel of Wadi el-Arish is designated as a seventh-order stream, only five tributaries are reached to sixth-order stream (Table 3 & Fig. 3).

4.2.2 Stream Number (Nu)

As per Horton's law (1945)[3] of stream numbers, "the number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio". The maximum stream order frequency is observed in case of first-order streams and then for second order. In all 7447 drainage lines were identified of which 5242 (70.39%) are first order, 1680 (22.56%) are second order, 436 (5.86%) are third order, 65 (0.87%) are fourth order, 18 (0.24%) are fifth order and only 5 (0.07%) comprise the sixth order (Table 3). it is noticed that there is a decrease in stream frequency as the stream order increases and vice versa.

4.2.3 Stream Length (Lu)

Stream length is one of the most important hydrological aspect of the area as it gives information about surface runoff characteristics. The stream length is a measure of the hydrological characteristics of the bedrock and the drainage extent. Wherever the bedrock and formation is permeable, only a small number of relatively longer streams are formed in a well-drained watershed, a large number of streams of smaller length are developed where the bedrocks and formations are less permeable. Stream length data (Table 3) indicates that the total stream length of Wadi el-Arish network is 19402 km. In general, the stream length is inversely proportional to the stream order. First order has highest cumulative length of streams, it has 9710 km (50.05%), second order stream is 4935 km (25.44%), third order stream is 2578 km (13.29%), fourth order stream is 1229 km (6.33%), fifth order stream is 545 km (2.81%), sixth order stream is 246 km (1.27%) and seventh order of the main channel is 160 km (0.82%). It is clearly identified that the cumulative stream length is higher in first-order streams and decreases as the stream order increases. These may be due to the variations in rock/soil types, vegetation and slope in these sub basins. Hence, the stream length is an indicator of the relation between the climate, vegetation, and the resistance rock and soil to erosion. Under similar climatic conditions, impervious rocks exhibit a longer stream length.

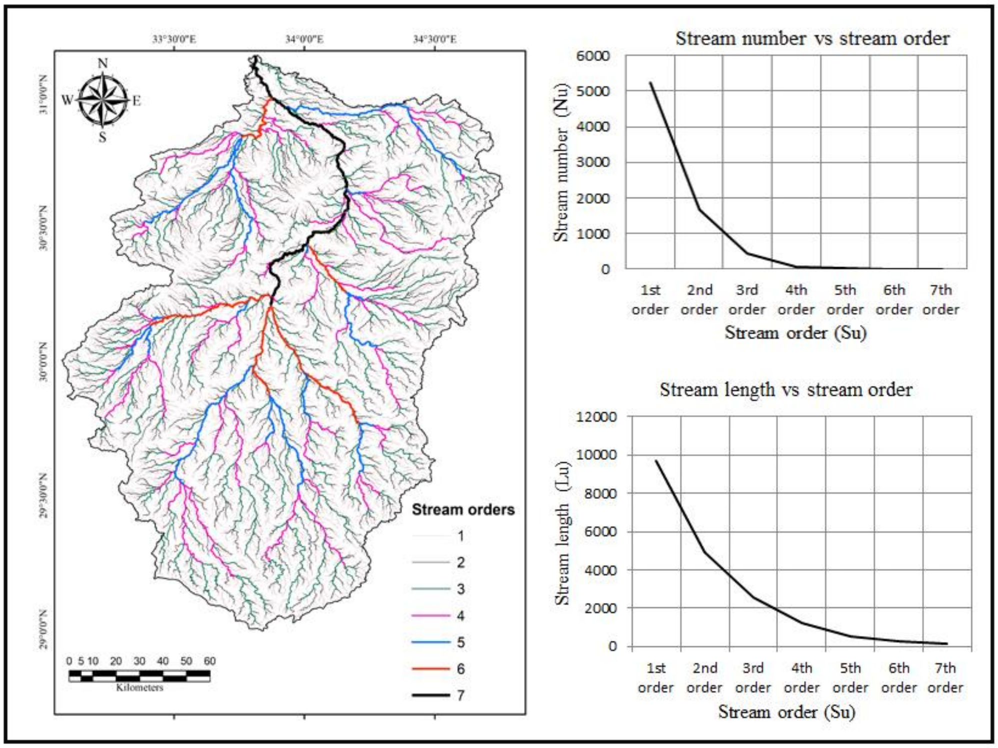

Fig. 3: Drainage network of Wadi el-Arish watershed and Stream number, Stream length vs Stream order.

4.2.4 Mean Stream Length (Lum)

Mean Stream length (Lum) is a dimensional property revealing the characteristic size of components of a drainage network and its contributing watershed surfaces[9]. The mean stream length has been calculated by dividing the total length of stream of an order by total number of segments in the order. Mean stream length (km) of the drainage networks under investigation based on stream order is shown in the Table 3. The mean stream length of first order stream is 1.85 km, second order stream is 2.94 km, third order stream is 5.91 km, fourth order stream is 18.90 km, fifth order stream is 30.29 km, sixth order stream is 49.22 km, and seventh order stream is 159.78 km. It is clearly observed that the Lum values increase with increase of the stream order. The Lum values differ with respect to different basins, as it is directly proportional to the size and topography of the basin. Strahler (1964) indicated that the Lum is a characteristic property related to the size of drainage network and its associated surfaces.

TABLE 3

STREAM ORDERS, STREAM NUMBERS, STREAM LENGTH (KM) OF WADI EL-ARISH WATERSHED

St. Order (Su)	St. Number (Nu)	St. Length (Lu)	M. St. Length (Lum)	A (km^2)	Am (km^2)
1^{st} order	5242	9709.73	1.85	11883.21	2.267
2^{nd} order	1680	4934.54	2.94	6051.76	3.602
3^{rd} order	436	2577.94	5.91	3157.66	7.241
4^{th} order	65	1228.73	18.90	1505.98	23.169
5^{th} order	18	545.16	30.29	667.79	37.099
6^{th} order	5	246.11	49.22	301.34	60.268
7^{th} order	1	159.78	159.78	196.06	196.06
Total	7447	19401.99	-	23763.80	-

4.2.5 Bifurcation Ratio (Rb)

Depending on Strahler ordering, the bifurcation ratio (Rb) is defined as the ratio of the number of the stream segments of a given order (Nu) to the number of streams in the next higher order (Nu+1). Horton (1945)[3] considered the bifurcation ratio as index of relief and dissertation. Strahler (1957) demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. The bifurcation ratio is dimensionless property and generally ranges from 3.0 to 5.0. The lower values of Rb are characteristics of the watersheds, which have affectless structural elements [9].

The bifurcation ratio (Rb) of Wadi el-Arish drainage network varies from 3.12 to 6.71 with mean bifurcation ratio equal 4.32. The mean bifurcation ratio values of sub-watershed drainage networks vary from 3.10 to 4.64 with general average of 4.06 (Table 4) these values may show little difference in the environmental conditions of the sub-watersheds as well as they have low runoff potential.

TABLE 4

BIFURCATION RATIO (RB) OF WADI EL-ARISH WATERSHED AND SUB-WATERSHEDS.

	Stream orders	1/2	2/3	3/4	4/5	5/6	6/7	Mean
Wadi el-Arish Basin		3.12	3.85	6.71	3.61	3.60	5.00	4.32
Sub-basins	el-Hasana	4.25	3.94	4.36	3.67	3.00	-	3.84
	el-Bruk	4.43	3.77	4.30	2.5	4.00	-	3.80
	el-Roak	5.00	4.58	5.00	4.00	3.00	-	5.12
	Aqabah	4.17	5.15	4.33	2.00	3.00	-	3.73
	Abu Qurayah	5.34	4.78	2.70	3.33	3.00	-	3.83
	average	4.64	4.44	4.14	3.10	3.20	-	4.06

4.2.6 Stream Frequency (Fs)

Stream frequency (Fs) is the total number of stream segments of all orders per unit area [23]. Stream frequency mainly depends on the lithology of the basin and reflects the texture of the drainage network. This study indicated that the Fs value of Wadi el-Arish drainage network as a whole is 0.313 km/sq.km, while the values of the sub-watersheds drainage networks range from 0.271 to 0.293 km/sq.km, with an average of 0.283 km/sq.km (Table 5), indicating the increase in stream population with respect to increase in drainage density.

TABLE 5

STREAM FREQUENCY (FS) AND DRAINAGE DENSITY (DD) OF WADI EL-ARISH WATERSHED AND SUB-WATERSHEDS

	Basin	Nu	Lu (km)	A (sq.km)	Fs	Dd
Wadi el-Arish Basin		7447	19401.99	23765	0.313	0.816
Sub-basins	el-Hasana	1055	3357	3606	0.293	0.931
	el-Bruk	937	2972	3326	0.282	0.894
	el-Roak	1727	5227	6381	0.271	0.819
	Aqabah	729	2029	2517	0.290	0.806
	Abu Qurayah	859	2522	3084	0.279	0.818
	average	-	-	-	0.283	0.854

4.2.7 Drainage Density (Dd)

Drainage density (Dd) is a measure the total stream length in a given basin to the total area of the basin [9]. It is significant aspect of drainage network analysis. Drainage density is related to various features of landscape dissection such as valley density, channel head source area, relief, climate, and vegetation [32], soil and rock properties[33] and landscape evolution processes. As these factors vary from region to region, large variations in Dd can be expected. In general, resistant surface materials and those with high infiltration capacities exhibit widely spaced streams, consequently yielding low Dd. As resistance or surface permeability decreases, runoff is usually accentuated by the development of a greater number of more closely spaced channels, and thus Dd tends to be higher [27] . Drainage density of Wadi el-Arish watershed is 0.816 km/sq.km, and it was ranged from 0.806 to 0.931 km/sq.km, with an average of 0.854 km/sq.km (Table 5). These values indicate that watershed of Wadi el-Arish has a highly permeable subsurface material with low drainage density and low runoff potential.

4.3 Relief Aspects

The most significant relief aspects of drainage basin are: the total relief (H), relief ratio (Rh1), relative relief (Rhp), ruggedness number (Rn) and hypsometric integral. Some were extracted using spatial analyst tools of Arc GIS 10.3, and others were calculated depending on conventional methods and functions (Table 6).

4.3.1 Basin Relief (H)

Basin relief is the maximum vertical distance between the highest and the lowest points of a basin. It is an important factor in understanding the denudation characteristics of the basin. Basin relief (H) of Wadi el-Arish watershed is 1632 m, while the basin relief of the sub-watersheds ranges from 768 m to 1327 m, with an average of 1071.83 m (Table 6 & Fig. 4) indicating the textural dissection of the investigated watershed and sub-watersheds was considered to be high and the land has moderate to steep slope.

TABLE 6
RELIEF ASPECTS OF WADI EL-ARISH WATERSHED AND ITS SUB-WATERSHEDS

	Basin	z (m)	Z (m)	H (m)	Rh1 (m/m)	Rh1 (m/km)	R_{hp} (%)	Rn
Wadi el-Arish Basin		0	1632	1632	0.0059	5.91	153.96	1.33
Sub-basins	el-Hasana	45	1077	1032	0.0113	11.34	287.47	0.96
	el-Bruk	288	1072	784	0.0077	7.69	212.47	0.70
	el-Roak	305	1632	1327	0.0098	9.76	265.93	1.09
	Aqabah	305	1193	888	0.0093	9.25	253.71	0.72
	Abu Qurayah	231	999	768	0.0105	10.52	219.43	0.63
	average	195.67	1267.5	1071.83	0.009	9.08	232.16	0.91

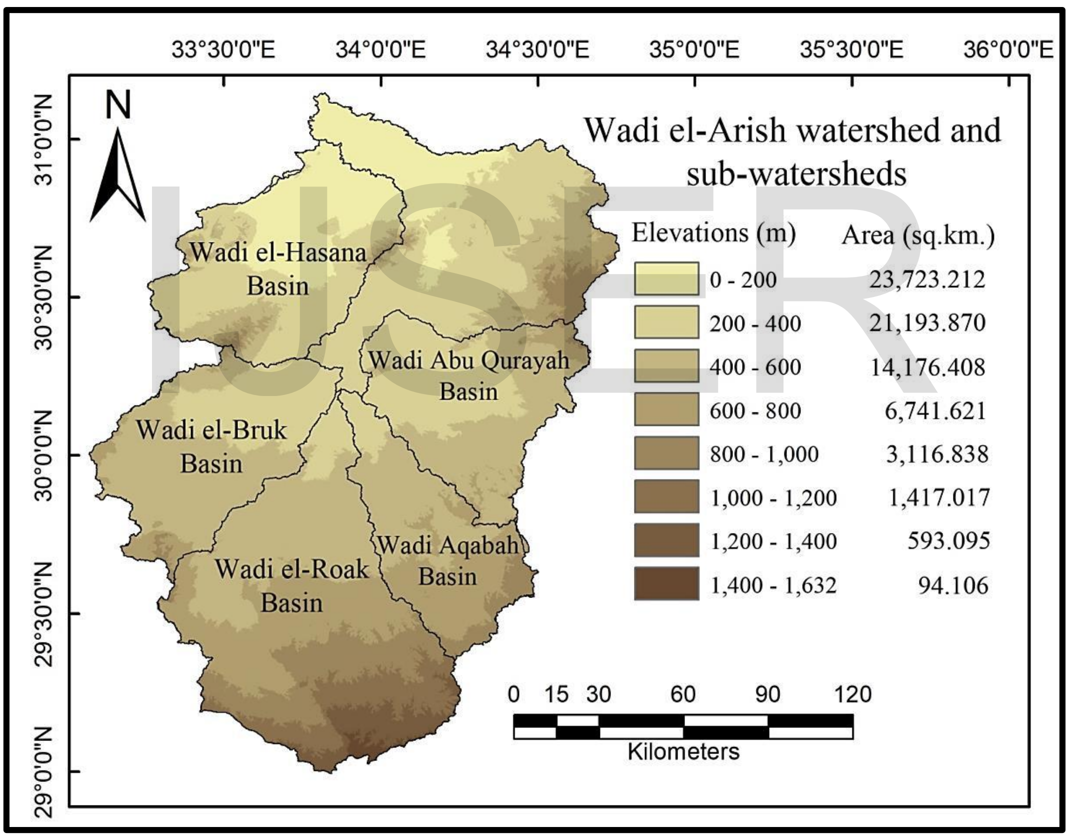

Fig 4: The relief (Earth's surface elevation) of Wadi el-Arish watershed

4.3.2 Relief Ratio (Rh1)

The relief ratio is defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956)[10]. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin suggested by Schumm (1956)[10] who found that sediments loose per unit area is closely correlated with relief ratios. As given in Table 6 the value of relief ratio in Wadi el-Arish watershed is 5.91 m/km, indicating moderate relief and moderate slope, while those of the sub-watersheds are ranged from 7.69 m/km (el-Bruk) to 11.34 m/km (el-Hasana), with an average of 9.08 m/km. The higher values may indicate the presence of sedimentary rocks that are exposed in the area with higher degree of slope. While the low values of relief ratio are mainly attributed not only to the common flat and gentle slopes, but also to highly permeability of the subsoil condition. Therefore, wide area around valley sides and their alluvial fans could be basically used for agricultural activities, depending on winter rainfall and available underground water.

4.3.3 Relative Relief (Rhp)

Relative relief is an important morphometric variable used for the assessment of morphological characteristics of any topography [34]. Relative relief of Wadi el-Arish watershed and sub-watersheds was calculated using Melton's formula. It was 153.96% in the watershed as a whole, while it was ranged from 212.47% to 287.47% with an average of 232.16% (Table 6). These higher values indicate that the steep slopes are dominated especially in the upper portions of Wadi el-Arish watershed.

4.3.4 Ruggedness Number (Rn)

Strahler (1964) [9] describes ruggedness number (Rn) as the product of maximum basin relief (H) and drainage density (Dd) and it usually combines slope steepness with its length. Extremely high values of ruggedness number occur when slopes of the basin are not only steeper but also long. The value of ruggedness number in Wadi el-Arish watershed is 1.33 and in the sub-watersheds range from 0.63 (Abu Qurayah) to 1.09 (el-Roak) with an average of 0.91 (Table 6). Therefore, the textural dissection of Wadi el-Arish watershed was considered to be high, although the drainage density and stream frequency are not.

4.3.5 Hypsometric Integral (HI)

Hypsometric integral is important indicator of watershed conditions [27]. Its value is controlled by basin geometry, relief and area of drainage basin [35], [36], [15], [37]. It was also found by Strahler (1952)[6] that the hypsometric integral is inversely correlated with total relief, slope steepness, drainage density and channel gradients. The geologic stages of landforms development and erosional status of the watersheds are quantified by hypsometric integral. High value of hypsometric integral indicates the youthful stage of less eroded areas and it decreases as the landscape is denuded towards the maturity and old stages. The HI is expressed as a percentage and is an indicator of the remnant of the present volume as compared to the original volume of the basin [27]. The hypsometric integral is also an indication of the "cycle of erosion"[6], [38]. The cycle of erosion is defined as the total time required for reduction of a land topological unit to the base level i.e. the lowest level. This entire period or the cycle of erosion can be grouped into three categories, each representing the three distinctive stages of the geomorphic cycle, viz.

(i) The monadnock or old stage if $HI \leq 0.35$, in which the basin is fully stabilized;
(ii) The equilibrium or mature stage if $0.35 \leq HI \leq 0.60$, in which the basin development has attained steady state condition and
(iii) The inequilibrium or young stage if $HI \geq 0.60$, where the basin is highly susceptible to erosion and is under development [6].

The hypsometric curve can be represented by an equation $X = f(Y)$ also known as hypsometric function. When the hypsometric function is integrated between the limits of $X = 0$ to $X = 1$, a measure of landmass volume with respect to total landmass volume above the horizontal plane passing through outlet is obtained. This integral is designated as hypsometric integral and denotes the area under the hypsometric curve. Hypsometric data of Wadi el-Arish watershed is presented in Table. 7 and the hypsometric curves of Wadi el-Arish watershed and sub-watersheds were illustrated (Fig.5).

TABLE.7

HYPSOMETRIC DATA OF WADI EL-ARISH WATERSHED

Contour ranges	Area (a) km2	Relative area (a/A) km2	Contour elevation (h) m	Relative contour elevation (h/H) m
1600-1632	0.572	0.000024	1600	0.980392
1400-1600	93.534	0.003936	1400	0.857843
1200-1400	593.095	0.024957	1200	0.735294
1000-1200	1417.017	0.059626	1000	0.612745
800-1000	3116.838	0.131152	800	0.490196
600-800	6741.621	0.283679	600	0.367647
400-600	14176.408	0.596525	400	0.245098
200-400	21193.870	0.891810	200	0.122549
0-200	23728.212	0.998452	0.00	0.00

Where: Area (A) = 23765 km2; total relief = 1632 m; mean elevation = 498.056

Hypsometric integral (Hi) which is equivalent to elevation relief-ratio (E) that proposed by Pike and Wilson (1971)[39] is more accurate and easier to calculate within GIS environment [40]. So that, Pike and Wilson's method was used to calculate the hypsometric integral values of Wadi el-Arish watershed and its main sub-watersheds. The relationship is expressed as:

$$E \approx Hi = \mathrm{Elevation}_{\mathrm{Mean}} - \mathrm{Elevation}_{\mathrm{Min}} / \mathrm{Elevation}_{\mathrm{Max}} - \mathrm{Elevation}_{\mathrm{Min}}$$

The $\mathrm{Elevation}_{\mathrm{Max}}$ and $\mathrm{Elevation}_{\mathrm{Min}}$ are the maximum and minimum elevation within the watershed and $\mathrm{Elevation}_{\mathrm{Mean}}$ is the weighted mean elevation of the watershed. The $\mathrm{Elevation}_{\mathrm{Max}}$ and $\mathrm{Elevation}_{\mathrm{Min}}$ were directly found out from the DEM of Wadi el-Arish watershed and $\mathrm{Elevation}_{\mathrm{Mean}}$ was obtained by the following formula:

$$Elevation_{Mean} = \left(\sum NiEi\right) / \left(\sum Ni\right)$$

Where: Ni is the number of the pixel corresponding to elevation Ei in digital elevation model of a watershed which was obtained from the attribute table of respective DEM (Table. 8).

TABLE 8

ESTIMATED HYPSOMETRIC INTEGRAL VALUES OF WADI EL-ARISH WATERSHED AND SUB-WATERSHEDS USING ELEVATION-RELIEF RATIO METHOD.

	Basin	Area (km^2)	Elevation (m)			Hypsometric Integral	Erosion stage
			Min.	Max.	Mean		
Wadi el-Arish		23765	0	1632	498.06	0.31	Monadnock
Sub-basins	el-Hasana	3606	45	1077	272.82	0.22	Monadnock
	el-Bruk	3326	288	1072	454.40	0.21	Monadnock
	el-Roak	6381	305	1632	767.97	0.35	Equilibrium
	Aqabah	2517	305	1193	606.66	0.34	Monadnock
	Abu Qurayah	3084	231	999	431.68	0.26	Monadnock
	average	3783	196	1268	506.71	0.28	Monadnock

As presented in Fig. 5 & Table. 8 the computed hypsometric integral (HI) value of Wadi el-Arish Watershed is 0.31, which represents the watershed is in monadnock or old stage, indicating the basin is fully stabilized. While the HI values of its sub-watersheds range from 0.21 to 0.35 indicating that the sub-watersheds are also in monadnock state. In comparison, the Wadi el-Roak watershed is considered the only exception where the HI value was 0.35; this means that the watershed of Wadi el-Roak was stopped at the equilibrium stage in its erosion cycle. Indeed, the highest point in the watershed of Wadi el-Arish as a whole is located within the Wadi el-Roak watershed.

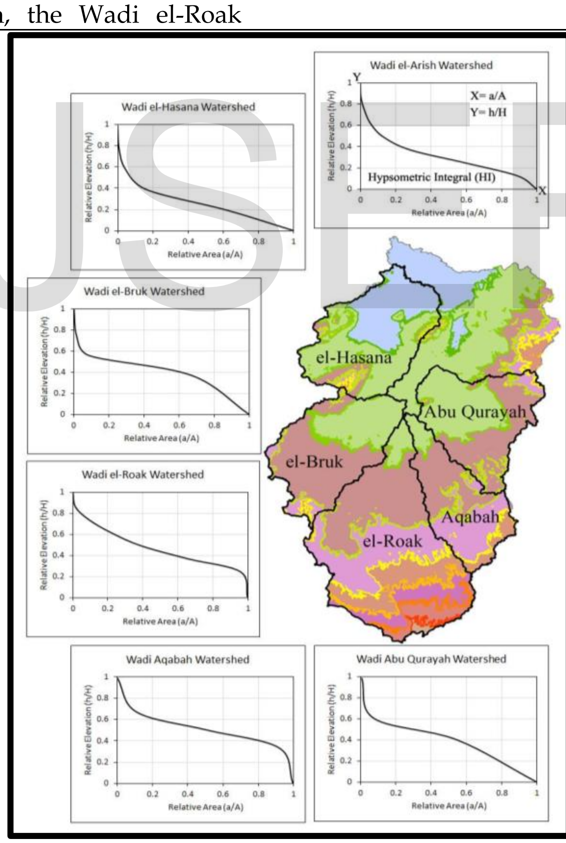

Fig. 1: Hypsometric curves of Wadi el-Arish watershed and its sub-watersheds

5. CONCLUSION

The morphometric analysis of Wadi el-Arish watershed and sub-watersheds was carried through measurement of basin geometry and form, Drainage network, and relief basin aspects. Geometric and formal analysis reveals that the Wadi el-Arish watershed has an area of about 23,765 sq.km. And the area of sub-watersheds ranged from 2,517 sq.km to 6,381 sq.km. with an average of 3,783 sq.km. Wadi el-Arish watershed and sub-watersheds tend to be elongated in shape indicating medium to high infiltration capacity and as well as runoff. Stream order, stream length and bifurcation ratio, indicate that the Wadi el-Arish watershed is 7th order basin due to ((flow accumulation > 1500 & watershed < 0), with homogeneous dendritic type of drainage pattern and complexity of structural control. Drainage density and stream frequency are the most important criterion for the morphometric categorization of watersheds which unquestionably control the runoff pattern, sediment yield and other hydrological parameters of the watershed. Values of drainage density and stream frequency reveal that the area of Wadi el-Arish watershed has high to moderate relief and low runoff potential, accordingly, the watershed subsurface strata may differ from fairly permeable to permeable, where the field work indicates that the watershed area has a good groundwater prospect can be used to agricultural activity.

Basin relief, relief ratio, relative relief, ruggedness number and hypsometric integral (HI) indicate that the study area is characterizing by variation in slope and topography with either monadnock or equilibrium stage of geomorphic development. The complete morphometric analysis of watershed indicates that the given area is having good groundwater prospect where the most rainfall infiltrate to recharge the groundwater storage across permeable soils and/or rocks in most of the investigated sub-watersheds.

It is important to be aware of the remotely sensed data (ASTER-DEM) and GIS software techniques-based approach in evaluation of drainage morphometric parameters and their influence on landforms is more appropriate than the conventional methods. Hence, from the study it can be concluded that ASTER (DEM) data, coupled with GIS techniques, prove to be a competent tool in morphometric analysis of watersheds. Finally, the study area is a promising area for the application of geomorphologic and water management studies.

6. REFERENCES

[1] C. Agarwal, "Study of drainage pattern through aerial data in Naugarh area of Varanasi district, UP," *Journal of the Indian Society of Remote Sensing,* vol. 26, no. 4, pp. 169-175, 1998.doi:10.1007/BF02990795.

[2] G. P. O. Reddy, A. K. Maji, and K. S. Gajbhiye, "Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India – a remote sensing and GIS approach," *International Journal of Applied Earth Observation and Geoinformation,* vol. 6, no. 1, pp. 1-16, 2004/11/01/ 2004.doi:https://doi.org/10.1016/j.jag.2004.06.003.

[3] R. E. Horton, "Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology," *Geological society of America bulletin,* vol. 56, no. 3, pp. 275-370, 1945.doi:10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2.

[4] L. B. Leopold and T. Maddock, *The hydraulic geometry of stream channels and some physiographic implications* vol. 252. USA: US Government Printing Office, 1953, pp. 1-57.

[5] A. D. Abrahams, "Channel networks: a geomorphological perspective," *Water resources research,* vol. 20, no. 2, pp. 161-188, 1984.doi:10.1029/WR020i002p00161.

[6] A. N. Strahler, "Hypsometric (area-altitude) analysis of erosional topography," *Geological Society of America Bulletin,* vol. 63, no. 11, pp. 1117-1142, 1952

[7] A. N. Strahler, "Quantitative analysis of watershed geomorphology," *Eos, Transactions American Geophysical Union,* vol. 38, no. 6, pp. 913-920, 1957.doi:10.1029/TR038i006p00913.

[8] A. N. Strahler, "Quantitative Slope Analysis," *Bulletin of the Geological Society of America,* vol. 67, no., pp. 571-596, 1958

[9] A. N. Strahler, "Quantitative Geomorphology of Drainage Basin and Channel Network," in *Handbook of Applied Hydrology*, V. T. Chow and V. T. Chow, Eds., ed USA: McGraw-Hill handbooks, 1964, pp. 39-76.

[10] S. A. Schumm, "Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey," *Geological society of America bulletin,* vol. 67, no. 5, pp. 597-646, 1956.doi:10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2.

[11] A. E. Scheidegger, "The algebra of stream-order numbers," *United States Geological Survey Professional Paper,* vol. 525, no., pp. 187-189, 1965

[12] R. Shreve, "1966: Statistical law of stream numbers," *The Journal of Geology,* vol. 74, no. 1, pp. 17-37, 1967

[13] K. Gregory and D. Walling, "The variation of drainage density within a catchment," *Hydrological Sciences Journal,* vol. 13, no. 2, pp. 61-68, 1968.doi:10.1080/02626666809493583.

[14] J. E. Mueller, "An introduction to the hydraulic and topographic sinuosity indexes," *Annals of the Association of American Geographers,* vol. 58, no. 2, pp. 371-385, 1968/06/01 1968.doi:10.1111/j.1467-8306.1968.tb00650.x.

[15] J. E. Hurtrez, C. Sol, and F. Lucazeau, "Effect of drainage area on hypsometry from an analysis of small-scale drainage basins in the Siwalik Hills (Central Nepal)," *The Journal of the British Geomorphological Research Group,* vol. 24, no. 9, pp. 799-808, 1999.doi:10.1002/(SICI)1096-9837(199908)24:9<799::AID-ESP12>3.0.CO;2-4.

[16] Dames and Moore, "Land classification and capability in Sinai, Sinai Development Study, Phase 1. Report submitted to the Advisory Committee for Reconstruction of the Ministry of Development, Cairo, Egypt, 1981."

[17] A. R. Shabana, "Geologic factors controlling shallow groundwater occurrence in carbonate and sandstone rocks in some localities in Sinai Peninsula, Egypt," *Egyptian Journal of Geology*, vol. 58, no., pp. 21-39, 2014

[18] M. Abdel Ghaffar, A. Abdellatif, M. Azzam, and M. Riad, "Watershed characteristic and potentiality of wadi el-arish, Sinai, Egypt," *Int J Adv Remote Sens GIS,* vol. 4, no. 1, pp. 1070-1091, 2015

[19] M. Farahat, A. Elmoustafa, and A. Hassan, "Developing Flash Floods Inundation Maps Using Remote Sensing Data, a Case Study: Wadi AL-Arish, Sinai, Egypt," *American Journal of Engineering Research,* vol. 6, no. 5, pp. 172-181, 01/01 2017

[20] N. Magesh, K. Jitheshlal, N. Chandrasekar, and K. Jini, "GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India," *Earth Science Informatics,* vol. 5, no. 2, pp. 111-121, 2012.doi:10.1007/s12145-012-0101-3.

[21] R. J. Chorley, "The Application of Statistical Methods to Geomorphology," in *Essays in Geomorphology*, G. H. Dury, Ed., ed London: Elsevier, 1967.

[22] V. C. Miller, "Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee," *Technical report (Columbia University. Department of Geology); no. 3*, no., 1953

[23] R. E. Horton, "Drainage-basin characteristics," *Transactions, American Geophysical Union,* vol. 13, no. 1, pp. 50-61, 1932

[24] M. A. Melton, "An Analysis of the Relations among the Elements of Climate, Surface Properties and Geomorphology. Technical Report 11. Department of Geology, Columbia University, New York, 1957."

[25] S. A. Schumm, "The relation of drainage basin relief to sediment loss," *International Association of Scientific Hydrology,* vol. 36, no. 1, pp. 216-219, 1954

[26] K. Pareta, "Hydro-Geomorphology of Sagar District (M.P.): A Study through Remote Sensing Technique," in *XIX M. P. Young Scientist Congress, Madhya Pradesh Council of Science & Technology (MAPCOST)*, Bhopal, 2004.

[27] D. F. Ritter, R. C. Kochel, and J. R. Miller, *Process Geomorphology*. Boston: McGraw Hill, 2002.

[28] V. Gardiner, "Drainage Basin Morphometry," *British Geomorphological Group, Technical Bulletin,* vol. 14, no., p. 48, 1975

[29] R. L. Chorley and P. Haggett, *Models in Geomorphology*. London: methuen, 1986.

[30] B. L. Gupta, *Engineering Hydrology*, 3rd ed. India: Standard Publishers Distributors, 1999, pp. 46-56.

[31] A. E. Scheidegger, *Theoretical Geomorphology*, 2nd ed. New York: Springer, 1970.

[32] G. Moglen, E. Eltahir, and R. Bras, "On the Sensitivity of Drainage Density to Climate Change," *Water Resources Research,* vol. 34, no. 4, pp. 855– 862, 04/01 1998.doi:10.1029/97WR02709.

[33] K. I. Kelson and S. G. Wells, "Geologic influences on fluvial hydrology and bedload transport in small mountainous watersheds, northern New Mexico, USA," *Earth Surface Processes and Landforms,* vol. 14, no. 8, pp. 671-690, 1989.doi:10.1002/esp.3290140803.

[34] S. Gayen, G. Bhunia, and P. Shit, "Morphometric analysis of Kangshabati-Darkeswar Interfluves area in West Bengal, India using ASTER DEM and GIS techniques," *Journal of Geology & Geophysics,* vol. 2, no. 4, pp. 1-10, 2013

[35] N. A. Lifton and C. G. Chase, "Tectonic, climatic and lithologic influences on landscape fractal dimension and hypsometry: implications for landscape evolution in the San Gabriel Mountains, California," *Geomorphology,* vol. 5, no. 1, pp. 77-114, 1992/05/01/ 1992.doi:https://doi.org/10.1016/0169-555X(92)90059-W.

[36] J. G. Masek, B. L. Isacks, T. L. Gubbels, and E. J. Fielding, "Erosion and tectonics at the margins of continental plateaus," *Journal of Geophysical Research: Solid Earth,* vol. 99, no. B7, pp. 13941-13956, 1994.doi:https://doi.org/10.1029/94JB00461.

[37] Y.-C. Chen, Q. Sung, and K.-Y. Cheng, "Along-strike variations of morphotectonic features in the Western Foothills of Taiwan: tectonic implications based on stream-gradient and hypsometric analysis," *Geomorphology,* vol. 56, no. 1, pp. 109-137, 2003/11/15/ 2003.doi:https://doi.org/10.1016/S0169-555X(03)00059-X.

[38] S. K. Garg, *Geology- the Science of the earth*. New Delhi: Khanna Publishers, 1983.

[39] R. J. Pike and S. E. Wilson, "Elevation-Relief Ratio, Hypsometric Integral, and Geomorphic Area-Altitude Analysis," *GSA Bulletin,* vol. 82, no. 4, pp. 1079-1084, 1971.doi:10.1130/0016-7606(1971)82[1079:erhiag]2.0.co;2.

[40] S. K. Sharma, S. Tignath, S. Gajbhiye, and R. Patil, "Use of geographical information system in hypsometric analysis of Kanhiya Nala watershed," *Int J Remote Sens Geosci,* vol. 2, no. 3, pp. 30-35, 2013

[41] Geological map of Sinai, Arab Republic of Egypt (1994). Sheet No. 2, 3, 4 and 5, Scale 1:250 000.

.