Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2015, Volume 4, Issue 1, pp. 1070-1091, Article ID Tech-406
ISSN 2320 - 0243

Research Article **Open Access**

Watershed Characteristic and Potentiality of Wadi El-Arish, Sinai, Egypt

Abdel Ghaffar, M.K., Abdellatif, A.D., Azzam, M.A. and Riad, M.H.

Soils, Water and Environment Research Institute, ARC, Giza, Egypt

Correspondence should be addressed to Abdel Ghaffar, M.K., mamdouh66swi@hotmail.com

Publication Date: 10 June 2015

Article Link: http://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-406

Abstract The present study is an attempt to evaluate the watershed characterization and potentiality of Wadi El-Arish, Sinai, Egypt using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Thirty morphometric parameters (e.g. stream numbers, orders, lengths, frequency as well as bifurcation ratio, drainage density and relief) were measured depending on SRTM data of digital elevation model (DEM) with 30m resolution that enhanced by topographic maps (1:50,000). Ten compound parameter values were calculated and prioritization rating for erosion risk assessment was carried out. Based on the values of the effective morphometric parameters, flash flood hazards were identified and evaluated. The land use map was constructed from the geomorphological units of Wadi El-Arish basin as well as the field observations. The drainage area of Wadi El-Arish watershed is 22260.3 km^2. It is subdivided into twelve sub-basins of different areas. The morphometric analysis indicates that the watershed is of eight stream order with dendritic type of drainage pattern and homogeneous nature. The relief ratio, slope, ruggedness number and visual interpretation of the DEM indicate variable slope and topography with late mature stage of geomorphic development. On the other hand, the drainage density, texture, circulatory and elongation ratios prove that the majority of the sub-basins are almost elongated and have coarse and intermediate drainage texture which indicate medium to high infiltration capacity. Accordingly, these sub-basins most probably have good groundwater prospect where the most rainfall infiltrate to recharge the aquifer via permeable soils and/or fractured and weathered rocks. Concerning the soil erosion condition, the sub-basins with the lowest compound parameter value (e.g. W10: Wadi Abu Aliqanah and W12: Wadi Aqabah) have been subjected to maximum soil erosion and need immediate soil conservation measures. Based on the morphometric parameters which have a direct influence on flooding prone area, the flash flood hazard of Wadi El-Arish sub-basins are classified into three groups; namely high, medium and low hazard degree. For mitigation measure (e.g. erection of the runoff water) some dams and dikes at the crossing point between the seventh stream order and eighth stream order are recommended to be constructed. In addition, these measures will support the recharging of the shallow groundwater storage and aquifers. According to the potentiality of the study watershed, the land use map which constructed from the geomorphological units classified the Wadi El-Arish basin into four classes;

namely high, moderate, low and non-suitability classes for agriculture uses. The volume of annual flood for Wadi El-Arish watershed was classified into five classes graded from very high to very low. The groundwater potentiality map indicates that the different geographic locations are suitable for groundwater storage with different magnitudes and potentialities, but the overall groundwater potential is of the moderate class. The Lower Cretaceous is considered to be the aquifer with the greatest development potential among the other aquifer systems due to their limited extent, poor productivity and/or water quality.
Keywords *Watershed; Morphometric Parameters; Landuse; Wadi El-Arish Basin*

1. Introduction

The present study deals with the watershed characteristics and potentiality of Wadi El-Arish basin and sub-basins, Sinai, Egypt using Geographic Information system (GIS) and Remote Sensing (RS) techniques.

Wadi El-Arish basin is located in the Sinai Peninsula, Egypt, where it flows toward the Mediterranean Sea and its downstream part is El-Arish City (Figure 1). This wadi infrequently receives flash flood water from much of southern and central Sinai which make a great threat to the life and property of El-Arish City residents. Wadi El-Arish watershed study area is the largest drainage basin in Egypt and comprises about one third of whole Sinai area. It is located between latitudes 29° 00 and 31° 10` N & longitude 33° 05` and 34° 40` E (Figure 1).

Wadi Al-Arish is characterized by arid to semi-arid climatic conditions. The average rainfalls range from 10 in the south of the basin mm to 125 mm at El-Arish town. There are major wadis pour into Wadi El-Arish, e.g. El-Brouk, El- Roak, Aqabah, Abu Aliqanah and El-Mahasham which receive rainfall from different regions of El-Egma and El-Tih plateaus with average of annual rainfall about 1101 million m^3 (El-Said, 1987). The majorities of this water are missing by evaporation and infiltration within soils or fracture rocks and recharge the aquifers. The climate is characterized in general by volatile rainy winter, hot and no rain in summer. In autumn and spring, the climate is less volatile than winter with sometimes heavy rainfall. There is high evapotranspiration up to 5.5 mm day^{-1} in July (summer) and minimum of 1.9 mm day^{-1} in January (winter). The temperature varies from 30.6°C in July and 18.5°C in winter. Relative humidity is higher in the summer than in the winter with maximum value of 75% in June and minimum of 66% in December.

Generally, the Wadi basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Doornkamp and Cuchlaine, 1971). To study the hydrological setting of Wadi Al-Arish watershed, several analyses have been done including hydromorphometric analysis.

The quantitative morphometric analysis of drainage system is an important aspect of characterization of watersheds (Strahler, 1964). Drainage pattern refers to spatial relationship among streams or rivers, which may be influenced in their erosion by inequalities of slope, soils, rock resistance, structure and geological history of a region. Morphometry is the measurement and mathematical analysis of the configuration of the earth’s surface, shape and dimension of its landforms. This analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contribution (Nag and Chakraborty, 2003). Amee et al. (2007) used a GIS procedure for morphometric analysis and prioritization of watersheds. Khan et al. (2001) studied for priority watershed delineation with the objective of selecting watersheds to undertake soil and water conservation measures using RS and GIS techniques.

The present study is an attempt to evaluate the drainage morphometric parameters including linear, areal and relief aspects as well the watershed potentiality including soil and water resources. The linear aspects include stream number (Nu), stream order (U), stream length (Lu), mean stream length (Lsm), stream length ratio (RL) and bifurcation ratio (Rb). The areal aspects include drainage density (Dd), stream frequency (Fs), infiltration number (FN), texture ratio (Rt), form factor (Rf), basin shape (Bs), basin shape index (Ish), elongation ratio (Re), circulatory ratio (Rc), length of overland flow (Lo), fitness ratio (Fr) and drainage pattern (Dp). The relief aspects include relief (R), relief ratio (Rr), ruggedness number (Rn) and slope (S).

GIS technique has been carried out to predict the approximate behavior of Wadi Al-Arish sub-basins to evaluate their flash flood hazard degree during period of heavy rainfall. Also, this study could be used for prioritization of these sub-basins for soil erosion risk.

The sustainable development of Wadi El-Arish watershed depends mainly on the available water resources from runoff water harvesting (RWH) and groundwater as well as the soil resources for agriculture and other purposes. When planning for the sustainable use of water and land, it must be taken into account the less optimistic Figures for either flash floodwater or groundwater.

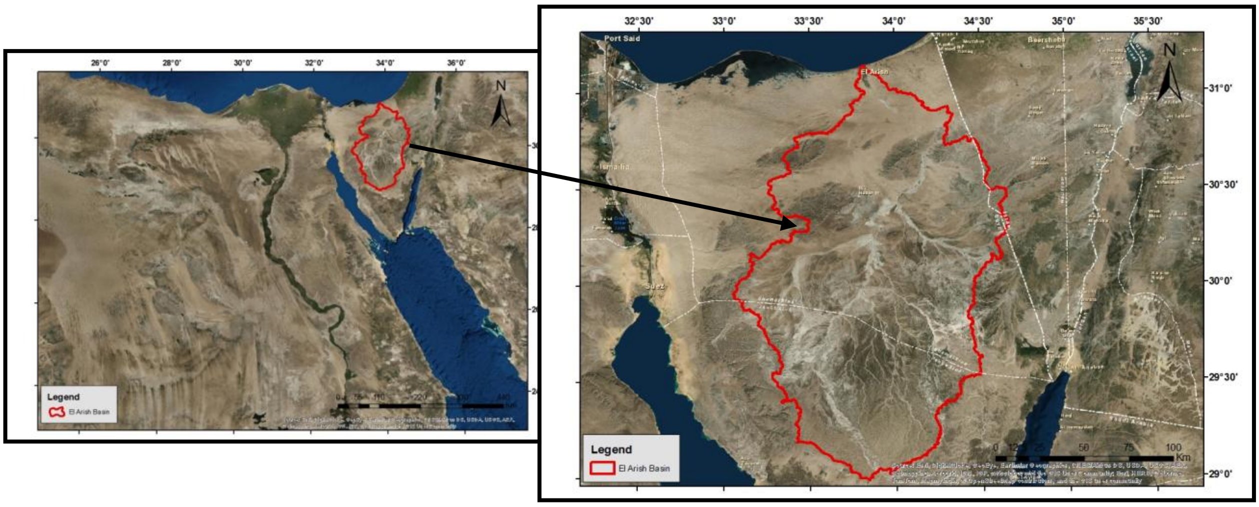


Figure 1: *Location Map of Wadi El-Arish Basin*

1.2. Geological Setting

Wadi Al-Arish's surface is covered by several outcrop rock units. It starts from the southern mountainous and rocky terrains of very steep slopes, then goes through the flat sedimentary areas in the middle, and finally ends at the sand dunes near El-Arish City in the north (Shatta and Attia, 1994). These rock units from older to younger are mentioned as follows (Geological Survey of Egypt, 1994; Figure 2):

- Triassic sedimentary rocks which consists mainly of well bedded fossiliferous limestone with gypsum, dolomite and marl interbeds.

- Jurassic sedimentary rocks that consists mainly of cross bedded sandstone intercalated with clay beds.

- Cretaceous sedimentary rocks including lower, middle and upper Cretaceous sequences. The lower Cretaceous consists of sandstone intercalated with mudstone and conglomerate. The middle Cretaceous consists of alternate beds of dolomitic limestone, marl and clay. The upper Cretaceous consists of alternate beds of clastic carbonate or argillaceous limestone and shale.

- Cretaceous- Paleocene sedimentary rocks which consists of white chalky limestone with marl and clay beds in the upper part.
- Paleocene sedimentary rocks that consists mainly of green shale interfingering laterally with soft marl.
- Eocene sedimentary rocks which consists mainly of varicolored fossiliferous limestone with chert and flint bands.
- Oligocene-Miocene extrusive basaltic rocks.
- Pliocene sedimentary rocks which consists mainly of bluish colored clay and limestone.
- Quaternary deposits including Pleistocene and Holocene. The Pleistocene consists of fanglomerate and alluvial Hamadah deposits, while the Holocene consists of playa, wadi, and sand dune and sand sheet deposits.

Geomorphologically, the study area is divided into nine major distinct geomorphic units (UNDP and UNESCO project, 2002; Figure 3). These units are: mountainous and hilly areas (6.1%), limestone plateaus (41.3%), karstified badlands (15.5%), playa deposits (0.3%), alluvial plains (14.9%), wadi deposits (11.8%), sand sheets (8.5%), sand dunes (0.5%) and cultivated area (0.2%).

It is observed that the rock units constituting these landforms are dissected by major and minor faults and fractures that initially controlled the formation of the mountains and plateaus as well as to some extend the main drainage channels. 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) (Figure 2).

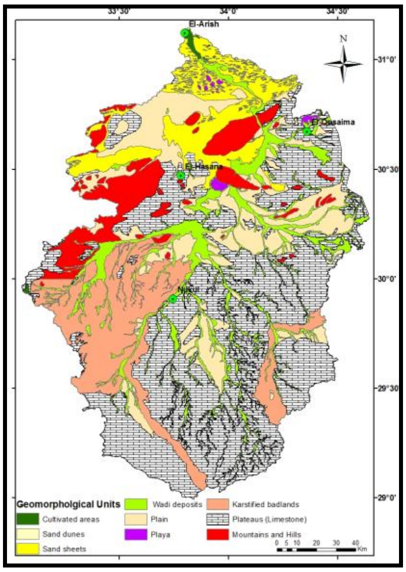
2. Methodology

Digital Elevation Model (DEM) with 30m resolution of the study area has been obtained from the SRTM (Shuttle Radar Topography Mission data) for year 2000, which was subsequently enhanced by the topographic contours, spot heights and streams of topo sheet 1:50.000 (EGACS, 1989) was exported to a Geographic Information System (GIS) environment (Arc GIS 10.1 software) to extract all possible morphological parameters of the catchment in the area. Using the Arc hydro and HEC-Geo HMS tools in Arc GIS 10.1 software, the drainage basin is divided into many sub-drainage basins with different areas based on water divide concept for morphometric analysis.

The digitization of drainage pattern was carried out in GIS environment (hydrology tool in Arc toolbox). The stream ordering was carried out using the Horton's law. The fundamental parameters namely; stream length, area, perimeter; number of streams and basin length were derived from the drainage layer. Thirty morphometric parameters for the delineated watershed area were calculated based on the formula suggested by Horton (1932 & 1945), Strahler (1952 & 1964), Faniran (1968), Schumn (1956), Melton (1957), Hagget (1965) and Miller (1953) are given in Table 1.

According to the potentiality of the Wadi El-Arish watershed, the study depends on using the most effective factors suitable for determining the water/land use priority areas in Wadi El-Arish watershed. These factors include: the volume of annual flood (VAF), which was calculated by the Finkel's method (1979) that gives the less optimistic probability of flood occurrence and its volume; the groundwater potentiality classes and the suitability of geomorphological units for land use (SGU). The agriculture land use map was constructed from the geomorphological units of Wadi El-Arish basin as well as the field observations. Additional modifications and enhancements of this map were performed using Landsat

ETM+ (acquired in 2014) images within the ERDAS Imagine 2013 Software platform. Precise correction, filtering, visual tracing and contrasting for the different units were carried out.



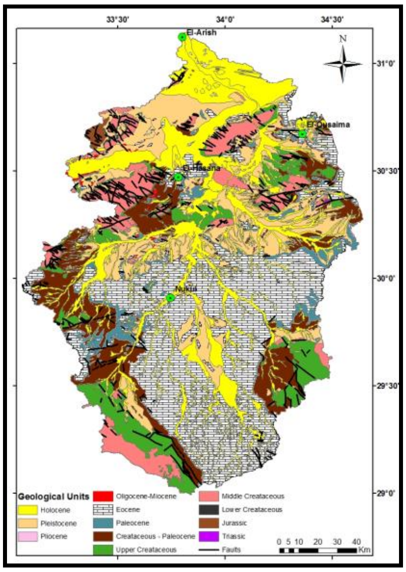


Figure 2: *Geological Map of Study Area (Modified after Geological Survey of Egypt, 1994)*

Figure 3: *Geomorphology Map of Study Area (Modified after UNDP and UNESCO Project, 2002)*

Table 1: *Morphometric Parameters Formulas*

No.	Morphometric Parameters		Formula	Reference
1	Watershed Area (A)	Basin Geometry	GIS software Analysis	
2	The basin length (Lb)		GIS software Analysis	
3	The basin perimeter (P)		GIS software Analysis	
4	Basin Width (W)		GIS software Analysis	
5	Stream Number (Nu)	Linear Aspect	Nu= N1+N2+…….Nn	Horton (1945)
6	Stream Order (U)		Hierarchical rank	Strahler (1964)
7	Stream Length (Lu)		Length of the stream	Horton (1945)
8	Mean Stream Length (Lsm)		Lsm = Lu/Nu	Strahler (1964)
9	Bifurcation Ratio (Rb)		$Rb = Nu/N_{u+1}$	Schumn (1956)
10	Mean Bifurcation Ratio (Rbm)		Rbm=Average of bifurcation ratio	Strahler (1964)
11	Drainage Density (Dd)	Areal Aspect	Dd=Lu/A	Horton (1945)
12	Stream Frequency (Fs)		Fs= Nu/A	Horton (1945)
13	Infiltration Number (FN)		FN = Dd*Fs	Faniran (1968)
14	Texture Ratio (Rt)		Rt= Nu/P	Horton (1945)
15	Form Factor (Rf)		$Rf=A/Lb^2$	Horton (1945)
16	Basin Shape (Bs)		$Bs=Lb^2/A$	Horton (1945)
17	Basin shape Index (Ish)		$Ish= 1.27\ A/Lb^2$	Hagget (1965)
18	Circularity Ratio (Rc)		$Rc=4\pi A/P^2$	Miller (1953)
19	Elongation Ratio(Re)		$Re=(2/Lb)X(A/\pi)^{0.5}$	Schumn (1956)
20	Length of overland flow (Lo)		Lo=1/Dd*2	Horton (1945)
21	Fitness Ratio (Fr)		Fr = Lb / P	Melton (1957)
22	Drainage pattern (Dp)		Stream network using GIS software Analysis	Horton (1932)
23	Compactness Constant(Cc)		$Cc=0.2821\ P/A^{0.5}$	Horton (1945)
24	Maximum elevation (H_{max})	Rel ief As	GIS software Analysis using DEM	
25	Minimum elevation (H_{min})		GIS software Analysis using DEM	

26	Relief (R)	Rf =Highest elevation-Lowest elevation	Strahler (1952)
27	Relief ratio (Rr)	Rr = Rf / Lb	Schumm (1956)
28	Slope (So)	GIS software Analysis using DEM	
29	Mean basin slope (Sm)	GIS software Analysis using DEM	
30	Ruggedness number (Rn)	Rn = Rf *.Dd	Melton (1957)

2.1. Hydromorphometric Analysis

The watershed of the Wadi El-Arish has an area of about 22260.3 km^2 (about one-third of the Sinai Peninsula area, while about 260 km^2 of which is located in El-Naqb Desert). The wadi morphology is characterized by high relief in the upper part of the basin, decreasing while approaching the sea as shown in the digital elevation model (DEM; Figure 4). El-Arish drainage basin consists of a number of main streams and by using the Arc hydro and HEC-Geo HMS tool in Arc GIS 10.1 software, the drainage basin is divided into twelve sub-basins with areas ranging between 103.6 and 3627.6 km^2 based on water divide concept for morphometric analysis (Figure 5). The development of drainage network in a region is dependent on the lithology, structure, topography, rainfall, apart from endogenetic and exogenic influences. Morphometric analysis of drainage network developed in the study area can help a lot in understanding the geomorphic processes and hydrological characteristic of the watersheds under study. The linear, relief and areal aspects of the El Arish watershed and sub-basins have been analyzed as follows:

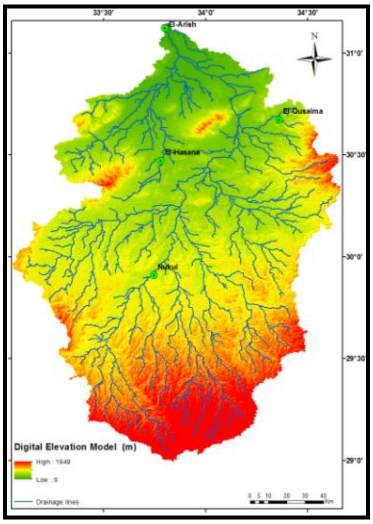


Figure 4: *Digital Elevation Model (DEM) of Wadi El-Arish Basin*

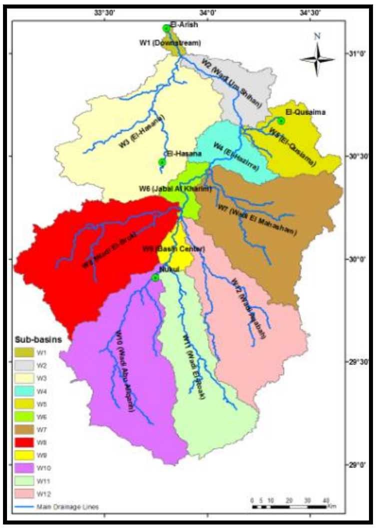


Figure 5: *Sub-Basins and Main Drainage Lines of Wadi El-Arish Basin*

2.2.1. Basin Geometry

a. *Watershed Area (A)*

According to Horton (1945), all the sub-basins were classified by size into the category of large basins i.e. all of them are more than 100 km^2. The area of the study sub-basins ranges from 103.6 Km^2 of W1 (Downstream) to 3627. 6 km^2 of W3 (El-Hasana) as shown in Table 3.

b. *The Basin Length (Lb)*

It indicates the travel time of surface runoff especially the flood waves passing through the basin (Pareta, 2012). Basin length of the study sub-basins ranges from 17.6 km of W1 (Downstream) to

123.1 km of W10 (Wadi Abu Aliqanah) as shown in Table 3. The length of El-Arish basin is 238.70 Km.

c. The Basin Perimeter (P)

It ranges between 79.5 km of W1 (Downstream) and 514 Km of W10 (Wadi Abu Aliqanah), while Wadi Al Arish basin is 1375.3 Km. It is noticed that there are direct positive relationship between the area, length and perimeter of study sub-basins (Table 3)

d. Basin Width (W)

The basin width of Wadi El-Arish Basin is 134.8 Km, however in sub-basins it ranges from 9.9 km of W1 (Downstream) to 69.8 km of W7 (Wadi El- Mahasham) as shown in Table 3. The small values of the basin width indicate to the elongated shape which led to groundwater recharge potentiality more than the large values.

2.2.2. Linear Aspects

Computation of the linear aspects such as stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and length ratio are described below. The properties of the stream networks are very important to study basin characteristics (Strahler, 1964). The linear aspect computations of the basin and the sub-basins are presented in Tables 2 (a) and (b).

a. Stream Order (U)

Stream ordering is the basic parameter of quantitative analysis of the drainage (Pareta, 2012). Application of this ordering procedure through GIS shows that the drainage network of the study area is of eight orders (Table 2 and Figure 6). It has observed that the maximum frequency is in the case of first order streams. It has also noticed that there is a decrease in stream frequency as the stream order increases.

b. Stream Number (Nu)

It is obvious that the total number of streams gradually decreases as the stream order increases. With the application of GIS, the number of streams of each order and the total number of streams was computed.

c. Stream Length (Lu)

The total stream lengths of the study basins have various orders, which have computed with the help of topographical sheets and ArcGIS software (Pareta, 2012). Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. Total stream length of El Arish basin is 48795.5 Km. Sub-basin W8 (Wadi El-Brouk) has highest cumulative length of streams (26380.8 Km), whereas Sub-basin W1 (Downstream) has lowest cumulative length of streams (119.42 Km). 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.

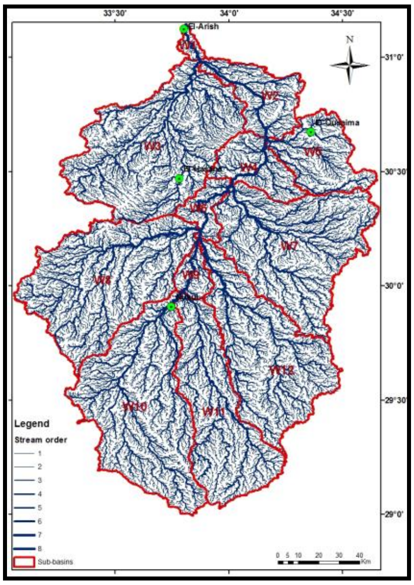


Figure 6: *Stream Orders and Drainage Pattern of Wadi El-Arish Watershed*

d. Mean Stream Length (Lsm)

The mean stream length of El Arish basin is 13.9, while in the sub-basins varies from 3.12 to 47.54. It is observed that in the sub-basins; mean stream lengths are irregular distribution with stream order. Such anonymity might be due to variations in slope and topography.

e. Stream Length Ratio (Rsm)

The stream length ratio between streams of different order in the study area shows variation. The stream length ratio in El Arish basin varies between 0.51 to 1.08. This variation might be attributed to variation in slope and topography, indicating the late youth stage of geomorphic development in the streams of the study area (Singh and Singh, 1997).

f. Bifurcation Ratio (Rb) and Mean Bifurcation Ratio (Rbm)

The bifurcation ratio (Rb) in El Arish sub-basins varies between 0.42 - 2.1 with mean bifurcation ratios (Rbm) equal 1.64. The low bifurcation values are indicative of relatively less structural complexity which in turn has not distorted the drainage pattern of the basin (Strahler, 1964). Also, these values may show little difference in the environmental conditions of the sub-basins.

2.2.3. Areal Aspects

a. Drainage Density (Dd)

A high value of basin drainage density indicates that a large amount of the precipitation runs off as in sub-basin W8 (Wadi El-Brouk; 8.04 km/km^2) while a low drainage density reflect erosion-resistant fractured hard rocks of the study area and indicates that the most rainfall infiltrates to recharge the groundwater storage as in most of the study sub-basins. The drainage density for the whole basin is 2.19 km/km^2 (Table 3).

b. Stream Frequency (Fs)

It mainly depends on the lithology of the basin and reflects the texture of the drainage network. Stream frequency of the study sub-basins ranges from 1.1 km/km^2 (W3: El-Hasana) which consists of different rock units to 1.22 km/km^2 (W1: Downstream) which consists of Quaternary friable deposits. The stream frequency for the whole watershed is 1.13 km/km^2.

c. Infiltration Number (FN)

It gives an idea about the infiltration characteristics of the basin reveals impermeable lithology and higher relief. The higher the infiltration number the lower will be the infiltration and consequently, leading to high hazardous surface runoff as in sub-basin W8 (Wadi El-Brouk).

d. Texture Ratio (Rt)

Smith (1958), classified the texture ratio of the basins into coarse (<6.4 km^{-1}), intermediate (6.4-16 km^{-1}) and fine (>16 km^{-1}). Table 3 shows that the study sub-basins have coarse texture except of W3, W7, W8, W10 and W12 have intermediate texture. The lower values of Rt indicate that has good chance for groundwater recharge, while the basins of high value where it is composed of hard rocks that have no ability for water infiltration and consequently has good chance to produce flash flood.

e. Form Factor (Rf)

Horton (1945) proposed this parameter to predict the flow intensity of a basin of a defined area. 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 (Gupta, 1999). Accordingly, The Rf of the whole basin is 0.39 indicating that the watershed is an elongated one and experience low peak flows for long duration. The Rf of the sub-basins ranges from 0.21 (W11; Wadi El-Roak) to 0.54 (W5: El-Qusiama) as shown in Table 3.

f. Basin Shape (Bs)

Basin shape is the ratio of the square of basin length (Lb) to the area of the basin (A). The Bs values of sub-watersheds (Table 3) indicate that W10, W11 and W12 have weaker flood discharge periods (Bs > 4.0), whereas W 3, 5 and W8 have sharp peak flood discharge (Bs < 2.5).

Table 2: *The Linear Morphological Analyses of Wadi El-Arish Basin and Its Sub-Basins*
(a) *Stream Numbers in Different Orders*

Basin\ Sub-Basin	Name	Stream Number (N) in Different Orders (1-8)								
		N1	N2	N3	N4	N5	N6	N7	N8	Total
W1	Downstream	63.0	31.0	2.0	0.0	0.0	0.0	1.0	29.0	126.0
W2	Wadi Um Shihan	528.0	257.0	139.0	13.0	14.0	1.0	0.0	79.0	1031.0
W3	El-Hasana	2012.0	966.0	499.0	258.0	173.0	41.0	30.0	0.0	3979.0
W4	El-Hazirra	428.0	204.0	110.0	67.0	7.0	0.0	1.0	41.0	858.0
W5	El-Qusiama	610.0	292.0	140.0	104.0	57.0	11.0	0.0	0.0	1214.0
W6	Jabal Al Kharim	221.0	118.0	49.0	13.0	0.0	0.0	3.0	42.0	446.0
W7	Wadi El Mahasham	1762.0	807.0	449.0	260.0	158.0	39.0	40.0	1.0	3516.0
W8	Wadi El-Brok	1880.0	910.0	410.0	266.0	191.0	38.0	52.0	0.0	3747.0
W9	Basin Center	170.0	90.0	43.0	5.0	0.0	2.0	34.0	0.0	344.0
W10	Wadi Abu Aliqanh	2016.0	965.0	492.0	351.0	171.0	108.0	16.0	0.0	4019.0
W11	Wadi El-Roak	1326.0	629.0	298.0	205.0	88.0	93.0	1.0	0.0	2640.0
W12	Wadi Aqabah	1636.0	759.0	414.0	218.0	120.0	83.0	31.0	0.0	3261.0
Arish	El-Arish Basin	12678.0	6037.0	3045.0	1660.0	980.0	413.0	202.0	189.0	25204.0

***(b)** Length of Streams*

Basin\ Sub-Basin	Length of Streams (Km)								
	N1	N2	N3	N4	N5	N6	N7	N8	Total
W1	68.3	29.5	0.7	0.0	0.0	0.0	0.02	20.9	119.42
W2	588.6	304.4	146.6	32.6	12.1	0.02	0.0	60.9	1145.22
W3	2167.8	1154.5	580.2	319.3	188.2	40.2	22.7	0.0	4472.9
W4	477.2	222.5	122.9	63.9	12.9	0.0	0.02	37.9	937.32
W5	588.1	341.5	150.0	107.9	49.1	10.4	0.0	0.0	1247.0
W6	239.1	109.6	46.1	12.9	0.0	0.0	0.07	44.2	451.97
W7	1852.9	892.2	447.0	268.5	128.4	39.2	35.6	0.02	3663.82
W8	13122.6	6756.9	3258.1	1766.3	897.9	382.8	196.2	0.0	26380.8
W9	164.3	89.7	47.4	8.2	0.0	0.05	35.5	0.0	345.15
W10	2016.3	1030.9	525.8	231.2	152.0	94.5	20.7	0.0	4071.4
W11	1325.3	705.9	300.3	195.4	84.9	100.0	0.02	0.0	2711.82
W12	1625.1	796.4	409.4	211.3	106.8	66.3	33.4	0.0	3248.7
Arish	24235.6	12434.0	6034.5	3217.5	1632.3	733.5	344.2	163.9	48795.5

***c)** Mean Stream Length and Stream Length Ratio*

Basin\ Sub-Basin	Mean Stream Length									Stream Length Ratio						
	N1	N2	N3	N4	N5	N6	N7	N8	Total	2\1	3\2	4\3	5\4	6\5	7\6	8\7
W1	1.08	0.95	0.35	0.00	0.00	0.00	0.02	0.72	3.12	0.88	0.37	0.00	0.00	0.00	0.00	36.03
W2	1.11	1.18	1.05	2.51	0.86	0.02	0.00	0.77	7.52	1.06	0.89	2.38	0.34	0.02	0.00	0.00
W3	1.08	1.20	1.16	1.24	1.09	0.98	0.76	0.00	7.50	1.11	0.97	1.06	0.88	0.90	0.77	0.00
W4	1.11	1.09	1.12	0.95	1.84	0.00	0.02	0.92	7.06	0.98	1.02	0.85	1.93	0.00	0.00	46.22
W5	0.96	1.17	1.07	1.04	0.86	0.95	0.00	0.00	6.05	1.21	0.92	0.97	0.83	1.10	0.00	0.00
W6	1.08	0.93	0.94	0.99	0.00	0.00	0.02	1.05	5.02	0.86	1.01	1.05	0.00	0.00	0.00	45.10
W7	1.05	1.11	1.00	1.03	0.81	1.01	0.89	0.02	6.91	1.05	0.90	1.04	0.79	1.24	0.89	0.02
W8	6.98	7.43	7.95	6.64	4.70	10.07	3.77	0.00	47.54	1.06	1.07	0.84	0.71	2.14	0.37	0.00
W9	0.97	1.00	1.10	1.64	0.00	0.03	1.04	0.00	5.77	1.03	1.11	1.49	0.00	0.00	41.76	0.00
W10	1.00	1.07	1.07	0.66	0.89	0.88	1.29	0.00	6.85	1.07	1.00	0.62	1.35	0.98	1.48	0.00
W11	1.00	1.12	1.01	0.95	0.96	1.08	0.02	0.00	6.14	1.12	0.90	0.95	1.01	1.11	0.02	0.00
W12	0.99	1.05	0.99	0.97	0.89	0.80	1.08	0.00	6.77	1.06	0.94	0.98	0.92	0.90	1.35	0.00
Arish	1.91	2.06	1.98	1.94	1.67	1.78	1.70	0.87	13.90	1.08	0.96	0.98	0.86	1.07	0.96	0.51

***D)** Bifurcation Ratio*

Basin\ Sub-Basin	Bifurcation Ratio							
	1\2	2\3	3\4	4\5	5\6	6\7	7\8	Mean
W1	2.03	15.50	0.00	0.00	0.00	0.00	0.03	2.51
W2	2.05	1.85	10.69	0.93	14.00	0.07	0.00	4.23
W3	2.08	1.94	1.93	1.49	4.22	0.24	0.00	1.7
W4	2.10	1.85	1.64	9.57	0.00	0.00	0.02	2.17
W5	2.09	2.09	1.35	1.82	5.18	0.19	0.00	1.82
W6	1.87	2.41	3.77	0.00	0.00	0.00	0.07	1.16
W7	2.18	1.80	1.73	1.65	4.05	0.25	40.00	7.38
W8	2.07	2.22	1.54	1.39	5.03	0.20	0.00	1.78
W9	1.89	2.09	8.60	0.00	0.00	0.00	0.00	1.80
W10	2.09	1.96	1.40	2.05	1.58	0.63	0.00	1.39
W11	2.11	2.11	1.45	2.33	0.95	1.06	0.00	1.43
W12	2.16	1.83	1.90	1.82	1.45	0.69	0.00	1.41
Arish	2.10	1.98	1.83	1.69	2.37	0.42	1.07	1.64

Table 3: *Areal and Relief Morphometric Analyses of Wadi El Arish Basin and Its Sub-Basins*

Basin\ Sub-Basin	Area (Km^2)	Perimeter (Km)	Basin Length (Km)	Basin Width (Km)	Drainage Density (km/Km^2)	Stream Frequency	Infiltration Number	Texture Ratio Km^{-1}	Circulatory Ratio	Elongation Ratio
W1	103.6	79.50	17.60	9.90	1.15	1.22	1.40	1.58	0.21	0.65
W2	918.4	272.2	55.20	36.4	1.25	1.12	1.40	3.79	0.16	0.62
W3	3627.6	482.4	87.20	58.20	1.23	1.10	1.35	8.25	0.20	0.78
W4	758.8	214.5	44.90	26.70	1.24	1.13	1.40	4.00	0.21	0.69
W5	1086.0	266.6	51.00	39.30	1.15	1.12	1.29	4.55	0.19	0.73
W6	376.1	177.7	33.10	17.50	1.20	1.19	1.43	2.51	0.15	0.66
W7	3122.9	478.0	87.40	69.80	1.17	1.13	1.32	7.36	0.17	0.72
W8	3279.7	472.3	83.90	62.00	8.04	1.14	9.16	7.93	0.18	0.77
W9	285.7	135.6	30.30	17.60	1.21	1.20	1.45	2.54	0.20	0.63
W10	3497.5	514.0	123.10	55.10	1.16	1.15	1.33	7.82	0.17	0.54
W11	2394.4	450.3	106.10	41.80	1.13	1.10	1.24	5.86	0.15	0.52
W12	2809.6	504.4	111.60	54.80	1.16	1.16	1.35	6.47	0.14	0.54
Arish	22260.3	1375.3	238.70	134.80	2.19	1.13	2.47	18.33	0.15	0.71

Basin\ Sub-Basin	Compact-ness Constant	Form Factor	Basin Shape	Basin Shape Index	Length of Overland Flow	Fitness Ratio	Mean Slope	Relative Relief in (m)	Relief Ratio	Rugged-ness value
W1	2.2	0.33	2.99	0.42	0.43	0.22	4.2	170.0	9.7	0.20
W2	2.53	0.30	3.32	0.38	0.40	0.20	6.3	839.0	15.2	1.05
W3	2.26	0.48	2.10	0.61	0.41	0.18	9.3	1051.0	12.1	1.29
W4	2.19	0.38	2.66	0.48	0.40	0.21	7.9	778.0	17.3	0.96
W5	2.28	0.54	2.40	0.68	0.43	0.19	11.3	911.0	17.9	1.05
W6	2.58	0.34	2.91	0.44	0.42	0.19	5.0	437.0	13.2	0.52
W7	2.41	0.41	2.45	0.52	0.43	0.18	7.8	905.0	10.4	1.06
W8	2.32	0.47	2.15	0.59	0.06	0.18	6.8	756.0	9.0	6.08
W9	2.26	0.28	3.21	0.36	0.41	0.22	3.9	262.0	8.6	0.32
W10	2.45	0.23	4.33	0.29	0.43	0.24	8.4	1261.0	10.2	1.46
W11	2.60	0.21	4.70	0.27	0.44	0.24	11.3	1320.0	12.4	1.49
W12	2.68	0.23	4.43	0.29	0.43	0.22	9.2	1104.0	9.9	1.28
Arish	2.60	0.39	2.56	0.50	0.23	0.17	4.06	1649.0	6.9	3.61

g. Basin Shape Index (Ish)

According to Haggett (1965), the calculated value of Ish of the study basin is 0.5 and for sub-basins ranges from 0.27 to 0.68. The higher the value of Ish is more circular shape of the basin and vice-versa. This is matching with the elongation ratio, form factor ratio and circularity ratio.

h. Compactness Constant (Cc)

According to Horton (1945) Cc is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin. The values of Cc of the study sub-basins vary from 2.19 of W4 (El-hazirra) to 2.68 of W12 (Wadi-Aqabah) showing little variations across the sub-basins.

i. Elongation Ratio (Re)

Elongation ratio determines the shape of the watershed and can be classified based on these values as circular (0.9 - 1), oval (0.8 - 0.9), less elongated (0.7 - 0.8), elongated (0.5 - 0.7), more elongated

(<0.5) (Schumn, 1956). 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 El-Arish watershed is 0.71 indicating that the basin is less elongated and have moderate infiltration capacity and runoff. The Re values of the sub-basins are range from 0.52 (W11: Wadi El-Roak) to 0.78 (W3: El-Hasana) as given in Table 3. W10, W11 and W12 are elongated and have high infiltration capacity and low runoff, however the rest sub basins is less elongated and have moderate infiltration capacity and runoff.

j. Circulatory Ratio (Rc)

Rc values approaching 1 indicates that the basin shapes are like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at basin outlet (Miller 1953). The Rc of the whole basin is 0.15, which indicating that the basin is elongated in shape and low discharge of runoff.

k. Length of Overland Flow (Lo)

It is an important independent variable, which greatly affect the quantity of water required to exceed a certain threshold of erosion. In the study sub-basins, Lo ranges from 0.06 of W8 (Wadi El-Brouk) to 0.44 of W 11 (Wadi El-Roak). Sub-basins that have low values of Lo as W8 indicate that surface water concentrates faster than the basins of high values of Lo as in the rest sub- basins.

l. Fitness ratio (Fr)

Fr is the ratio of main channel length to the length of the basin perimeter which is a measure of topographic fitness (Pareta, 2011). The fitness ratio of the study El-Arish basin is 0.17. This indicates that the basin is elongated and has a good chance for groundwater recharge.

m. Drainage pattern (Dp)

Drainage pattern helps in identifying the stage of the cycle of erosion and reflects the influence of slope, lithology and structure (Pareta, 2011). Dendritic pattern is the main pattern of the study basin (Figure 6). This formed in a drainage basin composed of fairly homogeneity in texture and complexity of structural control.

2.2.4. Relief Aspects

a. Relief (R)

Basin Relief plays a significant role in landforms development, drainage development, surface and subsurface water flow, permeability and erosional properties of the terrain. The relative basin relief is 1649 m. The sub-basin relative relief values are given in Table (4) and vary from 170 m to 1320 m which represent the land has moderate to steep slope.

b. Relief Ratio (Rr)

The value of Rr in El-Arish basin is 6.9 indicating moderate relief and moderate slope, while those of the sub-basins are range from 8.6 (W9: Basin center) to 17.9 (W5: El-Qusiama) as given in Table 3. The higher values may indicate the presence of sedimentary rocks that are exposed in the area with higher degree of slope.

c. Ruggedness Number (Rn)

It is the product of maximum basin relief (Hmax) and drainage density (Dd), where both parameters are in the same unit. Extremely high values of ruggedness number occur when the basin has steep and long slope. The value of ruggedness number in El Arish basin is 3.61 and in the sub-basins range from 0.20 (W1: Downstream) to 6.08 (W8: Wadi El-Brouk).

d. Slope (S) and Mean Slope (Sm)

Slope is the most important and specific feature of the drainage basin form. Slope analysis of El-Arish watershed (Figure 7) showed that the slope varies from 0^{o} near coastal and low lands to 64.06^{o} in the high lands with mean slope of 4.06^{o}. The mean slope (Sm) of the study sub-basins are range from 3.9º of W9 (Basin center) to 11.3º of W5 (El-Qusiama) & W11 (Wadi El-Roak) as shown in Table (3 and Figure 8). The wide variations between the values of mean slope are due to the variation of the topography and lithology of the basins. Generally, the slope of the terrain affects the total runoff volume and time of concentration to the peak of hydrograph. Sub-basins of gentle slope produce less runoff volume and smaller peaks of the runoff hydrograph as in W1 (downstream) and W9 (Basin center). A steep slope produces greater velocities and allows faster removal of the runoff from the watershed; therefore, shorter concentration times to peak of hydrograph as in W5 (El-Qusiama) and W11 (Wadi El-Roak).

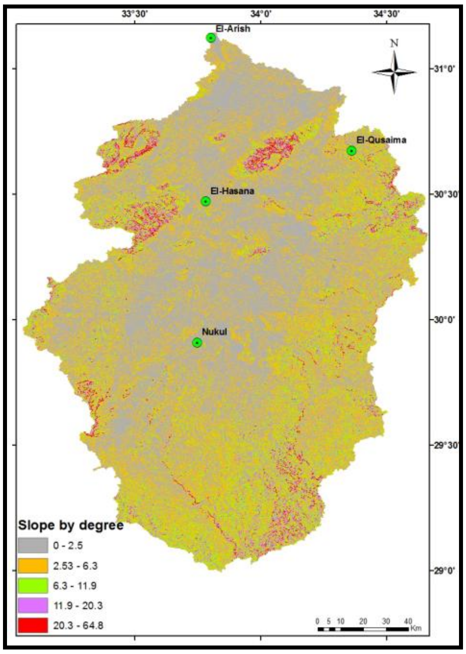


Figure 7: *Slope Map of Wadi El-Arish Watershed*

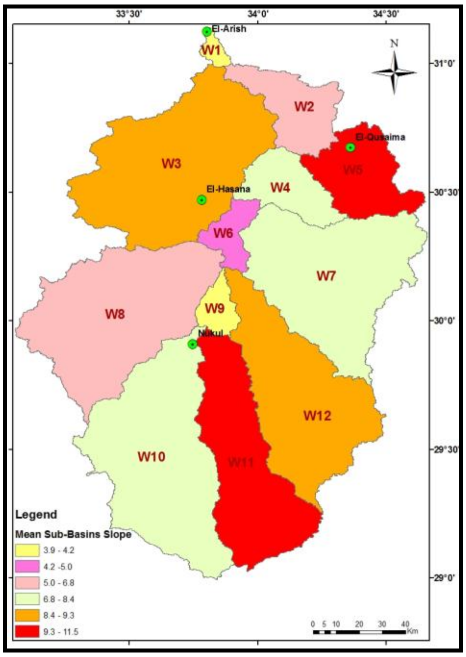


Figure 8: *Mean Slope of Sub-basins of Wadi El-Arish Watershed*

3. Priority of Sub-Basins for Erosion Risk

Ten morphometric parameters (i.e. Rbm, Dd, Cc, Bs, Fs, Rt, Lo, Rf, Rc and Re) are termed as erosion risk assessment parameters and have been used for prioritizing sub-basins. The Rbm, Dd, Fs, Rt and Lo parameters have a direct relationship with erodibility; higher the value more is erodibility. Hence prioritization of sub-basins; the highest value of these parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. The Cc, Bs, Rf, Rc and Re parameters have an inverse relationship with erodibility; lower the value more is the erodibility (Akram, et al., 2009). Thus the lowest value of these parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Accordingly, the ranking of the sub-basins has been determined by assigning the highest priority/rank based on highest value in case of the first parameters and lowest value in case of the second parameters (Table 3). Based on average value of these parameters, the sub-basins having the least rating value was assigned highest priority, next higher value was assigned second priority and so on.

The compound parameter values of the twelve sub-basins of El-Arish watershed were calculated and prioritization rating is shown in Table 4. Sub-basins Nos. W1, W7, W9, W10 and W12 with a compound parameter values from 5.9 to 6.1 receives the highest priority (one) with next in the medium priority list is sub-basins Nos. W2, W4, W8 and W11 having the compound parameter values from 6.2 to 6.7, while sub-basins Nos. W3, W5 and W6 receive the lowest priority with values from 7.1 to 7.5 (Figure 9). Highest priority indicates the greater degree of erosion in the particular sub-basins and it becomes potential area for applying soil conservative measure. Thus soil conservation measures can first be applied to sub-basins Nos. W1 (Downstream), W7 (Wadi El-Mahasham), W9 (Basin center), W10 (wadi Aliqanah), W12 (Wadi Aqabah) and then to the other sub-watersheds depending upon their priority.

Table 4: *Priorities of Sub Watershed and Their Ranks*

Sub-Basin	Mean Bifurcation Ratio (Rbm)	Length of overland flow (Lo)	Drainage Density (Dd)	Stream Freque-ncy (Fs)	Textu-re Ratio (Rt)	Elong-ation Ratio (Re)	Circu-latory Ratio (Rc)	Basin Shape (Bs)	Comp-actness Constant (Cc)	Form Factor (Rf)	Comp-ound Parameter	Final Priority
W1	3	2	11	1	12	6	11	7	2	6	6.1	4
W2	2	10	2	10	9	4	4	9	9	5	6.4	7
W3	8	9	4	12	1	12	10	1	3	11	7.1	10
W4	4	11	3	7	8	8	12	5	1	8	6.7	9
W5	5	6	10	9	7	10	8	3	5	12	7.5	12
W6	12	7	6	3	11	7	3	6	10	7	7.2	11
W7	1	5	7	8	4	9	6	4	7	9	6.0	3
W8	7	12	1	6	2	11	7	2	6	10	6.2	6
W9	6	8	5	2	10	5	9	8	4	4	6.1	4
W10	11	4	8	5	3	2	5	10	8	3	5.9	1
W11	9	1	12	11	6	1	2	12	11	1	6.6	8
W12	10	3	9	4	5	3	1	11	12	2	5.9	2

4. Flash Flood Hazard Evaluation

To evaluate the flash flood hazard of the study sub-basins, nine affected morphometric parameters (i.e. A, Dd, Fs, Ish, Sm, Rr, Rn, Rt and Rbm) were chosen and their relationship with the flash flood was analyzed. All these parameters have a directly proportional relationship with the hazard morphometric parameters except for the Rbm which shows an inverse proportion. A hazard scale number starting with 1 (lowest) to 5 (highest) has been assigned to all parameters. The distributions of the hazard degrees for the study sub-basins have been carried out as follows:

- Determination of the minimum and maximum values of each morphometric parameter for the study sub-basins.
- Assessments of the actual hazard degree for all parameters which are located between the minimum and maximum values were depending on a trial to derive the empirical relation between the relative hazard degree of a basin with respect to flash floods and the morphometric parameters, the equal spacing or simple linear interpolation between data points procedure was chosen.

- Assuming a straight linear relation exists between the samples points, the intermediate values can be calculated from the geometric relationship (Davis, 1975).

$$\textit{Hazard}\text{ degree} = \frac{4\,(X - Xmin)}{(Xmax - Xmin)} + 1 \qquad (1)$$

- For the mean bifurcation ratio (Rbm) which shows an inverse proportion, the hazard degree was calculated using the following equation (Davis 1975).

$$\textit{Hazard}\text{ degree} = \frac{4\,(X - Xmax)}{(Xmin - Xmax)} + 1 \qquad (2)$$

Where X is the value of the morphometric parameters to be assessed for the hazard degree for each basin, Xmin & Xmax are the minimum and maximum values of the morphometric parameters of all basins respectively.

The hazard degree for the study sub-basins is calculated by equations (1) and (2). The summation of the hazard degrees for each basin represents the final flash flood hazard of that basin (Table 5). These values range between 16.21 (W9: Basin center) and 33.61 (W8: Wadi El-Brouk). The actual hazard degrees for all study basins are tabulated in Table 5. From the calculated values, according to their hazards one can classify the study sub-basins into three groups; Sub basins of low hazard degree (W1, W2, W6 and W9); Sub basins of medium hazard degree (W4, W7, W10, W11 and 12) and Sub basins of high hazard degree (W3, W5 and W8) (Figure 10).

For mitigation the flash flood hazards, some dams and dikes are very important to construct at the crossing point between the seventh stream order and eighth stream order in order to reduce the flow volume of flash flood water which is expected to reach the downstream regions at the El-Rawafaa Dam shown in Figure 11. In this case, water flowing towards the Mediterranean Sea without utilization, could be managed as resources for recharge to the groundwater aquifer and the threat of flash floods will be alleviated in this area. Another scenario is proposed by Sumi (2013) to construct a rechargeable dam below the El-Rawafaa dam where accumulated water will be used for two options, the first option is as surface water for agriculture purposes because the region below the El-Rawafaa dam is plain and can be reclaimed for cultivation purpose. The second option is to be recharged into the subsurface aquifer of W. El-Arish Delta. Accordingly, the problem of groundwater level decreasing and salt water intrusion increasing will be solved at W. El-Arish Delta and securing flash flood water will be utilized properly as a means to overcome the problem of water scarcity in such regions.

Table 5: *Hazard Degree of the Study Sub-Basins*

Sub-Basin	Area (A)	Drainage Density (Dd)	Stream Frequency (Fs)	Shape Index (Ish)	Mean Slope (Sm)	Relief Ratio (Rr)	Ruggedness Ratio (Rn)	Texture Ratio (Rt)	Mean Bifurcation Ratio(Rbm)	Summation of Hazard degree	Hazard degree
W1	1.0	1.01	5.0	2.46	1.16	1.74	1.0	1.0	4.13	18.5	11
W2	1.92	1.07	1.36	2.07	2.3	3.84	1.58	2.43	3.03	19.6	10
W3	5.0	1.06	1.0	4.32	3.92	2.51	1.75	5.0	4.65	29.21	2
W4	1.74	1.06	1.55	3.05	3.16	4.74	1.52	2.45	4.35	23.62	7
W5	2.12	1.02	1.36	5.0	5.0	5.0	1.58	2.78	4.58	28.44	3
W6	1.31	1.04	2.64	2.66	1.59	2.98	1.22	1.56	5.0	20.0	9
W7	4.43	1.02	1.55	3.44	3.11	1.77	1.59	4.47	1.0	22.38	8
W8	4.61	5.0	1.73	4.12	2.57	1.17	5.0	4.81	4.6	33.61	1
W9	1.21	1.05	2.82	1.88	1.0	1.0	1.08	1.58	4.59	16.21	12
W10	4.90	1.02	1.91	1.20	3.43	1.69	1.86	4.74	4.85	25.6	4

W11	3.6	1.0	1.0	1.0	5.0	2.64	1.88	3.57	4.83	24.52	5
W12	4.07	1.02	2.10	1.2	3.86	1.56	1.74	3.39	4.84	23.78	6

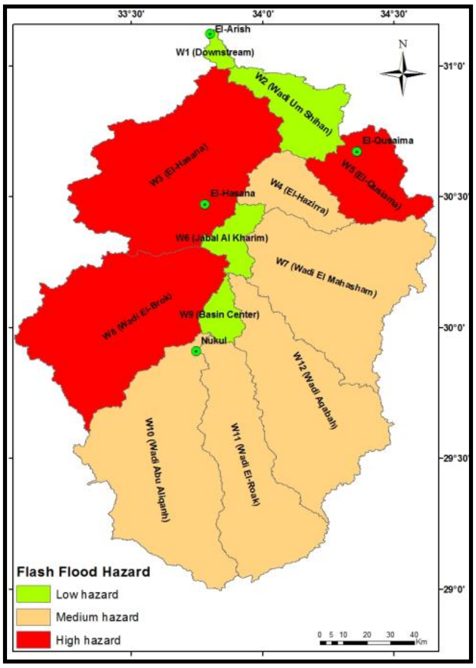


Figure 9: *Priority of Wadi El-Arish Sub-Basin Arish to Erosion Risk*

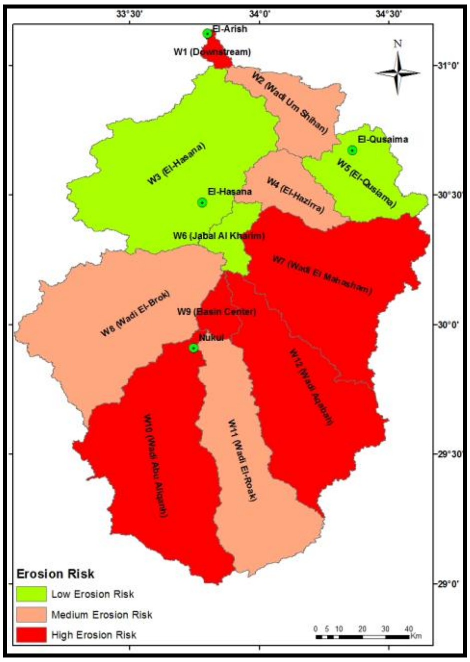


Figure 10: *Flash Flood Hazard Degree of Wadi El-Sub-Basins*

5. Water/ Land Use Promising Units for Sustainable Development

The sustainable development of Wadi El-Arish watershed depends mainly on soil and water resources for agriculture and other purposes.

5.1. Soil Resources

According to the land use map was constructed from the geomorphological units of Wadi El-Arish basin, the theme layer of these units was reclassified from high to non-suitability classes for agriculture use which mostly agree with the conclusion of Mohamed (2014) as follows (Figure 12):

- High suitability class is represented by wadi deposits (2617.5 km^2) especially in the north and middle of the El-Arish basin, reflecting their higher capability for agricultural use and can contribute to the storage of flood waters to raise the soil moisture needed for agriculture which indicated by the distribution of natural vegetations along the wadis. These soils are characterizing by very gently sloping, deep soil profile (>120 cm), loamy to gravelly sand texture and mostly non saline soils (< 4 ds/m).

- Moderate suitability class is represented by sand sheet unit (1884.0 km^2) which characterizing by nearly leveled topography, deep soil profile (>120 cm), sand texture and mostly non saline soils (< 4 ds/m).

- Low suitability class for land use was represented by alluvial plain, terraces and footslope deposits having gently to strongly sloping surface (3316.3 km^2) and consisting mainly of loamy sand to very gravelly sand texture. The depth of soil profiles is more than 80 cm and mostly moderate to high saline soils (> 4 – 16 ds/m).

- Non suitability class is represented by the hills and plateaus unit (Table 6).

Table 6: *Geomorphological Unit's Characteristics and Agriculture Land Use Suitability of Wadi El-Arish Basin*

Unit No.	Geomorphological Unit	Geological Age	Slope	Soil Profile Depth (cm)	Soil Texture	Soil Salinity Degree	Area (km^2)	Agriculture Land Use Suitability
1	Wadi deposits	Holocene	Very gently Sloping (1-2 %)	>120	Loamy sand to gravelly sand	Mostly Non saline	2617.5	High
2	Sand sheet	Holocene	Nearly level (0.5 -1%)	>120	Sand	Mostly Non saline	1884.0	Moderate
3	Plains, terraces and footslope	Pleistocene	Gently to strongly Sloping (2-15%)	> 80	Loamy sand to very gravelly sand	Mostly Moderate to high saline	3316.3	Low
4	Hills and Plateaus	Pre-Quaternary	Steep to very steep (>30 %)	<10	Rocks	-	14331.1	Non

5.2. Water Resources

5.2.1. Surface Water Resources

The volume of annual flood (VAF) is very important and effective factor in RWH, consequently in water/land use. The reclassified map of VAF classified Wadi El-Arish watershed into five classes graded from very high to very low (Elewa, 2014). The very high class in some regions in Wadi El-Arish watershed indicates more flooding possibilities and good chance for implementing agricultural development. The high-very high classes (>3,900 x 103m3/y) occur mostly in the extreme northeastern and the southeastern parts of the watershed, while decreasing to the west in the other classes (<3900 x 103 m3/y) (Figure 13).

5.2.2. Groundwater Resources

Elewa and Qaddah (2011) integrated Enhanced Thematic Mapper Plus (ETM+) images, GIS, a watershed modeling system (WMS) and weighted spatial probability modeling (WSPM) to identify the groundwater potential areas in the Sinai Peninsula, Egypt. Validation using measured well yield data was performed to check the WSPM results. Eight related thematic layers (rainfall amount, net groundwater recharge, lithology, lineament density, terrain slope, drainage density, depth to water, and water quality) were built in a GIS and assigned appropriate rankings. The WSPM was checked and validated by comparison with the published hydrogeological map of North Sinai in 1992 and actual borehole yield data and it was found that it correlates well with the previously published data and maps. The resulting groundwater potentiality map of Sinai (Figure 14) indicates that the different geographic locations are suitable for groundwater storage with different magnitudes and potentialities, but the overall groundwater potential is of the moderate class.

Three main deep aquifer systems have been identified in Wadi El-Arish watershed: the Eocene limestones, the Upper Cretaceous carbonates and the lower Cretaceous sandstones. The Lower Cretaceous is considered to be the aquifer with the greatest development potential among the other aquifer systems due to their limited extent, poor productivity and/or water quality (APRP, Water Policy Reform Activity Report; 1998). Table 2 shows some of hydrogeological characteristics for number of wells in Wadi El-Arish basin (Atlas of Water Resources, 2008; Figure 14).

Table 7: *Some Hydrogeological Characteristics for Number of Wells in Wadi El-Arish Basin*
(Atlas of Water Resources, 2008)

Map Well No.	Well Name	Well Depth (m)	Depth To water (m.b.s.l)	Salinity (mg/L)	Aquifer Age	Lithological Unit
1	Bir lahven	300	45	-	L.Createaceous	Sandstone
2	Um Shihan	905	165	4750	Eocene	Limestone
3	El-Qusima-3	285	78	6380	Eocene	Limestone
4	El-Halal	900	185	1410	L.Createaceous	Sandstone
5	Libni-1	300	190	4500	U.Createaceous	Limestone
6	Talet El-Badn	651	240	5360	L.Createaceous	Sandstone
7	Arif El-Naqa-2	870	450	3821	U.Createaceous	Limestone
8	El-Hasanat-4	1052	310	4154	L.Createaceous	Sandstone
9	El-Brouk-1	1000	321	5184	U.Createaceous	Limestone
10	Nukul-1	1020	435	1690	L.Createaceous	Sandstone
11	Sudr El-Hitan	1040	443	1656	L.Createaceous	Sandstone
12	El-thamad-1	805	615	1768	L.Createaceous	Sandstone
13	Abd Alla Suliman	1004	640	1572	U.Createaceous	Limestone

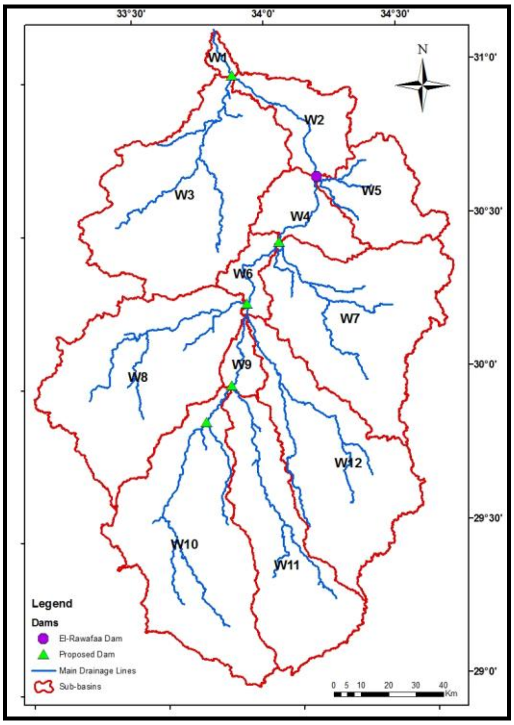


Figure 11: *Current and Proposed Dams in Wadi El-Arish Basin*

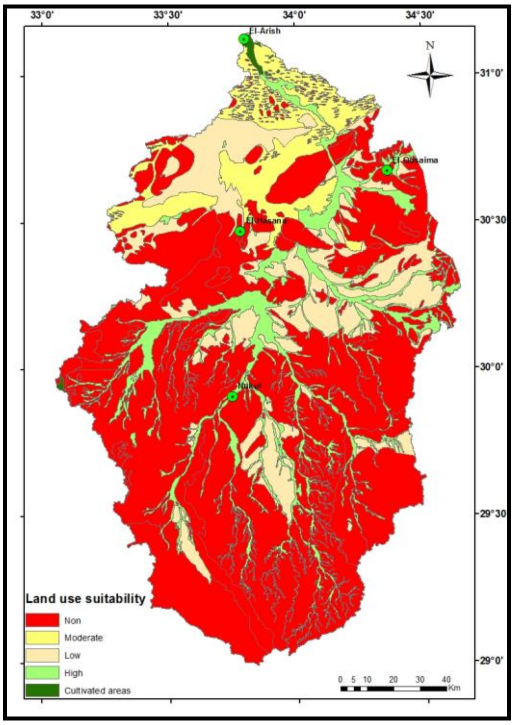


Figure 12: *Suitability of Geomorphological Units for Agriculture Landuse in Wadi El-Arish basin*

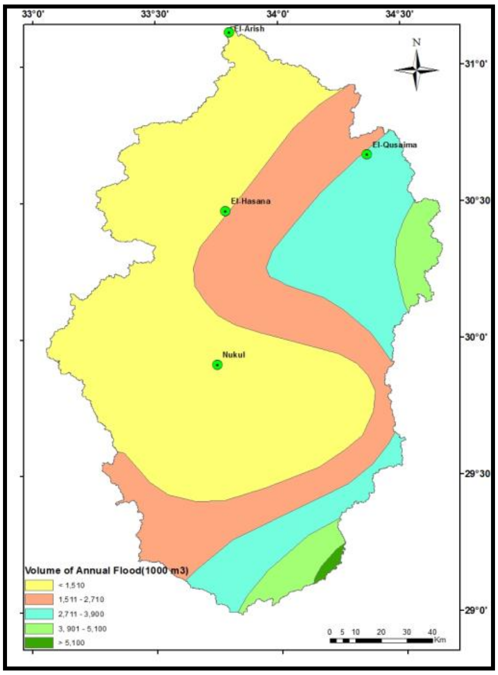


Figure 13: *Volume of Annual Flood (VAF) in Wadi El-Arish Basin*

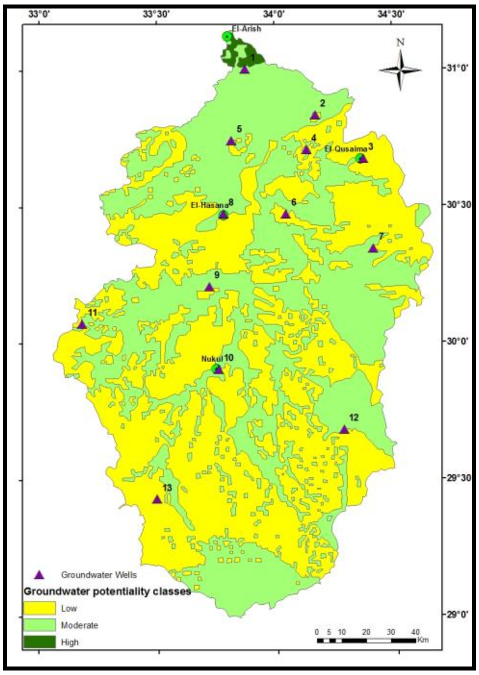


Figure 14: *Groundwater Potentiality and Wells*

6. Conclusions

GIS and Remote sensing techniques have proved to be accurate and efficient tool in drainage delineation and their updating. Bifurcation ratio, length ratio and stream order of basin indicates that the El-Arish watershed is eight order basin with homogeneous dendritic type of drainage pattern and complexity of structural control. Relief ratio, slope, Ruggedness number and visual interpretation of DEM indicate that the study area is characterizing by variation in slope and topography with late mature stage of geomorphic development. Drainage density, texture ratio, circulatory ratio and elongation ratio shows that the sub basins have coarse and intermediate drainage texture and the shape of sub-basins are almost elongated indicating medium to high infiltration capacity and runoff. The complete morphometric analysis of drainage basin 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 study sub-basins.

Priority for erosion risk indicate that Sub-basins Nos. W1, W7, W9, W10 and W12 receives the highest priority (one) with next in the medium priority list is sub-basins Nos. W2, W4, W8 and W11, while sub-basins Nos. W3, W5 and W6 receive the lowest priority. Highest priority indicates the greater degree of erosion in the particular sub-basins and it becomes potential area for applying soil conservative measure. Thus soil conservation measures can first be applied to sub-basins Nos. W1 (Downstream), W7 (Wadi El-Mahasham), W9 (Basin center), W10 (Wadi Abu Aliqanah), W12 (Wadi Aqabah) and then to the other sub-watersheds depending upon their priority.

The flash flood hazards of the study sub-basins are classified into three groups; Sub basins of low hazard degree (W1, W2, W6 and W9); Sub basins of medium hazard degree (W4, W7, W10, W11 and 12) and Sub basins of high hazard degree (W3, W5 and W8). For mitigation measure (e.g. erection of the runoff water) some dams and dikes at the crossing point between the seventh stream order and eighth stream order are recommended to be constructed. In addition, these measures will support the recharging of the shallow groundwater storage and aquifers.

According to the potentiality of the study watershed, the land use map which constructed from the geomorphological units classified the Wadi El-Arish basin into four classes; namely high, moderate, low and non-suitability classes for agriculture uses. The volume of annual flood for Wadi El-Arish watershed was classified into five classes graded from very high to very low. The resulting groundwater potentiality map indicates that the different geographic locations are suitable for groundwater storage with different magnitudes and potentialities, but the overall groundwater potential is of the moderate class. The Lower Cretaceous is considered to be the aquifer with the greatest development potential among the other aquifer systems due to their limited extent, poor productivity and/or water quality.

Acknowledgment

The authors wish to express their great gratitude to Dr. Mohamed Ibrahim El-Anbaway, Prof. of Environmental Geology, Faculty of Science, Cairo Univ. for reviewing and supporting the present paper. Also, great thanks to Prof Dr. Mohamed Ismail, Manager of Soil, water and environment institute for providing the facilities and encouragement during the preparation of this manuscript.

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