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Impact Of Morphometric Parameters On Surface Runoff In Wadi Atfih, Eastern Desert, Egypt

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Abstract:
Studies related to the analysis of morphological parameters are very important for knowing the hydrological conditions in watersheds, especially in arid and semi-arid regions. As a result of the climatic changes that the world has been witnessing recently, these areas are exposed to flash floods that lead to the destruction of main roads, villages, and infrastructure and the deaths of many people. However, there are no accurate measurements to calibrate rainfall and surface runoff. Among these areas is Wadi Atfih in the eastern desert of Egypt. Therefore, the aim of the research was to study the effect of the morphological parameters on the surface runoff in Wadi Atfih. The current study concluded that the volume of surface runoff was equal to 3.03 million cubic meters and the amount of recharge to the Quaternary aquifer was equal to 2.13 million cubic meters during the rainstorm that the wadi Atfih was subjected to on March 12 and 13, 2020. The DEM of Wadi Atfih was obtained from data from the Shuttle Radar Topography Mission (SRTM), and the DEM of the Wadi Atfih watershed was extracted using the extraction tool in ArcGIS. The software ArcGIS version 10.3 was used for the computation of various morphometric parameters and preparing maps, as well as to divide the Wadi Atfih into 5 subbasins and analyze and calculate 47 morphological parameters for the 5 subbasins of the Wadi Atfih. Thirty-five morphological parameters were defined for the five subbasins of Wadi Atfih, which are directly or inversely related to the hazard degree. The Wadi Atfih subbasins were classified as having five hazard degree groups using the Davis and Ranking methods of morphological parameters.

***Key Word**: Eastern Desert; Flash Flood Hazard; Runoff Volume; Surface Hydrology; Wadi Atfih.*

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I. INTRODUCTION

Assessed the flash flood hazards and water infiltration into aquifers in the Wadi Atfih by integrating remote sensing and a geophysical approach[1]. A watershed study based on morphometric characteristics is crucial and is the most effective way to determine how different characteristics of an area are related to one another[2]. A considered morphometric characterization is significant in hydrological research and in studies regarding the management and conservation of natural resources because it can comprehend a basin's hydrological pattern according to its geomorphology[3]. Pearson's correlation was used to classify the morphometric parameters based on their hydrological contribution to the flash flood event and identify the morphological parameters that have a strong correlation with storm flow generation on the east coast between Marsa Alam and Ras Gharib[4]. Concluded that remote sensing and GIS are the most effective tools used for morphometric analysis to develop regional hydrological models to solve diverse hydrological problems in non-pressurized watersheds, especially in developing countries such as India[5].

Wadi Atfih is located in the northern part of the Egyptian Eastern Desert. It is bounded by longitudes 29°10' and 29°30'E and latitudes 31°10' and 32°00'N and covers an area of about 433.25 square kilometers (Fig. 1a). The Quaternary sediments cover the Atfih wadi delta, which consists of Nile silt (silt, clay, and fine sand), wadi sediments (coarse sand and sandy loam with gravels and rock fragments), and plants. The third deposit is the Pliocene and Middle Eocene rock units exposed in the eastern and southern parts of the study area. Pliocene rocks include undifferentiated sedimentary deposits, including the Kom El Shelul Formation. The Middle Eocene rocks, on which the Pliocene units are based, consist of densely bedded limestone with local cherts and fine nummulites (Mokattam Group unit) (Fig. 1b).

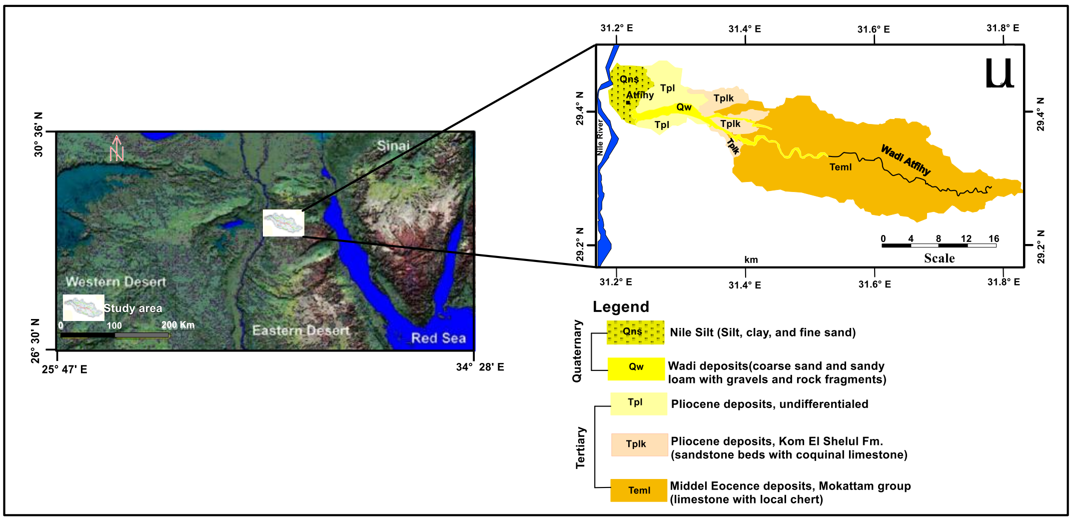

Fig. (1): (a) Location and (b) Geology map of the Wadi Atfih, Eastern Desert, Egypt

The Wadi Atfih has three main geomorphological units: the structural plateau (Gebel El-Galaa El Baharia). Which bounded from the west by the old alluvial plain, is overlain by Tertiary carbonaceous rocks. The elevation of this unit ranges from 300 to more than 600 m above sea level. The second unit is the old alluvial plain, whose surface is covered with a mixture of sand and gravel and whose elevation ranges from 90 to 300 meters above sea level. Recently, this plain has been reclaimed for cultivation, and weathering processes are very active in the exposed rock units. Its topography is characterized by gentle rolling sand plains with a general slope eastward towards the young alluvial plain. The third unit is the young alluvial plain, consisting of the low-lying relief and the flood plain of the River Nile. Its elevation ranges from 16 to less than 90 m above sea level and is covered by a thin silty clay layer and the Quaternary sediments, composed mainly of unconsolidated sands and gravels, limestone pebbles, and cobbles. (Figs. 2a and 2b)

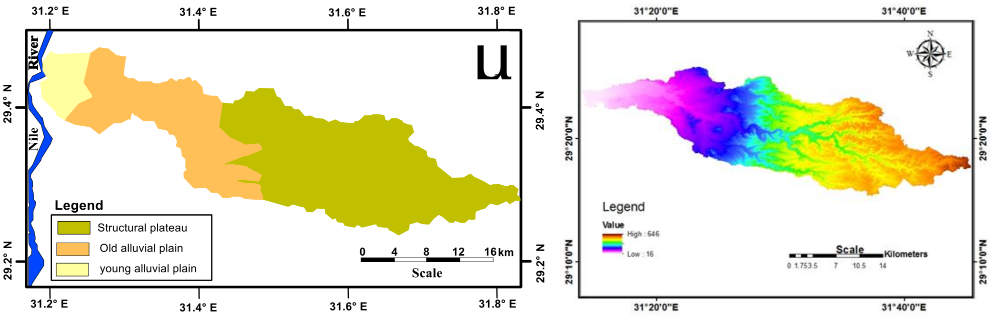

Fig. (2): (a) Geomorphological and (b) Digital elevation model map of the Wadi Atfih, Eastern Desert, Egypt.

During the past few decades, large areas of this alluvial plain of Wadi Atfih have been reclaimed for agricultural production, and new urban and rural areas have been added. This plain was also exploited in quarrying to extract raw building materials (such as sand and clay). There is also the Eastern Military Highway, which represents the main road to Cairo for nearly 20 million people living in Upper Egypt and crosses the mouth of Wadi Atfih. Occasional and dangerous flash floods are very common. So a flood stream was created in the area between the Eastern Military Highway and the Nile River. A flash flood on March 12 and 13, 2020, had a significant negative impact on road networks and agricultural fields. The flood course was breached, and quarry depressions were exposed to large amounts of flash flooding. Therefore, it was necessary to study the impact of morphological parameters on surface runoff to identify the most dangerous places in Wadi Atfih, as well as to determine the surface runoff volume and the amount of recharge to the Quaternary aquifer resulting from the flash flood on March 12 and 13, 2020.

II. MATERIAL And METHODS

- Four infiltration tests were conducted using the Duble Rings device to represent the various soil units in the study area.
- Data from the Shuttle Radar Topography Project (SRTM) was used to create the digital elevation model (DEM) of Wadi Atfih. The DEM of the Wadi Atfih basin and its subbasins was extracted using the ArcGIS extraction tool.
- Determined 47 morphometric parameters of the Wadi Atfih watershed and its subbasins and prepared maps using the program ArcGIS version 10.3.
- Using the Stormwater Management and Design Aid (SMADA) 6.3 program to generate hydrographs of Wadi Atfih.
- The results of infiltration tests were analyzed using the INFILTEST programme[6], based on [7, 8].
- The f-curve was used to calculate the amount of runoff as well as the amount of recharge from the groundwater into the Quaternary aquifer.
- In order to calculate the risk scores for the subbasins more accurately, the researcher modified the Davis method by using 35 morphometric parameters instead of the nine morphometric parameters used by the Davis method.
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III. RESULTS AND DISCUSSION

SURFACE HYDROLOGY

Morphomateric parameters

The term "morphometry" refers to the process of digital analysis of Earth's surface phenomena from data drawn from topographic maps that can be formed from aerial and satellite images and field measurements. The study of the morphometric characteristics of drainage basins is useful in identifying the hydrological characteristics affecting the volume of surface runoff and the occurrence of flood hazards. As well as knowing the extent of the danger posed by wadis and the degrees of their impact on human activity, which is useful in taking the necessary precautions to prevent and protect against their dangers.

To assess the morphometric parameters, data from the Shuttle Radar Topography Project (SRTM) was used to create the digital elevation model (DEM) of Wadi Atfih (Fig. 2b), and ArcGIS software version 10.3 was used in the estimation of 47 morphometric parameters of Wadi Atfih and their subbasins. As shown in Tables 1 and Table 2, were assessed and calculated using different methods and have been classified into:

Drainage network

The drainage network is a final result of the structural, rock, and climatic conditions of any drainage basin, and the geomorphological stage has a significant impact on the drainage network. The drainage network is the general shape in which a group of watercourses appears in a region. The nature of the drainage in the region depends on the type of rock and its characteristics in terms of porosity and permeability, the nature of the earth's surface slope, and the impact of tectonic movements in terms of fractures, twists, breaks, and crack movements, as they have a role in modifying the general appearance of the drainage shape and renewing the activity of the wadi streams, in addition to the climatic conditions in the region, especially the amount of rain, its effectiveness, and its season.

Stream order (Su)

According to [10], ArcGIS version 10.3 was used to determine the stream order of Wadi Atfih and its sub-basins. The bigger the basins are, in general, the higher the stream order, and this indicates a lower risk of flooding for these basins. According to Table 2, the stream order of the Wadi Atfih and its subbasins lies between 4 and 5.

Stream number (Nu)

The wadis in which the stream numbers are lower are the most dangerous wadis due to their small area and, thus, the decrease in the drainage time of the basin and the occurrence of strong flash floods.

Stream length (Lu)

It is known that stream lengths are directly related to stream order. The lowest stream order is the shortest in length, and vice versa. Any change in climatic conditions, rock type, composition, or geomorphological stage leads to discrepancies in the length ratio between one order and the next. The short lengths of streams lead to low drainage densities due to evaporation or leakage and an increase in the possibility of floods.

Bifurcation ratio (Rb)

The bifurcation ratio (Rb) is defined as the ratio between the number of streams of an order (Nu) and the number of streams of the next order (Nu+1) (after [11]). In the study area, Rb and Rbwm have values greater than 3; this reflects high, dissected mountainous areas and elongated basins, as shown in Table 1. Higher values of Rb indicate a high effect of structural control on the drainage pattern, as shown in Sub-3 and Sub-4 (Table 2). While the lower values, as shown in Sub-2 and Sub-5 (Table 2), indicate that the basins are less affected by structural disturbances. The lowest bifurcation ratio Wadis are considered more dangerous as the low branching rate leads to rapid flow, a decrease in the loss and non-dispersion of water, the continuity of feeding the main wadi with water, and an increase in the risk of flooding.

Lower values of Rb, in accordance with [11], indicate basin regions that have undergone fewer structural disturbances and that the drainage pattern has not changed as a consequence of the structural disturbances [25]. As well as lead to a rapid flow, a reduction in water loss and non-dispersion, continued water supply to the main wadi, and a rise in the danger of flooding.

Weight mean bifurcation ratio (Rbwm)

WMRb was introduced by [10] to reach the more representative bifurcation ratio (Rb) number. It is obtained by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values. Higher values of WMRb reflect high mountainous dissected areas and elongated basins, which means less risk, as shown in Table 2.

Sinuosity (Si)

Higher sinuosity values indicate that a wadi has the longest travel time and a high groundwater recharge potential. Therefore, the low sinuosity value has a high risk of flooding.

Main channel length (MC)

The main channel length, which is the length of the longest watercourse from the outflow point of the designated subwatershed to the upper limit of the watershed boundary, was calculated using ArcGIS 10.3 software.

Table (1): Stream length ratio, Mean stream length ratio, Weighted mean stream length ratio, Bifurcation ratios, Mean bifurcation ratio, and Weighted mean bifurcation ratios in Wadi Atfih and its subbasins

	Su	Lu	Lu / Nu	Lur	Lur-r	Lur * Lur-r	Nu	Rb	Nu-r	Rb*Nu-r	Luwm	Rbwm
Atfih	1	236.17	0.99				238.00				1.36	4.41
	2	80.44	1.44	1.45	316.61	458.31	56.00	4.25	294.00	1249.50		
	3	21.49	1.79	1.25	101.93	127.08	12.00	4.67	68.00	317.33		
	4	1.47	0.74	0.41	22.96	9.42	2.00	6.00	14.00	84.00		
	5	1.97	1.97	2.68	3.44	9.22	1.00	2.00	3.00	6.00		
Total		341.54	6.92	5.78	444.94	604.03	309.00	14.92	376.00	1656.83		
Mean				1.45*				3.73*				
Sub-1	1	35.91	0.95				38				2.16	4.48
	2	18.97	2.37	2.51	54.88	137.71	8	4.75	46.00	218.50		
	3	10.98	5.49	2.32	29.95	69.34	2	4.00	10.00	40.00		
	4	0.23	0.23	0.04	11.21	0.47	1	2.00	3.00	6.00		
Total		66.09	9.04	4.87	96.04	207.52	49.00	10.75	59.00	264.50		
Mean				1.62*				3.58*				
Sub-2	1	49.40	0.87				57				1.25	4.32
	2	14.73	1.23	1.42	64.13	90.83	12	4.75	69.00	327.75		
	3	3.87	0.97	0.79	18.60	14.66	4	3.00	16.00	48.00		
	4	1.14	1.14	1.18	5.01	5.90	1	4.00	5.00	20.00		
	5	0.15	0.15	0.13	1.29	0.17	1	1.00	2.00	2.00		
Total		69.29	4.35	3.51	89.03	111.56	75.00	12.75	92.00	397.75		
Mean				0.70*				3.19*				
Sub-3	1	59.45	1.01				59				1.32	3.18
	2	26.48	1.15	1.14	85.93	98.18	23	2.57	82.00	210.35		
	3	12.33	2.47	2.14	38.81	83.13	5	4.60	28.00	128.80		
	4	0.04	0.04	0.02	12.37	0.21	1	5.00	6.00	30.00		
Total		98.30	4.67	3.30	137.11	181.52	88.00	12.17	116.00	369.15		
Mean				1.10*				4.06*				
Sub-4	1	69.00	1.17				59				1.05	4.68
	2	14.87	1.24	1.06	83.87	88.87	12	4.92	71.00	349.08		
	3	3.23	1.08	0.87	18.10	15.73	3	4.00	15.00	60.00		
	4	1.65	1.65	1.53	4.88	7.48	1	3.00	4.00	12.00		
Total		88.75	5.14	3.46	106.85	112.07	75.00	11.92	90.00	421.08		
Mean				1.15*				3.97*				
Sub-5	1	29.32	0.95				31				1.76	4.61

	2	12.97	2.16	2.29	42.29	96.65	6	5.17	37.00	191.17		
	3	3.00	1.50	0.69	15.97	11.08	2	3.00	8.00	24.00		
	4	0.43	0.43	0.29	3.43	0.98	1	2.00	3.00	6.00		
Total		**45.72**	**5.04**	**3.27**	**61.69**	**108.72**	**40.00**	**10.17**	**48.00**	**221.17**		
Mean				**1.09***				**3.39***				

Su: Stream order, Lu: Stream length, Lur: Stream length ratio, Lum: Mean stream length ratio*, Lur-r: Stream length used in the ratio, Luwm: Weighted mean stream length ratio**,** Nu: Number of streams, Rb: Bifurcation ratios, Rbm: Mean bifurcation ratio*, Nu-r: Number of stream used in the ratio, Rbwm: Weighted mean bifurcation ratios

Table (2): Morphometric parameters of Wadi Atfih and its sunbasins

Morphometric parameters		*Formula*	*Reference*	Wadi Atfih	Sub-1	Sub-2	Sub-3	Sub-4	Sub-5
a) Drainge Network	1-Stream order(Su)	Hiearchical Rank	9,10,11	1 to 5	1 to 4	1 to 5	1 to 4	1 to 4	1 to 4
	2-Stream number (Nu)	Nu = 1+N2+…..+Nn	9	309.00	49.00	75.00	88.00	75.00	40.00
	3-Stream length (Lu)Kms	Lu=L1+L2+…...+Ln	11	341.54	56.08	69.29	107.63	88.75	45.72
	4-Stream length ratio (Lur) Kms	See table (1)	11	5.78	4.87	3.51	3.30	3.46	3.27
	5-Mean stream length ratio (Lurm)	See table (1)	11	1.45	1.62	0.70	1.10	1.15	1.09
	6-Weighted mean stream length ratio (Luwm)	See table (1)	11	1.36	2.16	1.25	3.30	1.05	1.76
	7-Bifureation ratio (Rb)	Rb =Nu / Nu-1	11	4 – 6	.04 - 2.51	.13 - 1.42	.02 - 2.14	.87 - 1.53	.29 - 2.29
	8-Mean bifureation ratio (Rbm)	See table (1)	11	3.73	3.58	3.19	4.06	3.97	3.39
	9 -Weightrd mean bifureation ratio (Rbmw)	See table (1)	10	4.41	4.48	4.32	3.18	4.58	4.61
	10-Main chanel length (Cl) Kms	GIS software Analsis		73.21	20.12	20.94	32.13	29.98	25.72
	11-Main channel index (Mci)	Mci=(Main channel length) / (Max. straight of the main channel)	12	29.28	24.54	19.04	42.84	23.79	18.37
	12-Valley length (Vl) Kms	GIS software Analsis		50.89	13.16	14.61	22.16	22.66	15.39
	13-Rho coefficient (p)	p= Lur / Rb	9	1.55	1.36	1.10	0.81	0.87	0.96
	14-Sinuosi ty (Si)	Si=Vl/Lb	13	0.97	0.90	1.97	0.89	0.95	1.11
b) Basin Geometry	15-Basin length (Lb) Kms	GIS software Analsis	14	52.27	14.66	7.42	24.89	23.78	13.84
	16-Basin width (Wb)	Wb= A / Lb	15	8.29	4.33	13.78	4.32	4.60	3.65
	17-Basin Area (A) sq Kms	GIS software Analsis	14	433.25	63.52	102.28	107.52	109.44	50.49
	18-Basin perimeter (P) Kms	GIS software Analsis	14	156.32	49.39	56.00	70.96	67.83	58.48
	19-Relative perimeter (Pr)	Pr= A / P		2.77	1.29	1.83	1.52	1.61	0.86
	20-Length area relation (Lar)	$Lar= 1.4 * A^{0.6}$	16	53.48	16.90	22.49	23.18	16.73	14.73
	21-Lemniscate's (K)	$K= Lb^2/4 * A$	17	1.58	0.85	0.13	1.44	1.29	0.95

	22-From factor ratio (Ff)	$Ff= A / Lb^2$	15	0.16	0.30	1.86	0.17	0.19	0.26
	23-Shape factor ratio (Sf)	$Sf= Lb^2 / A$	9	6.31	3.38	0.54	5.76	5.17	3.79

Table (2) (cont.)

Morphometric parameters		*Formula*	*Reference*	Wadi Atfih	Sub-1	Sub-2	Sub-3	Sub-4	Sub-5
b) Basin Geometry	24-Elongation ratio (Re)	$Re = \frac{2*\sqrt{A/\pi}}{Lb}$	14	0.45	0.61	1.54	0.47	0.50	0.58
	25-Elipticity index (Ie)	$Le= \pi * Vl^2 / 4 A$		4.69	2.14	1.64	3.59	3.68	3.68
	26-Texture ratio (Rt)	$Rt= \Sigma Nu / P$	9	1.98	0.99	1.34	1.24	1.11	0.68
	27-Circularity ratio (Rc)	$Rc= 4\pi * (A / P^2)$	18	0.22	0.33	0.41	0.27	0.30	0.19
	28-Circularity ration (Rcn)	Rcn=A / P	11	2.77	1.29	1.83	1.52	1.61	0.86
	29-Compactness coefficient (Cc)	$Cc= 0.2841*P / A^{0.5}$	19	2.13	1.76	1.57	1.94	1.84	2.34
	30-Fitness ratio (Rf)	Rf= Cl / P	20	0.47	0.41	0.37	0.45	0.44	0.44
	31-Wandering ratio (Rw)	Rw= Cl / Lb	21	1.40	1.37	2.82	1.29	1.26	1.86
	32-Basin shape index (Ish)	$Ish= 1.27 * A / Lb^2$	22	0.20	0.38	2.36	0.22	0.25	0.33
	33-Compactness ratio (Sh)		11	2.12	1.75	1.56	1.93	1.83	2.32
c) Drainge texture analysis	34-Stream frequency (Fs)	$Fs=\sum Nu / A$	15,9	0.71	0.77	0.73	0.82	0.69	0.79
	35-Drainge density (Dd) Km / Kms^2	$Dd=\sum Lu / A$	15,9	0.79	0.88	0.68	1.00	0.81	0.91
	36-Constant of channel maintence (Kms^2 / Km)	C= 1 / Dd	14	1.27	1.13	1.48	1.00	1.23	1.10
	37-Drainage indensity (Di)	Di= Fs / Dd	23	0.90	0.87	1.08	0.82	0.85	0.87
	38-Infiltration number (If)	If= Fs * Dd	23	0.56	0.68	0.50	0.82	0.56	0.72
	39-Length of overland flow (Lo) Kms	Lo= 1 / 2 * Dd	9	0.63	0.57	0.74	0.50	0.62	0.55
d) Relief characterizes	40-Maximum elevation (H_{max})	GIS software Analsis		646.00	646.00	576.00	460.00	508.00	202.00
	41-Minimum elevation (H_{min})	GIS software Analsis		16.00	375.00	352.00	143.00	81.00	16.00
	42-Relative Relief (R) (m)	R= Highest elevation - Lowest elevation	10	630.00	271.00	224.00	317.00	427.00	186.00
	43-Internal relief (E)	E= (E85-E10)	10	427.00	83.00	110.00	219.00	317.00	96.00
	44-Relief ratio (Rr)	Rr= R / Lb	14	0.01	0.02	0.03	0.01	0.02	0.01
	45-Slope index (Si %)	Si= (E / 0.75 Vl)	24	28.97	1.46	2.14	6.47	9.58	1.97
	46-Ruggness number (Rn)	Rn= R * Dd	20	0.50	0.24	0.15	0.32	0.35	0.17
	47-Hypsometric integral (Hi)	Hi = (mean elevation - elevation min) / (elevation max - elevation min)	10	0.50	0.50	0.50	0.50	0.50	0.50

Wadi Atfih's main channel is roughly 73.21 km long, while the subbasins' lengths range from 20.12 km for Sub-1 to 32.13 km for Sub-3. The wide variations between the main channel lengths of the study basins are due to the variation of the geological features of the study area.

Main channel index (MCI)

States that the main channel index assesses the main channel's divergence from its geometric course and is an index of the sinuosity characteristic. This suggests that the high-value main channel has a high probability and potential for groundwater recharge. This implies that the main channel index and the risk of flooding are inversely related[12].

Basin geometry

Basin area (A)

The basin area is of great importance in the study of flash floods. The larger the watershed area of the basin, the greater the amount of water it receives and the greater its load, assuming the stability of the rest of the other variables such as rock type, slope, and amount of water. There is also a direct relationship between the area of the basin and the amount of lost water, as the watershed area of the basin affects the size and amount of flooding. The larger the watershed area, the longer the basin's discharge period, and thus the greater the flood risk.

Basin length (Lb)

The basin length indicates the surface runoff's travel time, especially the flood waves passing through the basin, which plays a prominent role in determining the possibility of floods, as short basins help in floods due to the lack of water losses by evaporation and infiltration and the short discharge time. The greater the basin length, the greater the travel time, which gives a good chance and potential for groundwater recharge.

Basin width (Wb)

It is known that the wadis, which are characterized by an increase in their length compared to their width, are characterized by the arrival of water to the main channel at different times, and thus the flow continues for a longer period with a decrease in the value of the flood as a result of the concentration of the water and its lack of dispersion. The small values of the basin width indicate the elongated shape that leads to greater groundwater recharge potential.

Basin perimeter (P)

The water-dividing line separating the wadi drainage basin from the neighbouring basins is referred to as the basin perimeter. Considering the amount of vegetation and the type of rock, which play a role in regulating the amount of loss, the wadi's small basin perimeter makes it more dangerous due to the low water loss, high runoff, and regular occurrence of strong flash floods**.**

Circularity Ration (Rcn)

The circularity of the basin indicates the progression of the morphological stage that the wadi passes through, as the rivers usually dig and deepen their streams and then begin to expand them. Circularity basins gather most of the tributaries in one central area, and if runoff occurs, it arrives all at once, increasing the risk of flooding. The opposite occurs in basins that tend to elongate, where the runoff is more regular.

Form Factor Ratio (Ff)

This parameter gives an indication of the consistency of the parts of the basin and the regularity of its general shape. The form factor shows the relationship between the length and width of the wadi; high values indicate that the shape of the basin is close to rectangular. While low values indicate that the basin's shape is close to triangular, water collects in the upstream area to form a strong flash flood peak and a torrential flood in the downstream area.

Compactness Coefficient (Cc)

This coefficient refers to the extent to which the shape of the basin's perimeter is consistent with its area, the regularity and tortuousness of the water dividing lines, and the extent of their distance from the center. The high values of this factor indicate that these basins are characterized by a large perimeter at the expense of their total area, i.e., the perimeters meander and the degree of regularity of the basin shape decreases. The compactness coefficient is directly proportional to the erosion risk assessment; this means that high values signify more vulnerability to risk factors.

Elongation ratio (Re)

The shape of the river basin is measured by the elongation ratio, which mostly depends on geological and climatic factors and is also important to the estimation of flood hazards and understanding basin hydrology. A basin's shape is said to be elongated when the elongation ratio is less than unity and circular when the ratio is greater than unity. According to [28], surface runoff discharge is more effective in a circular basin than in an elongated basin; hence, larger elongation ratio values signify a higher danger of floods.

Circularity ratio (Rc)

The circularity ratio is mainly concerned with the length and frequency of streams, geological structures, land use, land cover, climate, relief, and slope of the basin. It is a significant ratio that indicates the dendritic stage of a watershed. Low, medium, and high values of Rc show the young, mature, and old phases, respectively, of the life cycle of the tributary watershed [27].

Texture ratio (Rt)

The texture ratio is related to the underlying lithology and relief aspects of the basin. A high texture ratio represents a higher relief condition, which indicates the extent to which the basin is affected by the amount of precipitation and runoff. The lower values of the texture ratio indicate that the basin has a good chance for groundwater recharge, while the basins with high values, where they are composed of hard rocks that have no ability for water infiltration, have a good chance to produce flash floods [28].

Basin shape index (Ish)

The basin shape index indicates the gradual descent of the mainstream from the gathering areas to the discharge area. The basin with a high value of the slope index is considered the most dangerous basin because it leads to an increase in the velocity of runoff and the flow of water to the outlet of the basin, which doubles its ability to wash away materials and thus exacerbates the severity of the risks and damages in the event of a flood.

Wandering ratio (Rw)

The wandering ratio is the ratio of the mainstream length to the valley length. Therefore, the higher its value, the more tortuous the wadi, and thus the less dangerous it is.

Shape factor ratio (Sf)

The lower values of the shape factor ratio indicate that the basin length is short, and vice versa. This means that the lower value of the shape factor ratio increases flash flood hazards in the basin.

Drainage texture

Stream* Frequency *(Fs)

Stream frequency is the ratio between the total stream numbers and the basin area. High stream frequency is related to the impermeable subsurface material, sparse vegetation, high relief, and low infiltration capacity of the region [29]. This means that high values of this coefficient indicate an increase in the probability of floods and an increase in the volume of runoff.

Drainage density (Dd)

The importance of calculating the drainage density network lies in the fact that it reflects the effects of each type of rock, its system, soil, topography, and vegetation cover. It also sometimes shows the human influence on the water drainage network. The area and drainage density have an inverse relationship, with drainage density increasing with a small pelvic area. The value of the drainage density depends on the amount of rain falling on the basin region and the rates of evaporation, leakage, and permeability. In general, the hydrology of a watershed changes significantly in response to changes in drainage density [30]. A high value of basin drainage density indicates that a large amount of the rainfall resulted in runoff, while a low drainage density reflects the erosion-resistant fractured hard rock of the study area and indicates that most of the rainfall infiltrates to recharge the groundwater storage.

Drainage intensity (Di)

The low value of drainage intensity (Di) indicates that drainage density and stream frequency have little effect on the extent to which the surface has been lowered by agents of denudation and surface runoff is not rapidly removed from the watershed, making it highly susceptible to flooding, gully erosion, etc.

Infiltration number (If)

The infiltration number is important in determining the infiltration character of the basin. It is inversely proportional to the infiltration capacity of the basin. The higher the infiltration number, the lower the infiltration, and this implie higher surface runoff [31].

Length of overland flow (Lo)

Overland flow length is one of the most important sovereign variables influencing drainage basin hydrologic and physiographic advancement [15]. Basins that have a low value of Lo indicate that runoff will take very little time to reach the outlet. As a result, they will be more vulnerable to flash flooding.

Constant of channel maintenance (C)

The constant of channel maintenance is the inverse of drainage density, so large values of C signify a higher infiltration rate and an older maturity stage of the river, i.e., the flood is a low risk.

Relief characterize

There is a relationship between surface runoff and the characteristics of the surface of the basin, and the importance of studying the erosion of the basins emerges as a result of the activity and strength of erosion processes and the impact of lithological and tectonic differences on this activity. When other parameters remain constant, basins with a steep slope help speed up runoff and reduce losses, while basins with a slight slope increase the probability of water loss due to the processes of evaporation and seepage.

Relative Relief (R)

Confirmed a negative correlation between relative relief and the degree of rock resistance to erosion factors when climatic conditions are constant [32]. The high relative relief indicates the intensity of the erosion and the roughness of the surface, and this can be attributed to the nature of the rocks and their complex structures, as we notice a clear increase in the intensity of fractures and faults on most rocks, which is one of the reasons leading to an increase in erosion. This means that the high values of relative relief for the basins are more dangerous due to the intensity of the relief and the speed of the flow.

Relief Ratio (Rr)

It directly indicates the degree of slope of the wadi, and the higher values of the relief ratio indicate an increased risk of flooding as a result of the speed of runoff and a decrease in losses. While the low relief ratio indicates that the basin went a long way in the erosion cycle and was able to reduce its relief.

Ruggedness number (Rn)

The ruggedness number is one of the most important morphometric measures that deal with the complex reciprocal relationship between more than one variable. It measures the relationship between each of the relief characteristics and the stream lengths and basin area. Because of the high value of the relief ratio and the steep and long slope, the risk of the basin increases as the value of the basin's ruggedness number increases.

Hypsometric integral (HI)

The lower values of the hypsometric integral indicate that the basin is more dangerous due to a decrease in concentration time and basin drainage. Presented a basin classification based on basin HI values [33]. Basins with HI values above 0.6 were classified as "young," whereas catchments with HI values below 0.3 were classified as "old" or "Monadnock." Mature-stage catchments have HI values greater than 0.3 and lower than 0.6. The value of the hypsometric integral of the wadi Atfih and its subbasins was 0.5, which indicated that these were mature.

The slope index (Si %)

The slope index is an indication of the channel slope, from which an assessment of the runoff volume can be made. Lower slope index values in the basin indicate more groundwater recharge potential.

Infiltration tests and analysis

Infiltration rate is defined as the volume flux of water flowing into the profile per unit of surface soil area. Consequently, it will determine how much water will enter the soil and how much will runoff. Therefore, knowledge of this process is a prerequisite for water management. Four infiltration tests were performed, representing the different soil units in the studied area, using a double-ring infiltrometer as described by [34]. By using the INFILTEST program [6] based on the [7, 8], the data from infiltration tests were processed. The results indicate that the infiltration rate ranges from 0.056 to 5.27 m/day, according to Kohnke's classification; the investigated soils in the study area vary from slow to rapid soil.

In conclusion, the subbasins of Wadi Atfih can be subdivided into runoff and abstraction areas. The sub-1, sub-2, and sub-3 of the wadi Atfih are areas of runoff, while the sub-4 of the wadi can be considered a runoff and abstraction area, and the sub-5 of the wadi can be considered an abstraction area, which helps in the replenishment of the groundwater in the Quaternary aquifer (Fig. 3).

Runoff volume

Estimating the runoff volume affects the sustainable development of water resources and flood protection. In general, the present work is concerned with the amount of runoff from a storm event in Wadi Atfih on March 12 and 13, 2020, that led to the destruction of main roads, villages, and infrastructure and the deaths of many people. The present study used two methods to estimate the surface runoff volume of this rainstorm in Wadi Atfih: the Stormwater Management and Design Aid Program (SMADA 6.3) and the F-curve.

Calculation of runoff volume by applying for the Smada program

The SMADA6.3 programme is a comprehensive hydrological package (the watershed characteristics, the rainfall event characteristics, and the hydrograph generation). It is important to note that the calibration and validation of the model are severely hampered by the lack of precise rainfall and runoff data. The "curve number" (CN) value is the primary unknown parameter that influences the outcomes of the simulation process used with the SMADA model [37]. The soil type, land use, hydrologic state, and antecedent moisture conditions all influence the

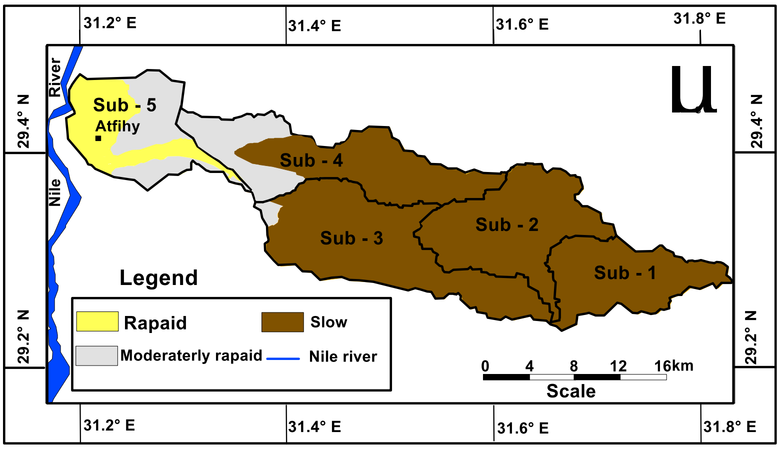


Fig. (3): Infiltration rates zonation map in Wadi Atifih, Eastern Desert.

curve number. The antecedent moisture content is a function of the total rainfall in the 5-day period preceding a storm [36]. In the present study area, the antecedent moisture condition can be disregarded because rain occurrences are extremely uncommon. According to [37], the curve number of Wadi Atfih is equal to 85.

The input data for the SMADA6.3 program are summarised in Table 3. Two storms with different amounts and durations of rainfall were entered for March 12 and 13 (2020). Two scenarios for the interaction between precipitation and runoff were identified for different rainfall depths. The maximum flow, peak time, and runoff volume were determined in each case. On March 12, 2020, the maximum flow was 444.557 m^3/s, the peak time was 1 hour, and the runoff volume was 2.65 MCM. On March 13, 2020, the runoff volume was 0.34 MCM, the maximum flow was 566.432 m^3/s, and the peak time was 0.42 hours (Fig. 4).

Calculation of runoff volume by applying the F-curve method

The f-curve is significant because it can be used to calculate both the amount of runoff and the amount of groundwater aquifer recharge. To generate the f-curve for the studied basin, the infiltration rate curve is applied to the chart showing the distribution of rainfall in a particular area during the storm and moved to keep the coordinates of the two curves parallel to the position at which the amount of rainfall above the curve is equal to the actually measured runoff (rainfall excess), and this curve in that position is called the f-curve. The total volume of runoff is about equal to 3.13 million cubic meters, and the Quaternary aquifer recharge was about 1.98 million cubic meters during the 12 and 13 rainstorms of March 2020 using the F curve method. In the study area, there is a flood current; the volume of runoff it accommodates was calculated and found to be equal to 0.58 million cubic meters, but the volume of runoff calculated using Smada and f-curve methods was 2.98 and 3.13

MCM, respectively, during the rainstorm on March 12 and 13, 2020, which means that the average volume of runoff is 3.05 MCM.

Table (3): Input and output parameters of the studied basin for hydrograph generation using SMADA 6.3

Parameters	**Discription of the parameters**	**Source Data**	**12/3/2020**	**13/3/2020**
Total Drainage Area (A) (Acres)	The area of the studied basin in Km^2	Input parameters	107056.4	107056.4
Impervious Drainage Area (Acres)	Area which is characterized by impermeable hydrologic conditions		55959.39	55959.39
% Impervious Directly Connected	Percentage Area which is characterized by impermeable hydrologic conditions		52.27	52.27
Length of Overland Flow (m)	the maximum length of surface flow generated by rain water before it gets into definite stream channels		360	360
Slope (m/m)	The average land slope		0.008605	0.008605
Time of Concentration (min)	Over land time to outlet (min)		11.3	11.3
Maximum Infiltration Capacity (inchs)	Capacity of soil for infiltration		207.48	207.48
SCS Curve Number for Pervious	is used for runoff assessment of the catchment and soil conservation		85	85
Initial Abstraction Factor			0.2	0.2
Total Rainfall Duration (hrs)	Event duration in hours	Rainfall	2.5	0.55
Time step for Rainfall (min)	Time step will affect calculation Accuracy in Hydrograph Generation		5	5
Total Rainfall (inch)	Total rainfall (inch) for a series of time increments		2.154	0.3
Maximum flow (m^3/sec)		Output parameters	4 440.557	**566.432**
Time to peak (hours)			1	0.42
Time to base (hours)			2.92	0.92
Runoff volume (m^3x10^6)			2.65 x 10^6	0.34x 10^6
Total runoff volume (m^3x10^6)			2.98 x 10^6	

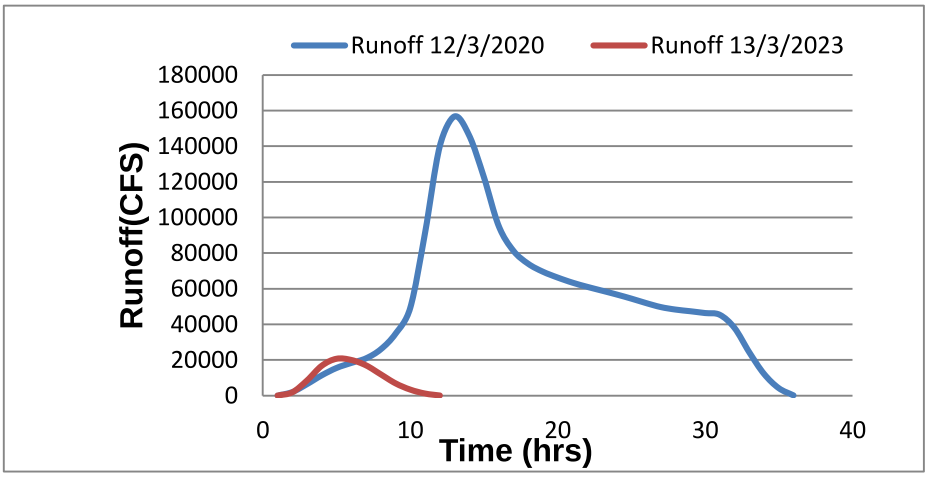


Fig. (4): Hydrograph of Wadi Atfih during the rainfall storms (12, 13 March 2020)

Therefore, to prevent damage and maximise benefits for the region's sustainable development, the flood stream must be widened to accommodate the volume of surface runoff from the floods.

Evaluation of flash flood hazards

To evaluate the most hazardous places in Wadi Atfih, the wadi was divided into 5 subbasins (Sub-1, Sub-2, Sub-3, Sub-4, and Sub-5). used the following methods to evaluate the hazard degrees of the subbasins of Wadi Atfih:

Modification of the Davis Method

Evaluated the direct or inverse relationship between nine morphometric parameters and basin hazards [38]. Instead of the nine morphometric parameters suggested by Davis' theory, the publisher used 35 morphometric parameters in this study.This will give a more accurate picture of the basins' degree of hazards. The paragraph "morphometric parameters" describes the relationship (direct or inverse relationship) between each of the 35 morphometric parameters and the hazard degrees. Table 8 shows the association between 35 morphometric parameters and hazard degrees (a direct or inverse relationship).

The equation [38] was used to calculate the hazard degree when it was directly related to morphometric parameters.

$$\mathbf{Hazarddegree} = \frac{\mathbf{4(X + Xmin)}}{\mathbf{Xmax + Xmin}} + \mathbf{1} \qquad (\mathbf{2})$$

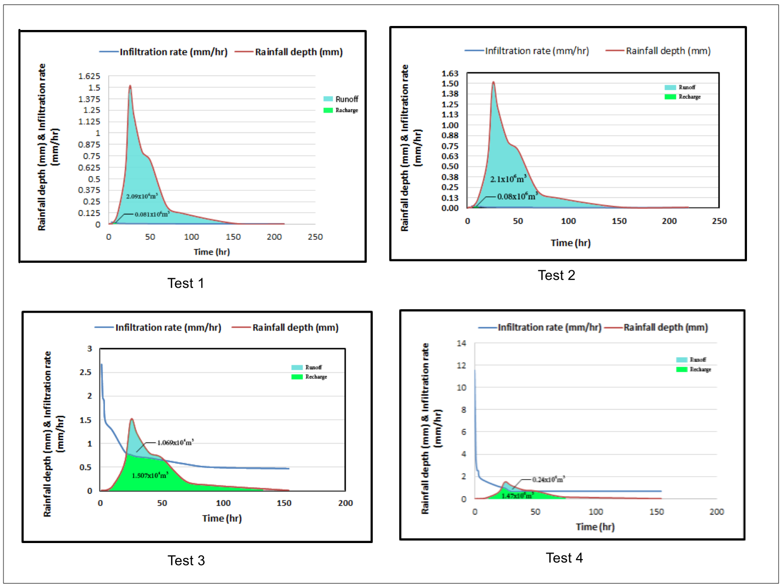
The following equation was used when the degree of the hazards had an inverse relationship to the morphometric parameters:

$$\mathbf{Hazarddegree} = \frac{\mathbf{4(X - Xmax)}}{\mathbf{Xmin - Xmax}} + \mathbf{1} \qquad (3)$$

Where X is the value of the morphometric parameters to be assessed for the hazard degree for each basin, and Xmin and Xmax are the minimum and maximum values of the morphometric parameters for all subbasins of Wadi Atfih, respectively. The hazard degree of the study of Wadi Atfih's subbasins is calculated using equations (2) and (3). The sum of the hazard degrees for each subbasin represents the final flood hazard for that basin (Table 8). These values ranged between 84.47 for Sub-3 and 102.82 for Sub-1. According to the calculated values, the studied subbasins can be divided into five groups: Sub-3 had a low hazard degree; Sub-4 had a moderately low hazard degree; Sub-5 had a moderate hazard degree; Sub-2 had a moderately high hazard degree; and Sub-1 had a high hazard degree, as shown in Table 8.

Ranking of Subwatersheds Based on Morphomatric Analysis

The direct and inverse relationships between 35 morphometric parameters and the flood hazard degrees. The morphometric parameters' highest degree of risk was given a rank of 5, the second highest a rank of 4, and so on until the lowest degree of risk was given a rank of 1. The compound factor (CF) was computed by summing the ranks of 35 morphometric parameters and then dividing by the number of them. Based on compound factor values, the analyzed subbasins could be classified into five groups, as shown in Table 9. Sub-3 had a low hazard degree, Sub-4 had a moderately low hazard degree, Sub-5 had a moderate hazard degree, Sub-2 had a moderately high hazard degree, and Sub-1 had a high hazard degree.



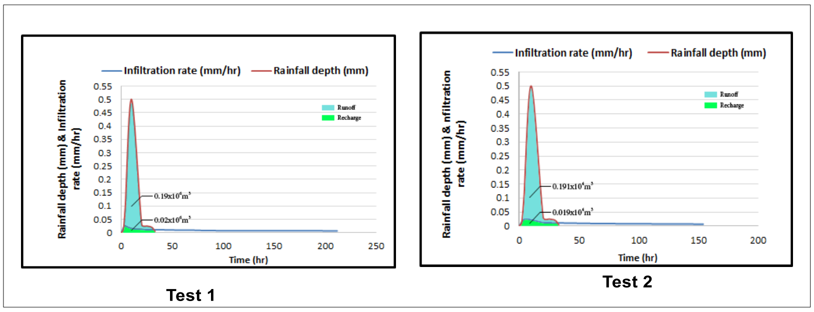


Fig. 7: F-curve for Wadi Atfih during the rainfall storm 12, 13 March 2020

Table (4): Hazard degree of Wadi Atfih and its subbasins by using the Davis modification Method

Morphometric parameters		Sub-1	Sub-2	Sub-3	Sub-4	Sub-5
a) DraingeNetwork	(Nu)	4.25	2.08	1.00	2.08	5.00
	(Lu)	4.33	3.48	1.00	2.22	5.00
	(Rbm)	1.36	1.81	5.00	1.08	1.00
	(Rbmw)	5.00	4.73	1.00	1.72	3.13
	(Cl)	5.00	4.73	1.00	1.72	3.13
	(Mci)	3.99	4.89	1.00	4.11	5.00
	(Si)	4.97	1.00	5.00	4.77	4.18
b) Basin Geometry	(Lb)	3.34	5.00	1.00	1.25	3.53
	(Wb)	1.27	5.00	1.27	1.38	1.00
	(A)	4.12	1.62	1.13	1.00	5.00
	(P)	5.00	3.77	1.00	1.58	3.31
	(K)	2.82	5.00	1.00	1.46	2.51
	(Ff)	1.29	5.00	1.00	1.05	1.21
	(Sf)	2.82	5.00	1.00	4.90	2.51
	(Re)	1.54	5.00	1.00	1.10	1.41
	(Rt)	2.88	5.00	4.39	3.57	1.00
	(Rc)	3.53	5.00	2.48	3.02	1.00
	(Rcn)	2.76	5.00	3.71	4.12	1.00
	(Cc)	0.52	1.00	0.06	2.41	5.00
	(Rf)	3.30	5.00	1.00	1.55	1.66
	(Rw)	4.71	1.00	4.92	5.00	3.47
	(Ish)	1.29	5.00	1.00	1.05	1.21
	(Sh)	1.98	1.00	1.63	0.32	5.00
c) Drainge texture analysis	(Fs)	3.59	2.44	5.00	1.00	4.21
	(Dd)	3.54	1.00	5.00	2.65	3.82
	(C)	3.88	1.00	5.00	3.04	4.12
	(Di)	4.15	1.00	5.00	4.59	4.13
	(If)	3.29	1.00	5.00	1.73	3.74
	(Lo)	3.88	1.00	5.00	3.04	4.12
d) Relief characterizes	(R)	2.41	0.18	3.17	5.00	1.00
	(Rr)	2.21	5.00	0.83	2.08	1.00
	(Si %)	1.00	1.34	3.47	5.00	1.25
	(Rn)	2.80	1.00	4.40	5.00	1.34
Summation of hazard degree		102.82	101.08	84.47	85.56	95.00
Hazard degree		5	4	1	2	3
Basin relative hazard degrees (BRHD)		High Hazard	Moderately High Hazard	Low Hazard	Moderately Low Hazard	Moderate Hazard

Table (5): Hazard degree of Wadi Atfih and its subbasins by using Rank

Morphometric parameters		Sub-1	Sub-2	Sub-3	Sub-4	Sub-5
a) Drainge Network	(Nu)	4.00	2.00	1.00	3.00	5.00
	(Lu)	4.00	3.00	1.00	2.00	5.00
	(Rbm)	3.00	5.00	1.00	2.00	4.00
	(Rbmw)	3.00	4.00	5.00	2.00	1.00
	(Cl)	5.00	4.00	1.00	2.00	3.00
	(Mci)	2.00	4.00	1.00	3.00	5.00
	(Si)	4.00	1.00	5.00	3.00	2.00
b) Basin Geometry	(Lb)	3.00	5.00	1.00	2.00	4.00
	(Wb)	3.00	5.00	2.00	4.00	1.00
	(A)	4.00	3.00	2.00	1.00	5.00
	(P)	5.00	4.00	1.00	2.00	3.00
	(K)	4.00	5.00	1.00	2.00	3.00
	(Ff)	4.00	5.00	1.00	2.00	3.00
	(Sf)	4.00	5.00	1.00	2.00	3.00
	(Re)	4.00	5.00	1.00	2.00	3.00
	(Rt)	2.00	5.00	4.00	3.00	1.00
	(Rc)	4.00	5.00	2.00	3.00	1.00
	(Rcn)	2.00	5.00	3.00	4.00	1.00
	(Cc)	2.00	1.00	4.00	3.00	5.00
	(Rf)	4.00	5.00	1.00	3.00	2.00
	(Rw)	3.00	1.00	4.00	5.00	2.00
	(Ish)	4.00	5.00	1.00	2.00	3.00
	(Sh)	2.00	1.00	4.00	3.00	5.00
c) Drainge texture analysis	(Fs)	3.00	2.00	5.00	1.00	4.00
	(Dd)	3.00	1.00	5.00	2.00	4.00
	(C)	3.00	1.00	5.00	2.00	4.00
	(Di)	3.00	1.00	5.00	4.00	2.00
	(If)	3.00	1.00	5.00	2.00	4.00
	(Lo)	3.00	1.00	5.00	2.00	4.00
d) Relief characterizes	(R)	3.00	2.00	4.00	5.00	2.00
	(Rr)	3.00	5.00	1.00	4.00	2.00
	(Si %)	1.00	3.00	4.00	5.00	2.00
	(Rn)	3.00	1.00	4.00	5.00	2.00
Summation of hazard degree		107.00	106.00	91.00	92.00	100.00
Compound factor (CF)		3.2424	3.2121	2.7576	2.7879	3.0303
Hazard degree		5	4	1	2	3
Basin relative hazard degrees (BRHD)		High Hazard	Moderately High Hazard	Low Hazard	Moderately Low Hazard	Moderate Hazard

IV Conclusion

Studies related to the analysis of morphological parameters are very important for knowing the hydrological conditions in watersheds, especially in arid and semi-arid regions. As a result of the climatic changes that the world has been witnessing recently, these areas are exposed to flash floods that lead to the destruction of main roads, villages, and infrastructure and the deaths of many people. However, there are no accurate measurements to calibrate rainfall and surface runoff. Among these areas is Wadi Atfih, which is in the northern part of the Egyptian Eastern Desert and covers an area of about 433.25 square kilometers. The Quaternary sediments cover the Atfih Wadi delta and the Pliocene and Middle Eocene rock units exposed in the eastern and southern parts of the study area. The Wadi Atfih has three main geomorphological units: the structural plateau, the old alluvial plain, and the young alluvial plain). The surface soil of the Wadi Atfih is characterised by slow-to-rapid soil. All the effective morphometric parameters of study basins were measured and calculated based on the integration between GIS techniques and the physiographic features of the study basin. According to the hazard degree, the sub-basins of the study area can be classified into the following five groups: Sub-3 had a low hazard degree, Sub-4 had a moderately low hazard degree, Sub-5 had a moderate hazard degree, Sub-2 had a moderately high hazard degree, and Sub-1 had a high hazard degree. Two methods were used to estimate runoff volume in Wadi Atfih: the Stormwater Management and Design Assistance Program (SMADA 6.3) and the F-curve. The average runoff volume was 3.05 MCM, while the Quaternary aquifer recharge averaged about 2.13 MCM during a rainstorm on March 12 and 13, 2020.

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