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IMPACT OF CLIMATIC VARIATIONS ON WATER RESOURCES IN WADI EL DIF, SOUTH EASTERN DESERT, EGYPT

BY

Ismail, Y. L, Omar M. M. *, Mohammed, M. H. and Sobhy, I. M.

Department of Hydrology, Desert Research Center, El-Matareya, Cairo, Egypt
***E-mail: omona5468@gmail.com**

ABSTACRT

Recent climatic variations have had a great impact on the availability of water resources in arid and semi-arid regions of the world. It is crucial to understand the integrated relationship between surface runoff and the aquifers. The present study aims to invistigate and evaluate the climatic factors, especially rainfall storms and their influence on water resources in Wadi El Dif, as well as an assessment the relationship of runoff to the replenishment of the groundwater aquifer. In addition, we use morphometric parameters of the investigated basin to elucidate their impact on the surface runoff within the main channel during rain storms.

Two storms of different rainfall depths (51.8 and 34 mm) having return periods of 20 and 8 years, respectively, were selected based on meteorological data of the Shalateen weather for the period (1979–2019). The SAMADA6.3 programme was applied to generate hydrographs for the two storms to calculate the peak runoff. The obtained volume of runoff varies from 0.884 million m3to 0.276 million m3.

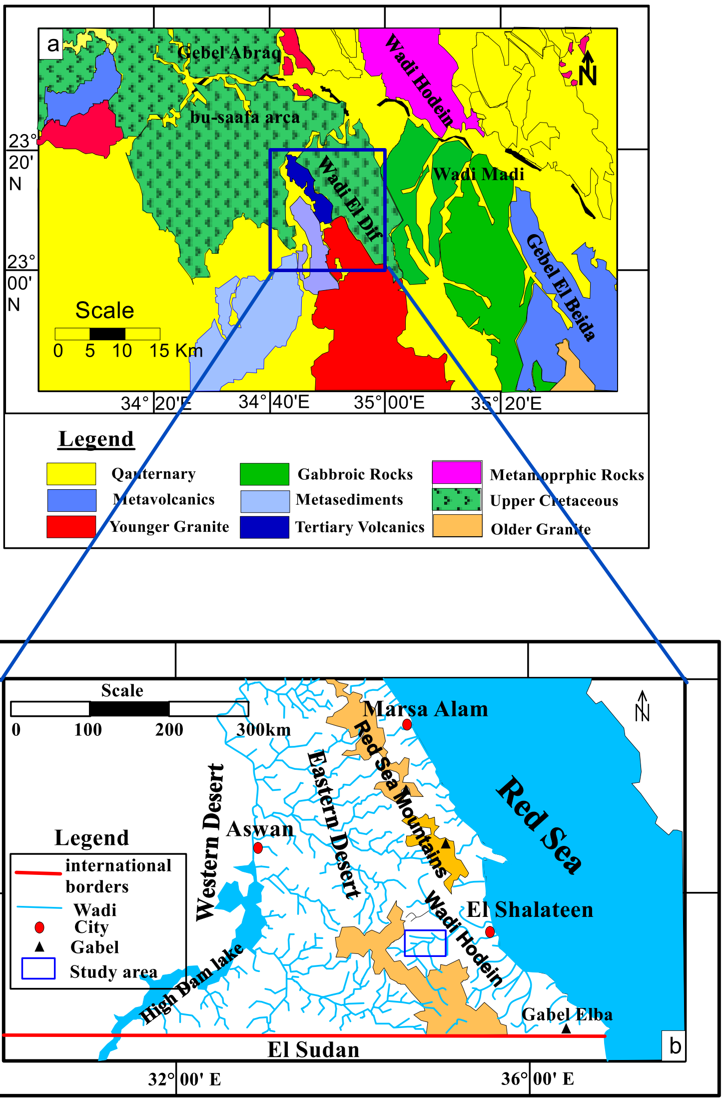
Wadi El Dif is consideredone of the main subbasins of Wadi Hodein and covers about 518 km^2. The catchment area of the Wadi El Dif is characterised by the mature hazards of flash floods. The obtained values for the infiltration rate in the study area range from 6 to 8 m/day, indicating that the soil of the Wadi El Dif is characterised by a very rapid rate of infiltration that directly impacts and replenishes the groundwater aquifer.

On the other hand, the relationship between the return period and the annual rainfall depth was inversely proportional. The groundwater of the Wadi El Dif is available from the Nubian Sandstone Aquifer. The water depth didn't signiticantly change from 23.66 to 23.7m in the period from 2007 to 2020, which means a balance between the amount of discharge and the amount of recharge to the aquifer. Groundwater replenishment amounts reached 2.69 million m^3 in 2018 and 1.41 million m^3 in 2019.The hydraulic parameters of the study aquifer revealed low potential and capability to transmit water through it due to partially penetration inthe studied aquifer.

Key words: Groundwater hydrology, Hydraulic parameters, Surface hydrology, Volume of runoff.

INTRODUCTION

Egypt is facing several water problems imposed by the prevailing environmental, climatic, and socio-economic conditions. On the other hand, it is characterised by high population growth rates. This has instigated economic growth in various industrial and agricultural fields to accommodate population growth and improve living standards. This is usually accompanied by social development, a rise inthe standards of living, and increasing in urban developments, social services, and tourism. This has led to an everyday increase in the demand for water in the mist of limited water resources. With an increase in water demand and a decreasing share of renewable fresh water resources, the need for new sources of fresh water supply has become critical to compensate for the shortage caused by the unbalance between renewable water resources and demand. So, the utilisation of unconventional water resources such as surface runoff water has become an important matter.Wadi El Dif is one of the main subbasins of Wadi Hodein. It is located between longitudes 34° 40' and 35° 00' E and latitudes 23° 00' and 23° 20' N (Fig. 1), and covers an area of about 518 km2. At present, more attention from Egyptian governement and investment authorities (World Food Program (WFP) and Food Agricaltare Organization (FAO)) has been directed towards the Wadi in the framework of the establishment of Bedouin communities based on the integrated management of water resources in Wadi El Dif. Meteorologically, the study area is characterised by a mean maximum temperature of 42.04°C in August and a mean minimum temperature of 22.98°C in January. The relative humudity ranges between 24 % and 62 % (Table 1).



`Fig.1: a. Geological map (after CONCO, 1987); b: location map of Wadi El Dif, South Eastern Desert, Egypt.

GEOLOGICAL SETTING

Accoding to the geological map (1981), (Fig. 1) and field observations, it is clear thatthe Wadi El Dif area is covered by the Upper Cretaceous Nubian Sandstone. El Nagar (1970) classified the Nubian Sandstone Formation from older to younger as follows:

1 Abu Aggag Formation

Abu Aggag Formation is composed of conglomeritic to coarse-grained kaolinitic sandstone and is structurally characterisedby cross-bedding and laminations. Its thickness ranges from 30 to

Table 1: Average climatic data for Shalateen station (from 1979 to 2014). (SWAT Global Weather Data, 2019).

Month	Max. Temp. (° C)	Min. Temp. (° C)	Relative Humidity (%)
January	22.98	8.20	0.59
February	25.17	8.34	0.51
March	29.36	10.26	0.45
April	34.36	13.32	0.40
May	38.42	16.39	0.34
June	41.50	18.19	0.29
July	41.96	20.15	0.28
August	42.02	20.58	0.30
September	40.45	18.43	0.38
October	35.47	16.06	0.55
November	28.87	13.02	0.62
December	24.30	9.78	0.60

40m. It is unconformably underlain by the fractured basement rocks and conformably overlain by the Timsah Formation, which is assigned to the Turonian age.

2 Timsah Formation

The Timsah Formation is composed of a sequence of silt and fine-grained sandstone with thick shale intercalations of near-shore marine to deltatic deposites and comprises two or three oolitic iron-ore beds. The thickness of this formation ranges between 5 and 130m. The Timsah Formation conformably overlies the Abu Aggag Formation and disconformably underlies the Umm Barmil Formation. It ranges in age from Coniacian to Santonian.

3 Umm Baramil Formation

The Umm Baramil Formation is composed of fluvial deposits that include coarse to medium-grained sandstone that is tabular and trough cross-bedded on a large scale.Its thickness attains 40m at the type locality (Gabal Umm Baramil) and 260m at the Wadi El Dif area (Abdel Razik, 1972; and Endriszewitz, 1988). The Umm Baramil Formation overliesthe Timsah Formation with an erosional contact. Its age ranges from Santonian to Lower Campanian (Kiltzsch et al., 1986).

SURFACE HYDROLOY

1 Climatic analysis

The climatological conditions are recognised by arid characteristics. The nearest meteorological station for the study area is El Shalateen station, which is located at35° 00’ 00” N and 22° 56’ 56” E. Precipitation represents an important meteorological factor in this study. As a result, the precipitation data was detailed, as shown in Figure 2, which shows:

- The highest amounts of rainfall were118 mm in 1995, followed by 115 mm in 1996, 84 mm in 1992, and 51.8 mm in 2018.
- In the 1980s the rainfall vales were moderate, but in the 1990s the values were relatively highin. Then a drought was occurred in the period from 2000 to 2013, then climatic changes began to occur in the 2017. In the years 2018 and 2019 are relatively high because of the rainy seasons.

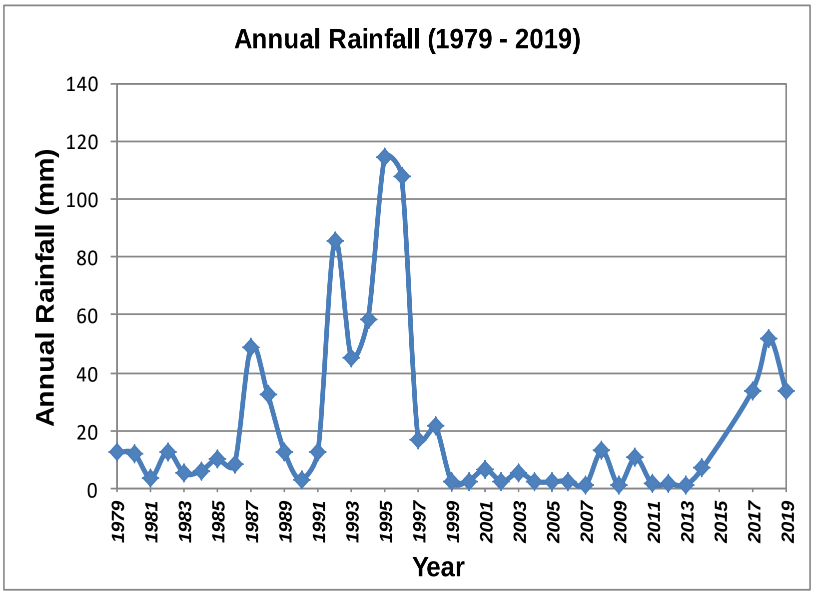


Fig. (2): Annual rainfall records in the period from 1979 to 2019.

2 Morphometric parameters

The morphometric analysis of the Wadi El Dif was carried out on topographical map on the scale 1:100,000. Morphometric parameters such as stream length, basin area, main channel length, and watershed basin parameter were measured. The 47 morphometric parameters were measured and calculated by using the methods of Horton (1932 and 1945), Strahler (1953, 1957, and 1964), and other references, and has been classifed into:

2.1- Drainage network

In the study area,the totallength of streams found was 304.2 km, out of which185.5 km was of first order, 59.7 km of second order, 24.9 km of third order, and 34.1 km of fourth order (Fig. 3 and Table 2). The stream length decreases as the stream order increases, and this change may be due to the flowing of streams from high altitudes, lithological variations, and moderately steep slopes (Singh and Singh, 1997). The change in stream length ratio is shown in Table (2) from one order to another indicates the late youth stage of geomorphic development of streams in the interbasin area. The bifurcation characteristically ranges between 3 and 5 for watersheds in which the geophysicalstructures do not distort the drainage pattern. In the present study, the higher value of the bifurcation ratio indicates strong structural control over the drainage pattern.

The bifurcation ratio and weighted mean bifurcation ratio values are close to 5, indicating a clear structural influence on the watershed systemand similarity of the lithological characteristics (Table 3). In general, the sinuosity value varies from 1 to 4 or more. Rivers having a sinuosity of 1.5 are called sinuous, and those above 1.5 are called meandering (Leopold et al., 1964). It is a significant quantitative index for interpreting the significance of streams inthe evolution of landscapes. Main channel length, main channel index, and sinuosity were calculated and measured as shown in Table (4). Basins with high values of main channel and sinuosity have a high potential for groundwater recharge and vice versa.

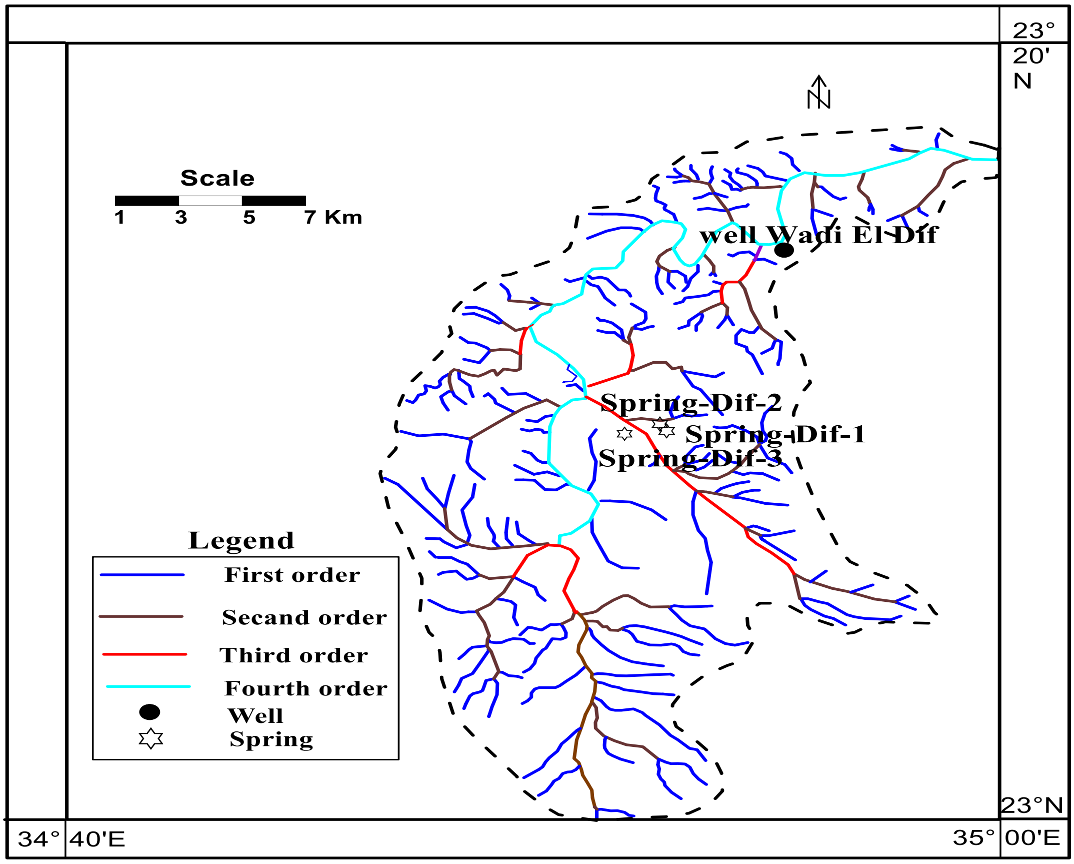


Fig. (3): Drainage map of Wadi El Dif, South Eastern Desert, Egypt.

Table (2): Stream length, and stream length ratio in Wadi El Dif.

Su	**Lu**	**Lu / Nu**	**Lur**	**Lur-r**	**Lur * Lur-r**	**Luwm**
1.00	185.50	1.34				2.59
2.00	59.70	1.81	1.35	245.20	330.00	
3.00	24.90	4.15	2.29	84.60	194.07	
4.00	34.10	34.10	8.22	59.00	484.80	
Total	304.20	41.40	11.86	388.80	1008.87	
Mean			3.95*			

Su: Stream order, Lu: Stream length; Lu / Nu: Stream length ratio; Lur-r*: Mean stream length ratio; Lur-r: Stream length used in the ratio; Luwm: Weighted mean stream length ratio

Table (3): Stream order, stream number, and bifurcation ratios in Wadi El Dif.

Su	Nu	Lu	Lsm	Rl	Rb	Nu-r	Rb*Nu-r	Rbwm
1	138.00	185.50	1.34					4.48
2	33.00	59.70	1.81	1.35	4.18	171.00	715.09	
3	6.00	24.90	4.16	2.30	5.50	39.00	214.50	
4	1.00	34.10	34.10	8.20	6.00	7.00	42.00	
Total	178.00				15.68	217.00	971.59	
Mean					5.23*			

Su= stream order, Lu=Stream length of order ‘U’ (km), Nu=Total number of stream segments , Rb=Bifurcation ratios, * Mean bifurcation ratios, Nu-r=Number of stream used in the ratio, Rbwm=Weighted mean bifurcation ratios

2.2 - Basin geometry

The Wadi El Dif basin has an area of 518 km2. Catchments with high values of length, width, and perimeter have higher potentials for groundwater recharge than those with low values (Youssef et al., 2020). The lemniscate (K) value for the watershed is 2.266 (Table 4), which shows that the watershedoccupies the maximum area in the region of inception with a large number of streams.

of higher order.The value of the form factor would always be less than 0.754 (for a perfectly circular

watershed). The watershed with high form factors has high peak flows of shorter duration, whereas elongated watersheds with low form factors (0.22) are elongated in shape and flow for a longer duration. Values of shape factor ratio and basin shape index are characterised by low values, indicating more possibilities for surface runoff accumulation. The values of the elongation ratio generally vary from 0.6 to 1.0 over wide variety of climate and geologic types.The varing slopes of watershedcan be classified with the help of the index of elongation ratio, i.e. circular (1.0 – 0.9), oval (0.9 – 0.8), lesselongated (0.8 – 0.7), elongated (0.7 – 0.5), and more elongated (< 0.5) (Pareta and Pareta, 2011). The elongation ratio of the Wadi El Dif watershed is 0.75, indicating that the watershed is elongated with high relief and steep slope.

	Morphometric parameters	Formula	Reference	Result
a) Drainge Network	~~1-Stream order(Su)~~	~~Hiearchical Rank~~	Horton (1945), ~~Strahler (1952 &~~ 1964)	~~1 to 4~~
	2-Stream number (Nu)	Nu = N1+N2+…..+Nn	Horton (1945)	178.000
	3-Stream length (Lu) Kms	Lu=L1+L2+…...+Ln	Strahler (1964)	304.200
	4-Stream length ratio(Lur) Kms	See table	Strahler (1964)	11.860
	5-Mean stream length ratio (Lurm)	See table	Horton (1945)	3.950
	6-Weighted mean stream length ratio (Luwm)	See table	Horton (1945)	2.590
	7-Bifurcation ratio (Rb)	Rb =Nu / Nu+1	Strahler (1964)	4.18 - 6
	8-Mean bifurcation ratio (Rbm)	See table	Strahler (1964)	5.230
	9-Weighted mean bifurcation ratio (Rbmw)	See table	Strahler (1952)	4.480
	10-Main channel length (Cl) Kms	GIS software Analsis		45.558
	11-Main channel index (Mci)	Mci=(Main channel length) / (Max. straight of the main channel)	Mueller (1968)	8.233
	12-Valley length (Vl) Kms	GIS software Analsis		44.040
	13-Rho coefficient (p)	p= Lur / Rb	Horton (1945)	2.700
	14-Sinuosity (Si)	Si=Vl/Lb	Gregory and Walling (1973)	1.285
b) Basin Geometry	15-Basin length (Lb) Kms	GIS software Analsis	Schumm (1956)	34.274
	16-Main Basin width (Wb)	Wb= A / Lb	Horton (1932)	15.124
	17-Basin Area (A) sq Kms	GIS software Analsis	Schumm (1956)	518.364
	18-Basin perimeter (P) Kms	GIS software Analsis	Schumm (1956)	91.450
	19-Relative perimeter (Pr)	Pr= A / P		5.668
	20-Length area relation (Lar)	$Lar= 1.4 * A^{0.6}$	Hack (1957)	59.554
	21-Lemniscate's (K)	$K= Lb^2 /4 * A$	Chorley (1959)	2.266
	22-Form factor ratio (Ff)	$Ff= A / Lb^2$	Horton (1932)	0.441
	23-Shape factor ratio (Sf)	$Sf= Lb^2 / A$	Horton (1945)	2.266
	24-Elongation ratio (Re)	$Re = \frac{2*\sqrt{A/\pi}}{Lb}$	Schumm (1956)	0.750
	25-Elipticity index (Ie)	$Le= \pi * Vl^2 / 4 A$		2.937
	26-Texture ratio (Rt)	Rt= ΣNu / P	Horton (1945)	1.946
	27-Circularity ratio (Rc)	$Rc= 4\pi * (A / P^2)$	Miller (1953)	0.779
	28-Circularity ration (Rcn)	Rcn=A / P	Strahler (1964)	5.668

Table (4): Morphometric parameters formulas

Table (4): Cont.

	Morphometric parameters	Formula	Reference	Result
	29-Compactness coefficient (Cc)	**$Cc= 0.2841*P / A^{0.5}$**	**NookaRatnam** et. al. **(2005)**	**1.141**
	30-Fitness ratio (Rf)	**Rf= Cl / P**	**Melton (1957)**	**0.498**
	31-Wandering ratio (Rw)	**Rw= Cl / Lb**	**Smart & Surkan (1967)**	**1.329**
	32-Basin shape index (Ish)	**$Ish= 1.27 * A / Lb^2$**	**Haggett (1965)**	**0.560**
	33-Compactness ratio (Sh)	$Sh = \frac{P}{2*\sqrt{A\pi}}$	**Horton(1945)**	**1.133**
c) Drainage texture analysis	**34-Stream frequency (Fs)**	**Fs=∑ Nu / A**	**Horton (1932 & 1945)**	**0.343**
	35-Drainage density (Dd) Km / Kms^2	**Dd=∑ Lu / A**	**Horton (1932 & 1945)**	**0.587**
	36-Constant of channel maintainance (Kms^2 / Km)	**C= 1 / Dd**	**Schumm (1956)**	**1.704**
	37-Drainage indensity (Di)	**Di= Fs / Dd**	**Faniran (1968)**	**0.584**
	38-Infiltration number (If)	**If= Fs * Dd**	**Faniran (1968)**	**0.201**
	39-Length of overland flow (Lg) Kms	**Lg= 1 / 2 * Dd**	**Horton (1945)**	**0.852**
d) Relief characteristies	**40-Maximum elevation (H_{max})**	**GIS software Analsis**		**445.000**
	41-Minimum elevation (H_{min})	**GIS software Analsis**		**431.000**
	42-Relief (m) (R)	**R= Highest elevation - Lowest elevation**	**Strahler (1952)**	**14.000**
	43-Internal relief (E)	**E= (E85-E10)**	**Strahler (1952)**	**51.000**
	44-Relief ratio (Rr)	**Rr= R / Lb**	**Schumm (1956)**	**0.000**
	45-Slope index (Si %)	**Si= (E / 0.75 Vl)**	**Majure and Soenksen (1991)**	**0.002**
	46-Ruggness number (Rn)	**Rn= R * Dd**	**Melton (1957)**	**0.008**
	47-Hypsometric integral (Hi)	**Hi = (mean elevation - elevation min) / (elevation max - elevation min)**	**Strahler (1952)**	**0.500**

2.3- Drainage texture

Stream frequency (Fs) is related to permeability, infiltration capacity and relief of watershed. Generally, high stream frequency is related to impermeable sub surface material, sparse vegetation, high relief and low infiltration capacity ofthe region. In the present study, the stream frequency of Wadi El Dif is 0.343.

Drainage density provides a numerical measurement of the landscape dissection, runoff potential, and infiltration capacity of the land, as well as the climatic condition and vegetation cover of the basin. The high drainage density of the basin is the result of impermeable subsurface material, sparse vegetation, and mountainous relief. Based on Strahler (1957), the constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific connotation. The channel maintenance constant of the watershed is 1.704 km^2/km. The infiltration number gives an idea of the infiltration characteristics of the watershed. Catchments of penetration, resulting in a high potential for flash floods.The low value of drainage indensity (0.587) implies that stream frequency and drainage density have little effect on the extent to which the surface has been lowered by agents' denudation. Low values of stream frequency, drainage density, and drainage intensity, indicate that surface runoff is not quickly removed from the watershed, making it highly susceptible to flooding, gully erosion, and landslides. Horton (1945) used this term to refer to the length of water over the ground before it gets concentrated into definite stream channels. The Wadi El Dif is the structurally complex and quickest runoff process due to the low value of Lg (0.852).

2.4 - Relief characteristics

The low value of the ruggedness number for Wadi El Dif (0.03) implies that the area is less prone to soil erosion and has intrinsic structural complexity in association with relief and drainage density. The value of the relief ratio is 0.0004. The low value ofthe relief ratio is mainly due tothe resistant basement rocks of the basin and the low degree of slope.

Based on Hurtiez et al. (1999) and Singh et al. (2008), the hypsometric integral value ranges from 0 to 1. Chorley and Morley (1959) classified the basins into threecategories based on the value of Hi; old catchments where the value of Hi is lower than 0.3; mature, where the value of Hi is from 0.3 to 0.6; and young, where the value of Hi is more than 0.6.

Young basins have a high possibility of groundwater recharge, while old basins have a high possibility of flash flood with a high hazard degree, and mature basins have an s-shape curve and are characterised by moderate surface water accumulation and groundwater recharge.

The hypsometric integral value of Wadi El Dif is close to 0.5, indicating that the Wadi El Dif catchment is mature and hazard-proneto flash floods.

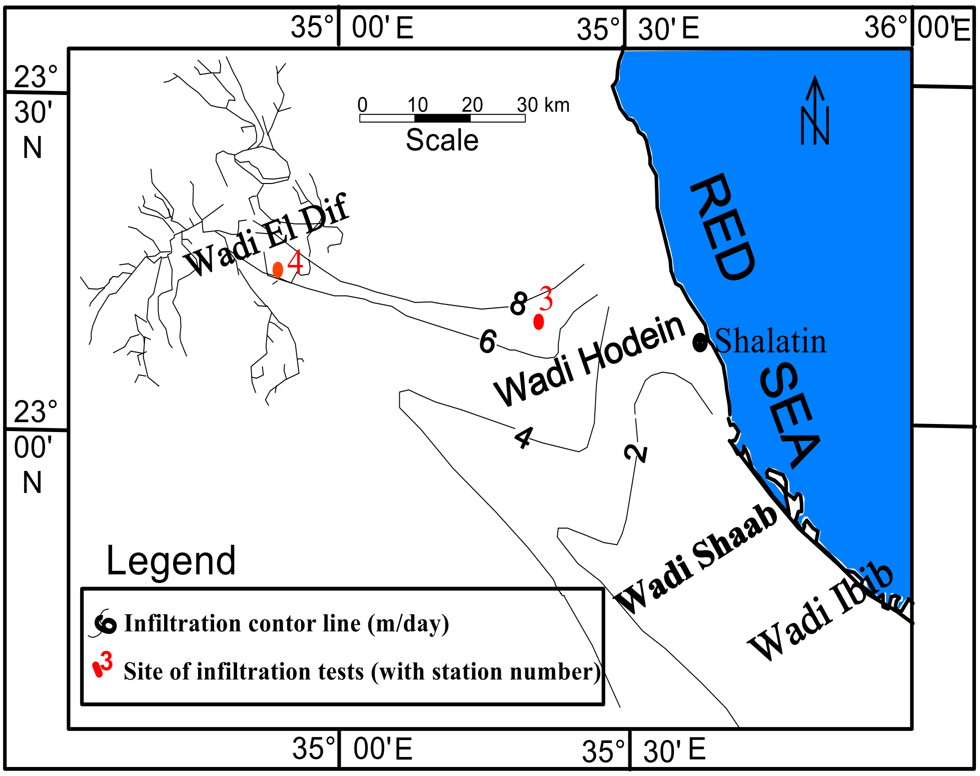


Fig. (4): Infiltration contour map for the Wadi El Dif (after Elewa, 2000).

INFILTRATION CAPACITY

Infiltration capacity is the maximum rate at which water can move into alluvial deposits. It occurs when the alluvial deposits are covered by bonded rainfall, surface runoff, irrigation water, streams or other surface water bodies. The infiltration rate is high at the beginningof the infiltration process and then decreases as infiltration continues and the water zone in the soil extends downwards. The infiltration rate may eventually become constant.

Due to the wide extension of the investigated area and for good representation of infiltration tests, two sites were selected to representthe different alluvial deposits (soils) in different locations by infiltration tests (Fig. 4) (Elewa, 2000).

The values of the infiltration rate range from 6 to8 m/day. According to Kohnke's (1980) classification, the investigated soil of Wadi El Dif is characterised by a very rapid rate.

1 - Rainfall – Runoff relationship

The rainfall–runoff relationship is critical for catchment management, i.e., for the sustainable development of water resources and flood protection.In general, surface runoff occurs when rainfall intensity exceeds the abstractive capability of the catchment area. The present work is concerned with the amount of runoff generated for a given rainfall pattern. Stormwater Management and Design Aid program (SMADA6.3) has been used to generate the regional hydrographs of Wadi El Dif during the rainfall storms.

Table (5): Input data for SAMADA 6.3 program.

Parameters	**Discription of the parameters**	**Source Data**	**Result**
Total Drainage Area (A) (Acres)	The area of the studied basin in Km^2	Watershed	128090.5
Impervious Drainage Area (Acres)	Area which is characterized by impermeable hydrologic conditions		6404.524
% Impervious Directly Connected	Percentage Area which is characterized by impermeable hydrologic conditions		5
Length of Overland Flow (m)	The maximum length of surface flow generated by rain water before it gets into definite stream channels		852
Slope (m/m)	The average land slope		0.000318
Time of Concentration (min)	Over land time to outlet (min)		21
Maximum Infiltration Capacity (inchs)	Capacity of soil for infiltration		314.961
SCS Curve Number for Pervious	Used for runoff assessment of the catchment and soil conservation		74.43
Initial Abstraction Factor			0.2
Total Rainfall Duration (hrs)	Event duration in hours	Rainfall	1.5
Time step for Rainfall (min)	Time step will affect calculation Accuracy in Hydrograph Generation		5
Total Rainfall (inch)	Total rainfall (inch) for a series of time increments		2.04

SMADA6.3 programme is a complete hydrology package that includes a number of separate executable files that allow for hydrograph generation. The executable files of SMADA6.3 are the watershed characteristics, the rainfall event characteristics, and the hydrograph generation. Table (5) summarises the input data for the SMADA6.3 program.Two storms (51.8 and 34), with different return periods (20 and 8 years) respectivity, are used as input data in the SMADA6.3 program. Two scenarios for the rainfall–runoff relationship were carried out according to the different rainfall depths.In each case, the maximum flow and maximum runoff volume were determined. The maximum flow was 28.23 m^3/sec and the runoff volume was 0.884 million m^3, with a return period of 20 years in 2018. In 2019, the maximum flow was 13.26 m^3/sec and the runoff volume was 0.276 million m^3 with a return period of 8 years (Table 6 and Fig. 5).

Table (6): Output parameters of the hydrograph during the rainfall storms (2018 and 2019).

Parameters	2018	2019
Maximum flow ($m^{3/}sec$)	28.23	13.26
Runoff volume ((m^3x10^6)	0.884	0.276
Time to peak (hours)	1.33	1.67
Time to base (hours)	2.33	2.58

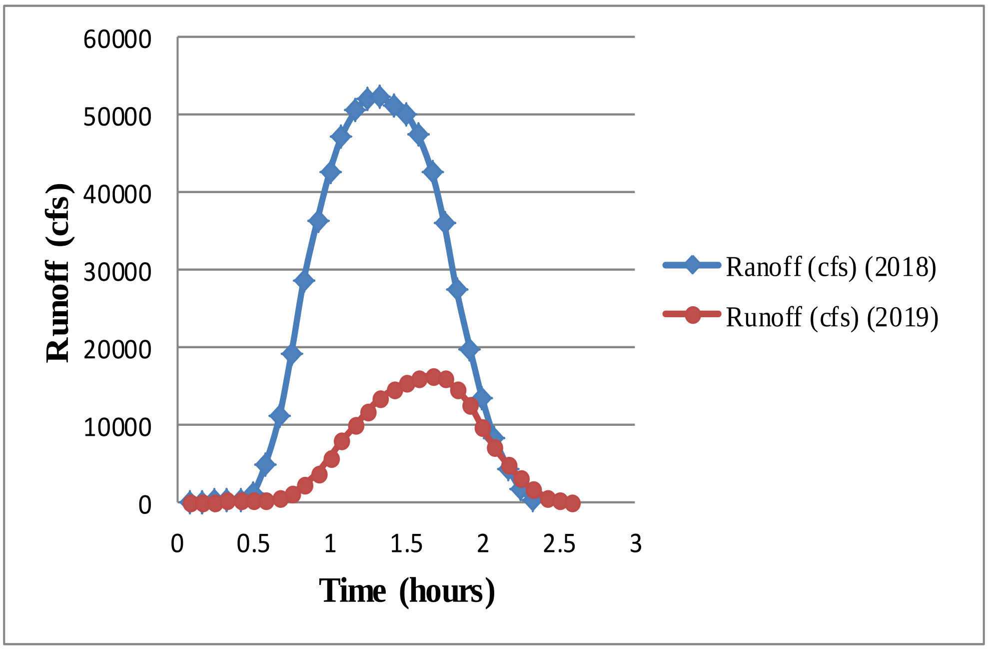


Fig. (5): Hydrograph of Wadi El Dif during the rainfall storms (2018 and 2019).

2 - Analysis of probability and return period

A return period is a basic means of quantifying and communicating risk, which is usually used in the context of natural events like storms, floods, and earthquakes. The essential idea is that the severity of natural events is correlated with their frequency of occurrence, which is the most common means used in hydrology to indicate the probability of an event.

The data used was that of rainfall records during the period (1979–2019) of El Shalateen meteorological station. The data were continuous in that there were no years with missing data. The period of the data was chosen because of consistency and the need to, as much as possible, make use of recent data. This was with a view to incorporating recent changes in climate as well as climate variability. The various storms during the period of records may be arranged in descending order of their magnitude (maximum depth or intensity), with the highest having the highest valuein the ranked order. When arranged in descending order, if there are a total number of (n) items and the order number or rank of any particular storm (maximum depth or intensity) is (m), then the return period T of the particular flood peak is given using the Weibull's (1939) method as seen in equation (5):

$$T = (N-1) / M \qquad (5)$$

Where:
T: is the return period in years;
N: is the number of events in the series; and
M: is the rank (from largest to smallest) of each rainfall intensity.

The relationship between the probability of exceedance P(x) return period T are given by following formula (Ponce, 1989) and tabulated in Table 7:

$$P(x) = 1 / T$$

The relation between the annual rainfall depth and return period was plotted using a semi log paper (Fig. 6). A line can be fitted to the points to get the following equation:-

$$Y = 6.043951 \ln(x) + 1.601335$$

Where:-
Y = Annual rainfall depth (mm); and
x = Return period (years)

The return periods as well as, the exceedance probability (Fig. 7) indicated that the highest AEP (Rain Exceedance Probabilities) during the years of study was that of 2007 (0.25 mm) with the probable return period being 1.03 year (Table 7). 97.5% probability of the Wadi El Dif experiencing this scale of rain storm in any year, the storm, although relatively rate, however has a probability of occuring at least once in fourty years.

While the annual rainfall of 21.22 mm can occur every 40 years with a probability of exccedence equal to 2.5%, which indicated that the relation between the return period and the annual rainfall depth is inversely proportional, i.e. when the rainfall increases, the return period becomes longer and vise versa.

Table (7): Annual exceedance probability showing return period.

Year	Annual Rainfall (mm)	Rank (m)	Retrun Period (T) year	Probability of exceedence (P (x)) (%)
1992	21.22	1	40.00	2.5
2018	17.30	2	20.00	5
2017	17.00	3	13.33	7.5
1994	13.01	4	10.00	10
2019	11.30	5	8.00	12.5
1996	10.71	6	6.67	15
1988	9.51	7	5.71	17.5
1995	8.24	8	5.00	20
1987	7.73	9	4.44	22.5
1998	7.38	10	4.00	25
1982	6.19	11	3.64	27.5
1993	6.18	12	3.33	30
1989	3.62	13	3.08	32.5
1991	3.04	14	2.86	35
1980	2.80	15	2.67	37.5
1997	2.76	16	2.50	40
1979	2.74	17	2.35	42.5
2010	2.49	18	2.22	45
1986	2.44	19	2.11	47.5
2001	2.23	20	2.00	50
1985	2.06	21	1.90	52.5
2002	1.90	22	1.82	55
2008	1.89	23	1.74	57.5
2003	1.28	24	1.67	60
1984	1.23	25	1.60	62.5
1983	1.23	26	1.54	65
2014	1.15	27	1.48	67.5
1999	1.14	28	1.43	70
1981	1.08	29	1.38	72.5
2006	0.81	30	1.33	75
2005	0.74	31	1.29	77.5
2000	0.54	32	1.25	80
2004	0.54	33	1.21	82.5
2009	0.53	34	1.18	85
2011	0.48	35	1.14	87.5
2012	0.37	36	1.11	90
1990	0.36	37	1.08	92.5
2013	0.27	38	1.05	95
2007	0.25	39	1.03	97.5

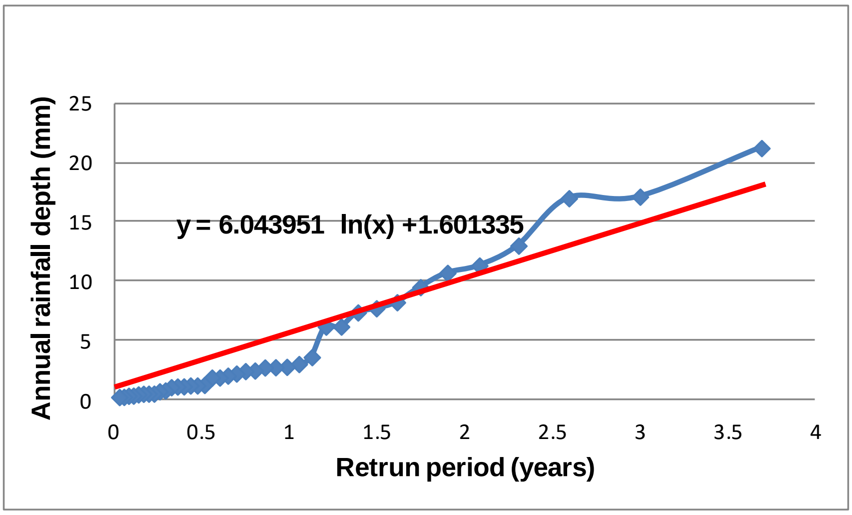


Fig.6: Relation between return period (years) and annual rainfall depth (mm).

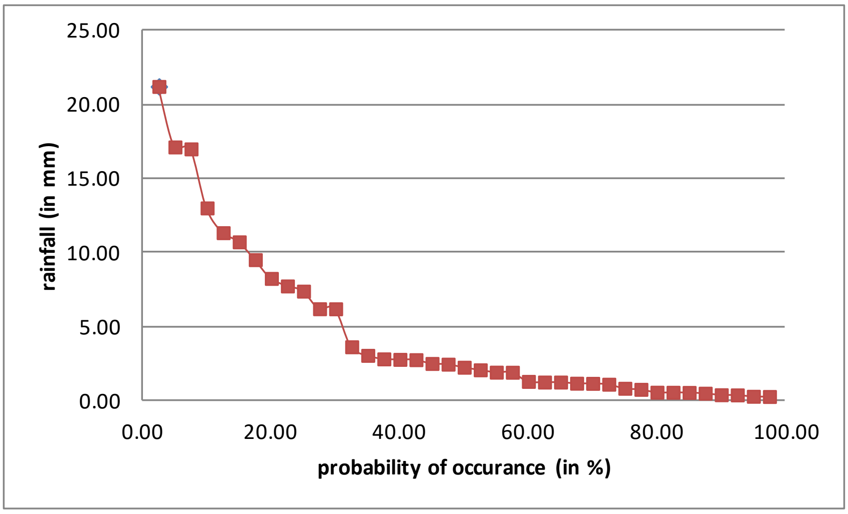


Fig.7: Rainfall exceedance probabilities for Wadi El Dif.

GROUNDWATER HYDROLOGY

The groundwater of the Wadi El Dif is available from the Nubian Sandstone Aquifer. The groundwater of this aquifer is discharged through the Wadi El Dif well and three springs (Table 8).

The water depth varies from 23.66m to 23.7m from the groundwater in the period from 2007 to 2020, i.e. the value of the water depth is almost constant in this period, which means a balance between the amount of discharge and the amount of recharge to the aquifer.

1- Aquifer replenishment

The recharge of the groundwater aquifer of Wadi El Dif is controlled by geological, topographic, and land-cover aspects. Based on the intensive studies of sources of surface hydrology

Table (8): Periodic monitoring of water depths and water salinity for the water points of Wadi El Dif.

water point	Location of water point		Depth to water (m)				Water salinity (ppm)				
	Latitude (N)	Longitude (E)	1997	2007	2017	2020	1997	2002	2007	2017	2020
Well Wadi El Dif	23° 14' 08"	34° 55' 36"	21.75	23.66	23.68	23.7	1000	932.6	1000	950	950
Spring-El-Dif-1	23° 12' 40.5"	34° 49' 59.7"	-	-	-		-	872.3	-	-	850
Spring-El-Dif-2	23° 12' 45"	34° 49' 47"	-	-	-		-	663.8	-	-	1250
Spring-El-Dif-3	23° 12' 3.5"	34° 49' 55.1"	-	-	-		-	-	-	-	1150

and groundwater monitoring, it is obvious that rainfall events and flash floods are the main sources of aquifer recharge. Rainfall amounts of 51.8 mm in 2018 and 34 mm in 2019 have a pronounced effect ongroundwater levels and aquifer recharge.

The infiltration factor of the surface soil of the Wadi El Dif basin ranges from 8-10% (Chatterjee and Ray 2014). Table (9) shows the rainfall infiltration factor used in modeling for groundwater recharge calculations,which is based on the equation:

Recharge (m^3) = Area (m^2) x Infiltration factor (%) x rainfall intensity (m)

In 2018, and 2019, the amount of recharge is 2.69 million m^3 and 1.41 million m^3, respectively.

2 - Water quality

Periodic monitoring of water salinity for water points and springs has been carried out during the period from 1997 to 2020 (Fig. 8).

According to the obtained results, the quality of the water is mostly fresh water. In addition, the salinity of water has decreased in recent periods due to the direct replenishment of the aquifer during the continuous rainfall storms as a result of climatic changes.

3 - Hydraluic parameters of the study aquifer

With respect to hydraulic parameter evaluation, one pumping test has been carried out during the field work on El Dif production well using the AQTESOLV Program for Windows Version 4.According to Georhage classification (1979) Table (10), the aquifer has low potential and capabilit to transmit

Table (9): Rainfall vs. infiltration factor used in groundwater recharge calculations.

Serial No.	Rainfall (mm)	Infiltration factor (%)			
		Quarternary	Tertiary	Permian	Precambrian
1	0-20	0	0	0	0
2	20-50	10	8	6	4
3	50-100	12	10	8	6
4	> 100	12	10	8	6

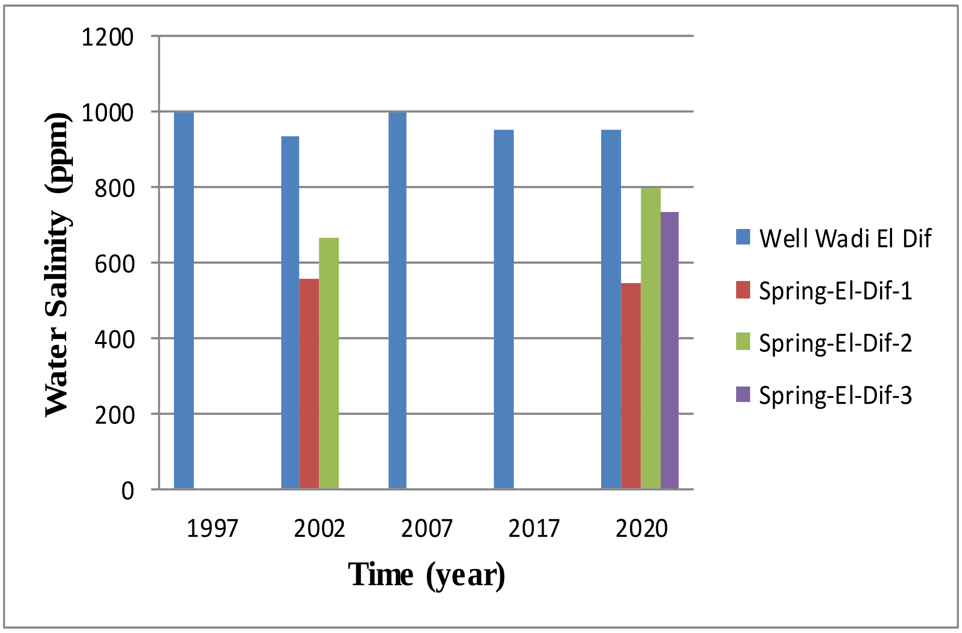


Fig. 8: Fluctuation of water salinity for the water points of Wadi El Dif.

water through it due to the partially pentered nature of the study aquifer and clay intercalation, where its transmissivity equals 30 m2/day (Table 11 and Fig.9).

CONCLUSION AND RECOMMENDATIONS

Recent climatic changes have had a great impact on the availability of water resources in arid and semi-arid regions of the world. It is crucial to understand the integration relationship between surface runoff and the groundwater aquifers.The Wadi El Dif is consideredone of the subbasins of Wadi Hodein and covers about 518 km^2. The watershed is elongated and in a high relief. The Wadi El Dif is structurally complex, with a rapid runoff process and a mature flash flood hazard.The surface soil of the WadiEl Dif is charaterised by a very rapid infiltration rate, which has a direct impact on groundwater aquifer replenishment.Storm water Management and Design Aid program (SMADA6.3) has been used to generatethe regional hydrographs of Wadi El Dif during the rainfall storms,

Table (10): The Classification of the Potentiality of the Aquifer on The Basis of the Transmissivity Values 'T' (after Georhage, 1979).

Aquifer Potentiality (Georhage, 1979)	
Potentiality of The Aquifer	**Transmissivity (m^2/day)**
High	>500
Moderate	50 – 500
Low	5 – 50
Very low	0.5 – 5
Negligible	< 0.5

Table (11): Calculation of the transmissivity for the investigated aquifer.

Well Name	Total Depth (m)	Depth to water (m)	Discharge (m^3/h)	Total drowdown (m)	Pumping duration (m)	T (m^2/day)	T.D.S. (ppm)
El Dif well	90	23.68	12	8	90	30	950

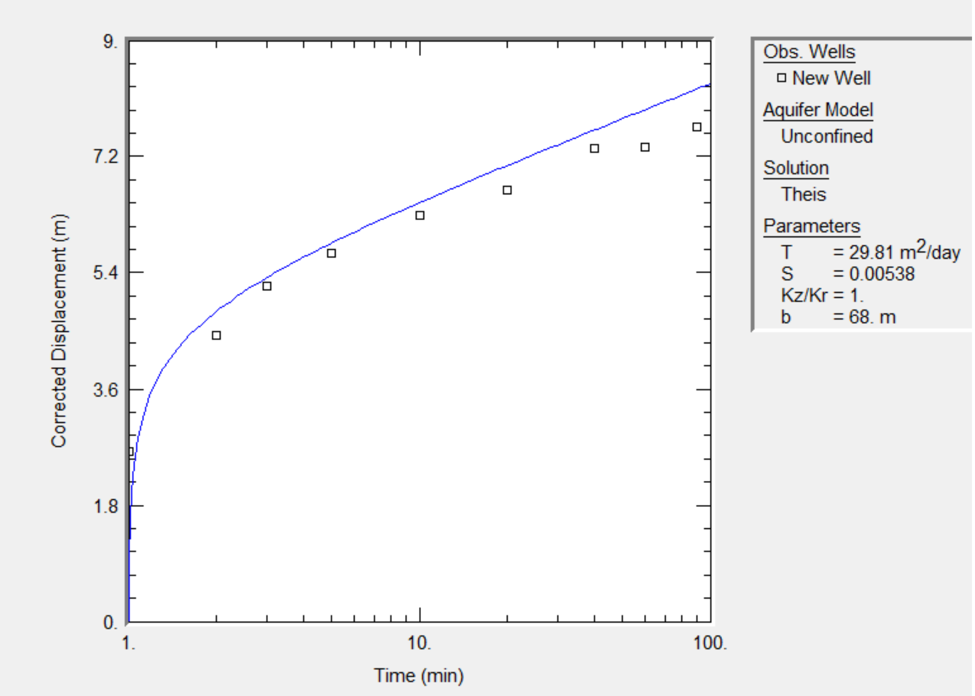


Fig. (9): Analysis of pumping test data of production well (Using the AQTESOLVE program).

2018 and 2019 respectivelly. The volume of runoff varies from 0.884 million m^3 to 0.276 million m^3. In addition, the return period and the annual rainfall depth is inversely proportional relationship. Above all, the application of advancent harvesting techniques for surface runoff and its maintance programes plays a treniendous importance in avoiding the much damageof flash flood and reduce the velocity of surface runoff to givethe chance to replenish the groundwater aquifer.The groundwater of the Wadi El Dif is available from the Nubian Sandstone Aquifer. The water depth is almost constant in the period 2007 to 2020, which means that balance between the amount of discharge and the amount of recharge to the aquifer. Also, the salinity of water is more or less constant due to the direct replenishment of the aquifer duringthe continuous rainfall storms as a result of climatic changes. The amounts of groundwater aquifer reach 2.69 millionm^3, 1.41 million m^3, in 2018 and 2019, respectively. The aquifer has low potentiality and capability to transmit water through it, due to the partially penetration of the study aquifer.

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