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Mitigation of flash flood hazard in Wadi Gheweiba, El Ain El Sokhna area, Gulf of Suez, Egypt

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ABSTRACT

The West Gulf of Suez area represents one of the most strategic areas that received considerable attention from the Egyptian Government to become one of the sustainable development national project's regions. El Ain El Sokhna area was selected in the last 20 years to initiate many of governmental and investment programs. The present work aims to evaluate and manage the surface water resources in Wadi Gheweiba in the northwestern part of the Gulf of Suez in El Ain El Sokhna area. Forty-two morphometric parameters were measured and calculated. The degree of flash flood hazard in the study Wadi based on nine of morphometric parameters indicates that Wadi Gheweiba belongs to the highly hazardous degree. During the office work, three rainfall storms data of 2015, 2016, and 2020 from the Egyptian Meteorological Authority for the Suez station were collected, analyzed, and used as input data for the software SAMADA 6.0 to calculate and evaluate the total volume of runoff, peak of discharge, and time to beak for the Wadi. In addition, calculation of the amount of water replenishment for the Quaternary aquifer in the investigated Wadi by applying the F– curve method. Above all, the optimum utilization of harvesting techniques for the surface runoff of rain water has been recommended to avoid the damages of flash flood on the infrastructures in the study Wadi.

1. Introduction

The West Gulf of Suez area represents one of the most strategic areas that received considerable attention from the Egyptian Government to become one of the national project's regions. El Ain El Sukhna area was selected in the last 20 years to initiate many governmental and investment programs, there for many workers have worked in this area with an emphasis on groundwater hydrology, hydrogeology, related Hydrogeochemistry, and geophysical studies such as Abd Allatief et al. (1997), Geriesh et al. (2004), Nasr (2004), Abdel Samie et al. (2005), Andrawis (2007), Abdel Mogheeth (2008), Desert Research Center (2007), Hamed & Mahmoud (2009), Ismail (2017) and El Hazek et al. (2020).

The different activities in El Ain El Sukhna area depend mainly on the groundwater of the Quaternary aquifer, which forms the main water-bearing strata. Over the last few years, the rapid growth of industrial projects (cement, ceramic, iron steel, petrochemical, and electronics besides the new El Ain El Sukhna Harbor) causes a serious shortage in freshwater resources.

Nowadays, groundwater is being excessively pumped into the coastal zone through several hand-dug and drilled wells by the citizen and investors.

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These water resources are subjected to spatial diverse and temporal variations; this policy affects the aquifer's dependability as a continuous source of water and may eventually deteriorate its water quality due to the liability of the coastal zone to seawater intrusion problems. Therefore, integrated water resources management plays an outstanding role in the mitigation of groundwater deterioration quantitatively and qualitatively.

The study area is located in the northwestern part of the Gulf of Suez region and it is bounded by Gebel Ataqa at the north and Gebel El Galala El Baharya at the south. It lies between Latitudes 29° 30′ and 29° 50′ N and Longitudes 31° 45′ and 32° 30′ E which covers an area of about 3000 Km^2. It includes Wadi Gheweiba which draining towards the Gulf of Suez. (Fig. 1).

2. Geology, Geomorphology and Tectonic Setting

The sedimentary cover of the study area (Fig. 2) ranges in age from Upper Cretaceous to Quaternary as it lies principally to the north of El Galala El Baharya. The channel of the main Wadi and coastal plain in the study area are covered by the Quaternary deposits meanwhile the Middle Eocene limestone occupies a large part of the bedrock exposures. The lithostratigraphic units within the study area can be described briefly from older to younger as follow:

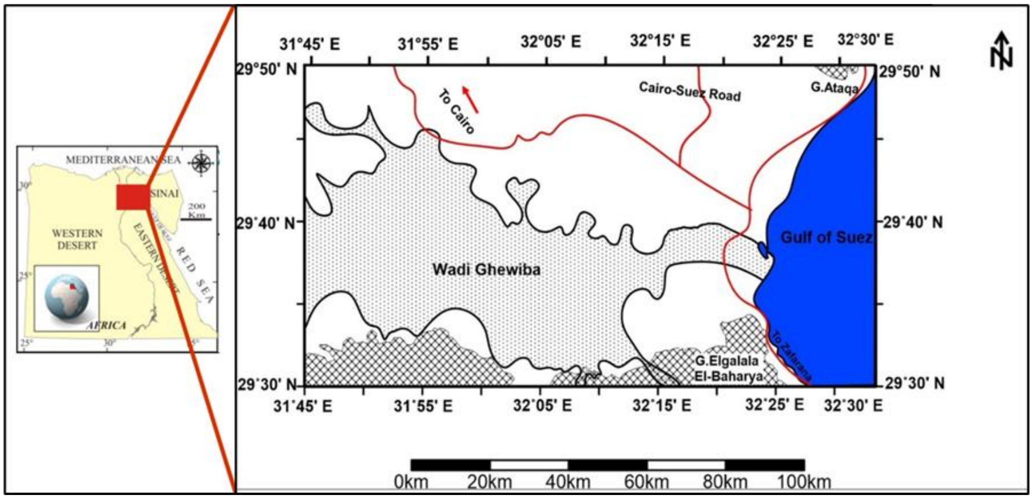

Fig. 1. Base map showing the location of Wadi Gheweiba

Jurassic rocks are located at the northeastern end of El Galala El Baharya and exposed only at Gebel Khashm El Galala. These rocks are characterized by cross-bedded sandstone at the bottom overlain by marls and dolomite bands. The upper part of this sequence consists of siltstone and sandstone intercalations.

Cretaceous rocks characterize the outcrops of the eastern and southern sides of Gebel Ataqa massif, the eastern cliff of El Galala El Baharya, and the escarpment of Khashm El Galala. The Cretaceous succession in the study area is subdivided into three rock units from older to younger, Malha, Galala, and chalky limestone units.

The Eocene rocks are the nummulitic limestones. It forms the main part of Gebel Ataqa and Gebel El-Galala El-Bahariya as well as the Faulted blocks of Akheider-Rammlyia and Um Zeita-Kahallya. The Eocene succession subdivided from base to top into the upper part of the Esna Shale Formation, Farafra Formation, Thebes Formation, Muweilih Formation, Mokattam Formation, Observatory Formation, Qurn Formation, Wadi Garawi Formation, and Wadi Hof Formation.

The Oligocene rocks are differentiated into two units; the lower unit is varicolored, consisting of unstratified sands, gravels, and sedimentary quartzite; the upper unit crops out in the central part of the study area and consists of basalt sheets of Gebel El Ahmer Formation.

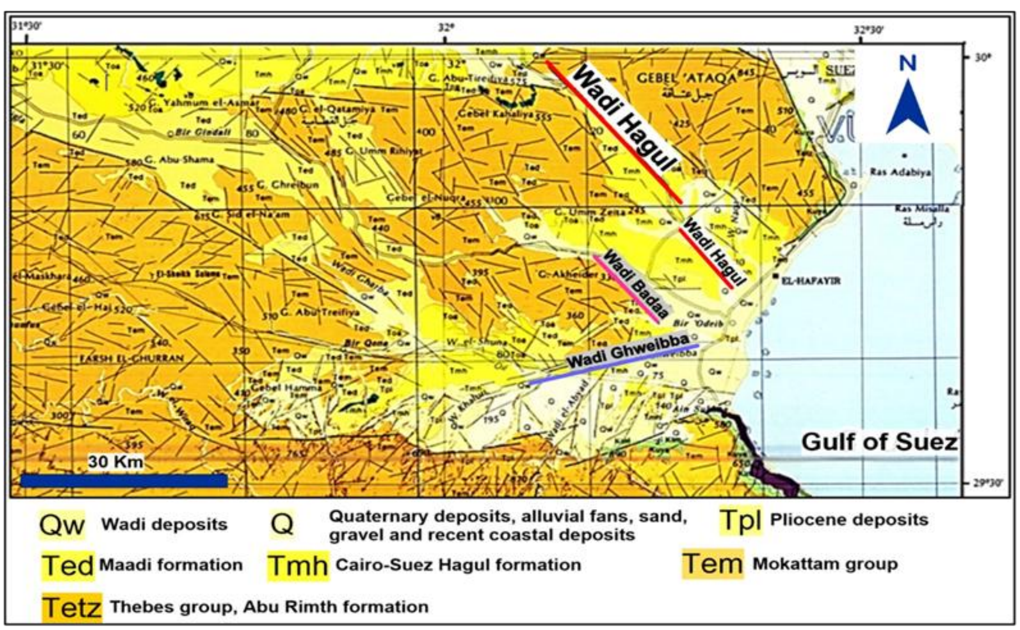

Fig. 2. Geological map of the study area and its surroundings (CONOCO, 1987).

The Miocene succession that is exposed in the Sadat area which is located 30 km to the southwest of Suez city and is subdivided from base to top to Sadat Formation (Early Miocene), Hommath Formation (Middle Miocene), Hagoul, and Gheweiba Formations (Late Miocene). These rocks characterized by sands, gravels, clays, sabkhas, and sand accumulations represent the recent deposits in the study area that covers large areas in Wadi Hagoul and Wadi Badaa.

Pliocene Rocks Made up of gravels and sands as patch distribution in Ataqa El Galala El Baharya depression.

Quaternary Deposits These are the youngest beds in the area and are represented by Wadi terraces forming pebbles and gravels, Wadi deposits, and fanglomerate. **Geomorphologically,** the study area can be subdivided into three main features: watershed areas "high tablelands", water collectors" hydrographic basins" and coastal plain.

The study area is located within the Cairo-Suez District, which represents a portion of the unstable area of the northern part of Egypt (Fig. 3). Cairo-Suez District extends for 120 km in an E-W direction from Cairo City towards Suez City and E to ENE and NW to WNW oriented faults dominate it. Structurally, the Cairo-Suez District can be subdivided into two major sectors relative to the Cairo-Suez Road. The northern Cairo-Suez District is located north of the Cairo-Suez Road and is characterized by the existence of Cretaceous, Eocene, Oligocene, and Miocene outcrops that are affected by faulting and folding (e.g., G. Shabraweet; G. Oweibed; G. Umm Raqm; G. Hamza).

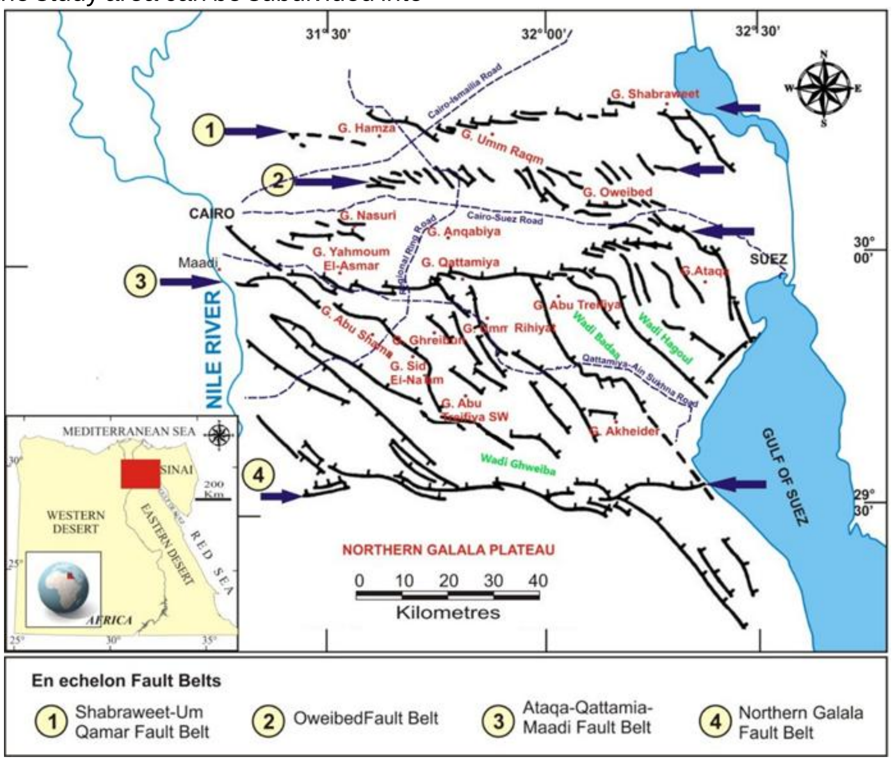

Fig. 3. Structural map of Cairo-Suez District and locations of studied Wadis (after Moustafa et al., 1998)

3. Methods and data acquisition

- A topographic map (Scale 1:50.000) and the tracing of the drainage network using the Digital Elevation Model (DEM) with 30 m resolution are used to determine the morphometric parameters of the study basin (Table 1) and (Fig. 4). This drainage basin is extracted from a digital elevation model (DEM). Based on Horton (1945) and Strahler (1957), the streams are ordered, and the different parameters are measured and calculated. The study basin is evaluated, morphometrically, by using the integration between morphometric parameters and GIS techniques to determine the flash flood-prone areas.
- Depending on the morphometric parameters for the studied basin, an assessment of the flash flood hazard degree can be estimated using Davis equation (1973);.

$$Y = \frac{(Ymax - Ymin)\,(X' - Xmin)}{(Xmax - Xmin)} + Ymin$$

where, Y is Relative hazard degree, Ymax is the upper limit of proposed scale (Class 5 or 5 degrees), Ymin is the lower limit of proposed scale (First class or 1 degree of this class), Xmax is the higher estimated value of any parameter, Xmin is the lower estimated value of any parameter, and X′ is the estimated value of any parameter between lower and higher value.

- Stormwater Management and Design Aid (SMADA 6.0) computer program used to generate a hydrograph for the wadi. A runoff hydrograph is simply a plot of flow rate versus time, which can calculate the time to peak, base time, and the maximum runoff (peak of discharge).
- Three storms of 2015, 2016, and 2020 obtained from the Egyptian Meteorological Authority for Suez station (Latitude 29° 30' 30.00" and Longitude 31° 45' 32.30") are used as input data in SAMADA 6.0 program for the studied Wadi.

Table 1. Morphometric parameters formulas

No.	Morphometric Parameter	Formula	Reference
1	Stream Order (Su)	Hierarchical Rank	Strahler (1952)
2	Stream Number (Nu)	Nu = N1+N2+…Nn	Strahler (1952)
3	Stream Length (Lu) Kms	Lu = L1+L2 ……Ln	Horton (1932)
4	Stream Length Ratio (Lur)	Lur = ∑ (Lu+1/Nu+1)/(Lu/Nu)	Strahler (1964)
5	Bifurcation Ratio (Rb)	Rb= Nu /Nu+1	Horton (1945)
6	Mean Bifurcation Ratio (Rbm)	Rbm = ∑Rb/N	Schumm (1956)
7	Weighted Mean Bifurcation Ratio (WMRB)	WMRb=∑ (Rbu /Rbu+1)(Nu+Nu+1)/∑N	Strahler (1953)
8	Main Channel Length (MCL) Kms	GIS Software Analysis	------------------
9	Main Channel Index (MCI)	MCI = MCL / Adm (H & TS)	Mueller (1968)
10	Valley Length (VL) Kms	GIS Software Analysis	------------------
11	Sinuosity (Si)	VL/Lb	Gregory and Walling (1973)
12	Rho Coefficient (ρ)	ρ = Lur / Rb	Horton (1945)
13	Basin Length (Lb) Kms	GIS Software Analysis	Schumm (1956)
14	Mean Basin Width (Wb)	Wb = A / Lb	Horton (1932)
15	Basin Area (A) Sq Kms	GIS Software Analysis	Schumm (1956)
16	Basin Perimeter (P) Kms	GIS Software Analysis	Schumm (1956)
17	Relative Perimeter (Pr)	Pr = A / P	Schumm (1956)
18	Length Area Relation (Lar)	Lar = 1.4 * A0.6	Hack (1957)
19	Lemniscate's (k)	k = Lb2 / 4A	Chorley (1957)
20	Form Factor Ratio (Ff)	Ff = A / Lb2	Horton (1932)
21	Shape Factor Ratio (Sf)	Sf = Lb2 / A	Horton (1932)
22	Elongation Ratio (Re)	Re = 2(A/π)0.5/LB	Schumm (1956)
23	Texture Ratio (Rt)	Rt = Nu / P	Schumm (1956)
24	Circularity Ratio (Rc)	Rc = 12.57 * (A / P2)	Miller (1953)
25	Compactness Coefficient (Cc)	Cc = 0.2841 * P / A 0.5	Gravelius (1914)
26	Fitness Ratio (Rf)	Rf = CL / P	Melton (1957)
27	Wandering Ratio (Rw)	Rw = CL / Lb	Smart & Surkan (1967)
28	Compactness Ratio (Sh)	Sh = pr/2√Aπ	Horton (1945)
29	Shape index (Ish)	Ish=1.27A/LB2	Hagget (1956)
30	Stream Frequency (Fs) km-2	∑ 〖Nu /A〗	Horton (1945)
31	Drainage Density (Dd) km-1	∑ 〖Lu/A〗	Horton (1945)
32	Infiltration Number (If)	If = Fs*Dd	Faniran (1968)
33	Length of Overland Flow (Lo) km	Lo = 1/2 D	Horton (1945)
34	Constant of channel maintenance (C)(Km)	C=1/Dd	Schumm (1956)
35	Maximum Elevation (Hmax)	GIS Software Analysis	------------------
36	Minimum Elevation (Hmin)	GIS Software Analysis	------------------
37	Relief Characteristic (R) m	Hmax - Hmin	Schumm (1956)
38	Internal Relief (E) m	E = E85-E10	Schumm (1956)
39	Slope index (SI)	SI=E/0.75VL	Majure and Soenken (1991)
40	Hypsometric Integral (Hi)	Hi = (mean elevation min)/ (elevation max-elevation min)	Strahler (1952)
41	Ruggedness Number (Rn)	R*D	Melton (1957)
42	Relief ratio (Rr)	R/LB	Schumm (1956)

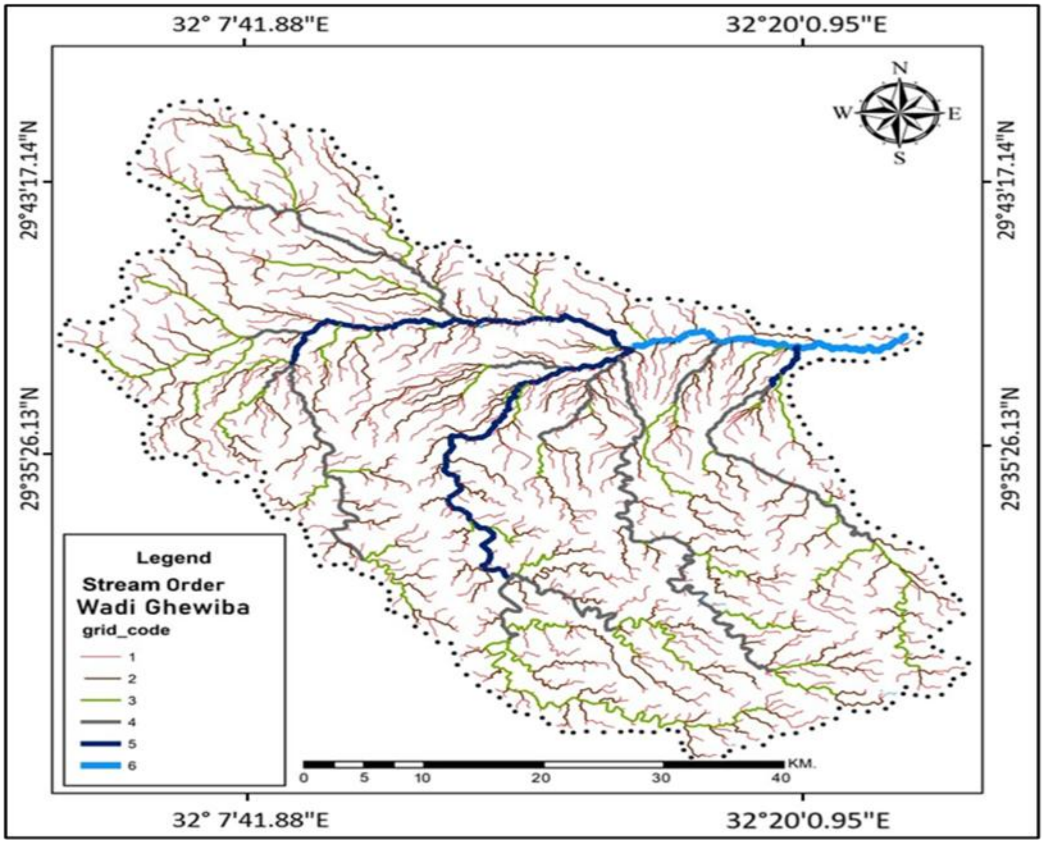

Fig. 4. Drainage map showing six stream orders of Wadi Gheweiba

4. Results and discussion

4.1. Surface Hydrology

4.1.1 Morphometric Analysis

The morphometric parameters were measured, and calculated, and classified into four classes: drainage network, basin geometry, drainage texture analysis, and relief characteristics (Table 2). Each morphometric parameter is illustrated and derived using mathematical equations in order to evaluate hazard degrees.

Nine of these parameters were used to determine the degree of flash flood hazards in studied Wadi which shows that Wadi Gheweiba belongs to the highly hazardous degree (Table 3).

4.1.2 Infiltration Capacity

The infiltration rate for the surface soil of the study Wadi plays an outstanding role in the replenishment of the shallow aquifers in the study area, in addition to, detection the suitable tools of harvesting techniques for the surface runoff during the rainfall storms. Six infiltration tests were carried out at selected Wadi by Ismail (2017) using a double ring infiltrometer (Fig. 5).

The infiltration rate calculations are performed using the computer program INFITEST (Sewidan, 1999), which is based on the Philip equation (1957a,b) (Table 4).

$$I = 0.5St^{-0.5} + A$$

where, (I) is the infiltration rate (m/day), S is the sorpitivity (Rate of penetration of the wetting front) and A is an infiltration value that is close to the value of the saturated hydraulic conductivity of the transmission zone.

It is obvious that the, infiltration rate is high in the upstream and low in the downstream of the Wadi. The infiltration rate for the surface soil is moderately slow downstream which belongs to group 3, while the infiltration rate in the upstream reflects a very rapid rate which belongs to group 7 according to Kohnke, 1980 (Table 5).

4.1.3. Rainfall-Runoff Relationship

Rainfall – runoff relationship is very important factor in the study of the integrated water resources management in the study area. The relation of rainfall-runoff in the selected Wadi aims to calculate the peak of discharge and total volume of runoff by applying SMADA 6.0 program (Storm water Management and Design Aid) the computer program was used to generate the hydrograph for the investigated Wadi (Fig. 6). Three storms of 2015, 2016, and 2020 obtained from the Egyptian Meteorological Authority for the Suez station (Table 6) are used as input data in SAMADA 6.0 program for studied Wadi.

Table 2. Morphometric parameters for Wadi Gheweiba

No.	Classes	Morphometric Parameter	Wadi Gheweiba
1	Drainage Network	Stream Order (Su)	6
2		Stream Number (Nu)	1316
3		Stream Length (Lu) Kms	2840.7
4		Stream Length Ratio (Lur)	9.824
5		Bifurcation Ratio (Rb)	3-4.529
6		Mean Bifurcation Ratio (Rbm)	4.037
7		Weighted Mean Bifurcation Ratio (WMRB)	4.414
8		Main Channel Length (MCL) Kms	81.27882
9		Main Channel Index (MCI)	26.922
10		Valley Length (VL) Kms	74.17356
11		Sinuosity (Si)	1.059
12		Rho Coefficient (ρ)	2.433
13	Basin Geometry	Basin Length (Lb) Kms	70
14		Mean Basin Width (Wb)	39.614
15		Basin Area (A) Sq Kms	2773
16		Basin Perimeter (P) Kms	271
17		Relative Perimeter (Pr)	10.23
18		Length Area Relation (Lar)	162.89
19		Lemniscate’s (k)	0.44
20		Form Factor Ratio (Ff)	0.566
21		Shape Factor Ratio (Sf)	1.76
22		Elongation Ratio (Re)	0.849
23		Texture Ratio (Rt)	4.85
24		Circularity Ratio (Rc)	0.4742
25		Compactness Coefficient (Cc)	1.462
26		Fitness Ratio (Rf)	0.299
27		Wandering Ratio (Rw)	1.16
28		Compactness Ratio (Sh)	1.4517
29		Shape index (Ish)	0.718
30	Drainage Texture Analysis	Stream Frequency (Fs) km-2	0.474
31		Drainage Density (Dd) km-1	1.0244
32		Infiltration Number (If)	0.485
33		Length of Overland Flow (Lo) km	0.488
34		Constant of channel maintainance (C) (Km)	0.97
35	Relief Characteristics	Maximum Elevation (Hmax)	1274
36		Minimum Elevation (Hmin)	0
37		Relief Characteristic (R) m	1274
38		Internal Relief (E) m	698
39		Slope index (SI)	0.01254
40		Hypsometric Integral (Hi)	0.5
41		Ruggedness Number (Rn)	1.305
42		Relief ratio (Rr)	0.0182

Table 3. Morphometric parameters and their impact on hazard degree

Morphometric Parameter	Wadi Gheweiba
A	5
F	3.72
D	2.235
Ish	5
SI	5
Rr	3.53
Rn	5
Rt	5
WMRB	1
Hazard Degree	4

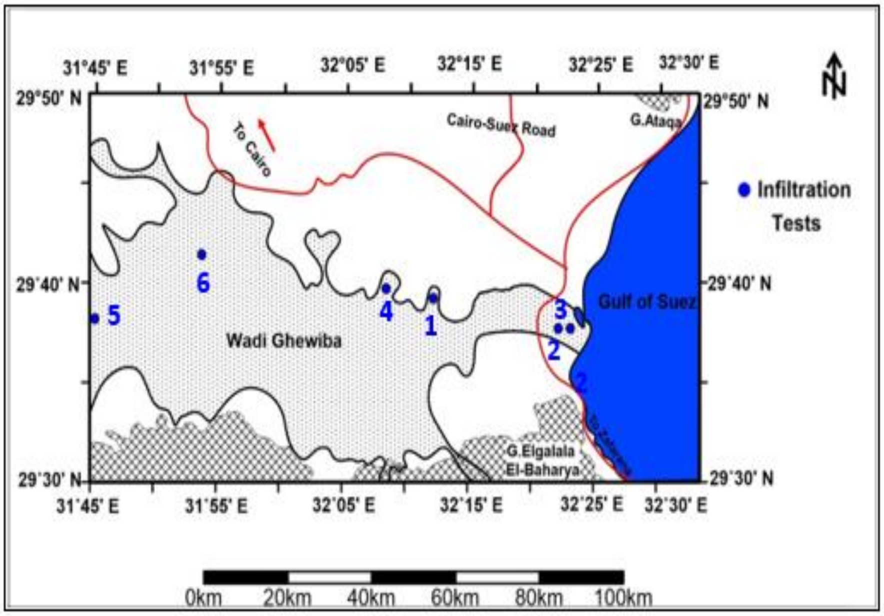

Fig. 5. Infiltration tests within Wadi Gheweiba, modified after (Ismail, 2017)

Table 4. Infiltration rate and degree of infiltrations obtained from infiltration tests in the study area (after Ismail, 2017)

Test No.	Wadi Name	Longitude	Latitude	Infiltration Rate (m/day)	Degree of Infiltration after Kohnke, 1980
1	Gheweiba	32° 13.313'	29° 38.373'	2.711	Moderately rapid
2		32° 18.702'	29° 37.416'	0.42	Moderately slow
3		32° 19.116'	29° 37.333'	3.94	Rapid
4		32° 11.25'	29° 38.7'	4.53	Rapid
5		31° 56.35'	29° 37.516'	8.1	Very rapid
6		32° 3.65'	29° 39.416'	5.7	Rapid

Table 5. Classification of infiltration rates concerning soil type (Kohnke, 1980)

Group	Degree		Possible Rates of Infiltration	
	US.SSM	PREFERRED	inch/hr	m/day
7	Very Rapid	Excessively Rapid	>10.00	6.096
6	Rapid	Rapid	5.00-10.00	3.048-6.096
5	Moderately Rapid	Good	2.50-5.00	1.524-3.048
4	Moderate	Slightly Restricted	0.80-2.50	0.488-1.524
3	Moderately Slow	Moderately Restricted	0.32-0.80	0.122-0.487
2	Slow	Severely Restricted	0.05-0.20	0.030-0.122
1	Very Slow	Relatively Impermeable	<0.05	<0.0305

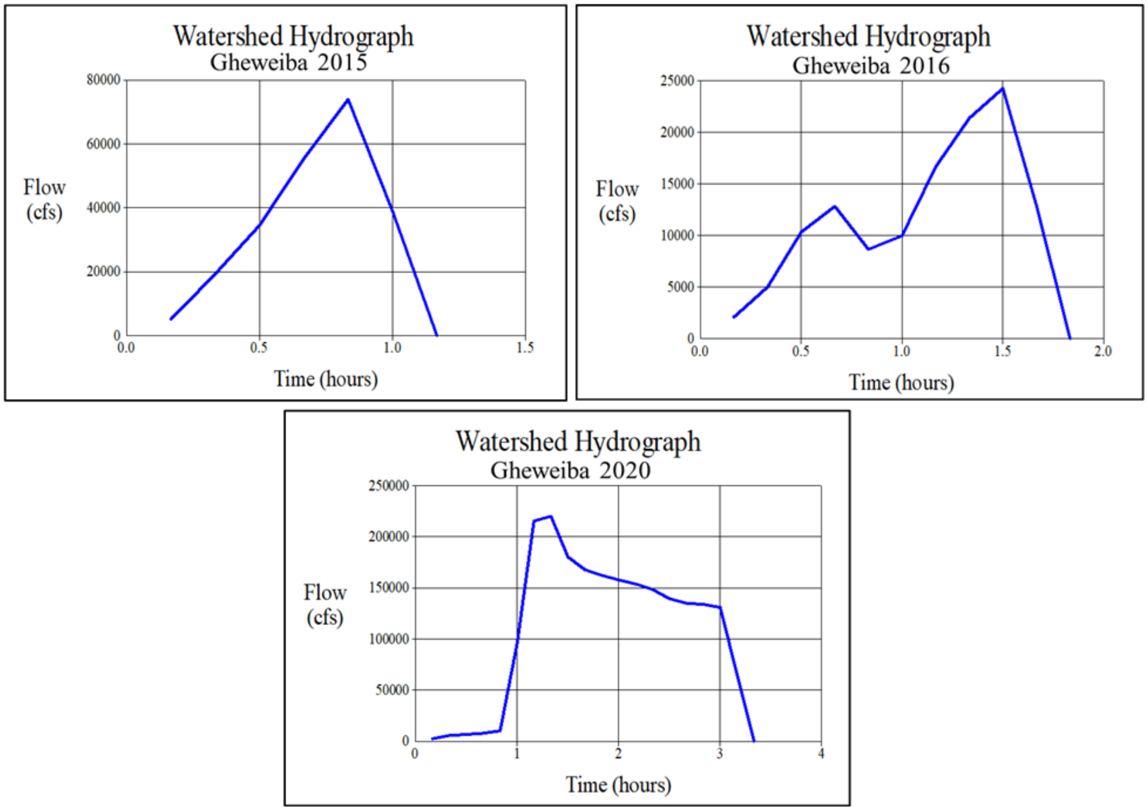

Fig. 6. Watershed Hydrographs of Wadi Gheweiba in 2015, 2016 and 2020.

Table 6. Three storms of 2015, 2016, and 2020 obtained from the Egyptian Meteorological Authority for Suez station.

Year	Total Rainfall (mm)	Rainfall Duration (hrs)
2015	18.9	0.88
2016	16	1.5
2020	44.1	3

Table 7. The estimated direct runoff volume applying SMADA 6.0 program (Storm water Management and Design Aid) during the rainfall storm of Wadi Gheweiba

Year	Area (km^2)	Rainfall (mm)	Duration (hr)	Intensity (mm/ h)	Runoff Volume (m^3)	Total Volume (m^3)
2015	**2773**	**18.9**	**0.883**	**21.4**	**2424592**	**3322743.8**
2016		**16**	**1.5**	**1.66**	**929052**	**1277083.7**
2020		**44.1**	**3**	**14.7**	**7425056**	**10217586.7**

The hydrograph of Wadi Gheweiba in 2015, 2016, and 2020 shows that the peak of discharge is 2094.16, 686.89 and 6227.06 m^3/sec and the total volume of runoff transferred to the delta of the investigated Wadi reaches 2424592, 929052 and 7425056 m^3. The total runoff transferred to the delta of the selected Wadi is 3322743.8 MCM in 2015, 1277083.7 MCM in 2016, and 10217586.7 MCM in 2020 (Table 7).

4.1.4 Aquifer Replenishment (Applying F- Curve method)

By using the F–curve method (Raghunath, 1990), the estimated direct aquifer recharge has been calculated during the three storms in (2015, 2016, and 2020) for Wadi Gheweiba. (Fig. 7). The amount of water that infiltrates into the aquifer is (758415.5, 924795.5, and 2302976.5) m^3 within the 2015, 2016, and 2020 storms, respectively (Table 8).

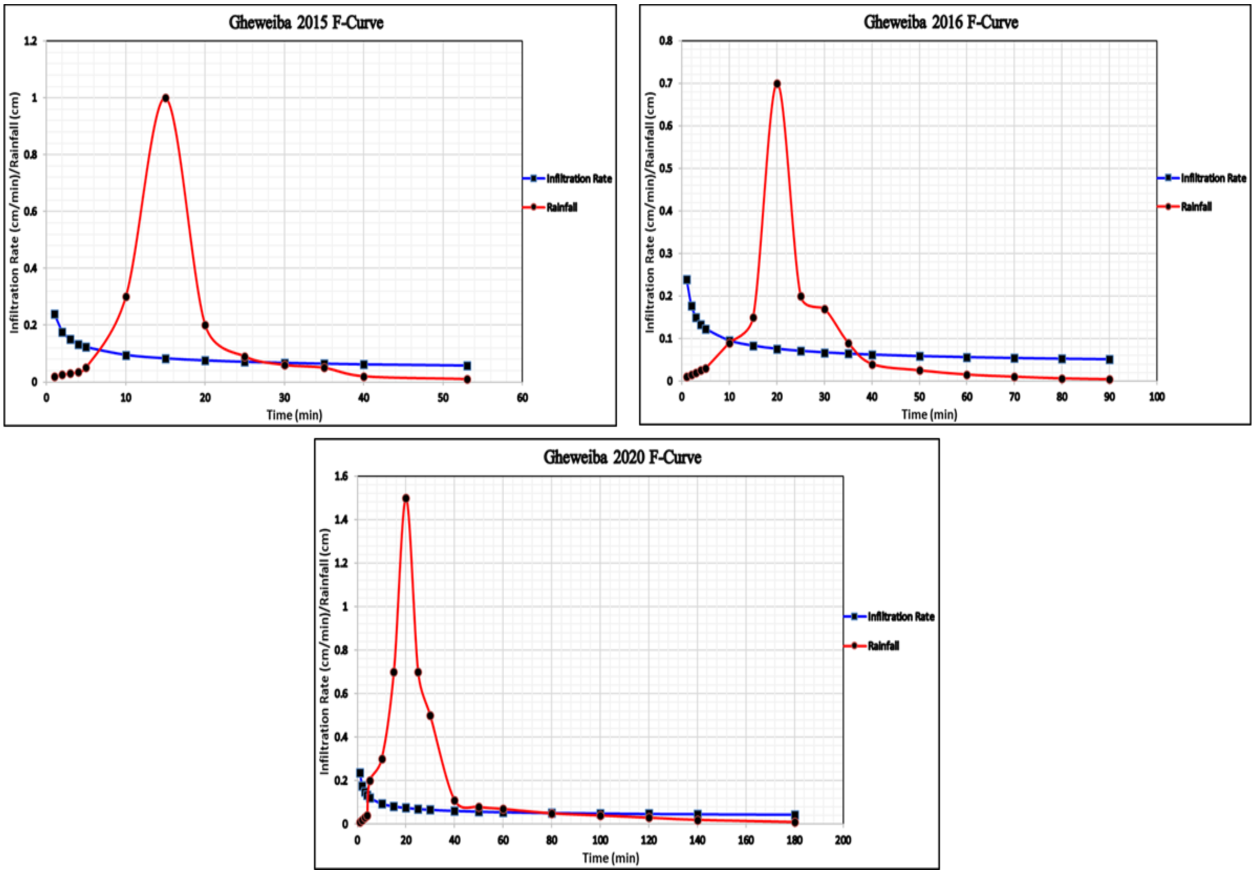

Fig. 7. F-curve for Wadi Gheweiba representing storm of 2015, 2016 and 2020.

Table 8. The estimated direct runoff volume applying the F–curve method during the rainfall storm of Wadi Gheweiba

Year	Area (km^2)	Rainfall (mm)	Duration (hr)	Intensity (mm/ h)	Runoff Volume (m^3)	Aquifer Recharge (m^3)	Total Volume (m^3)
2015	**2773**	**18.9**	**0.883**	**21.4**	**2193443**	**758415.5**	**2951858.5**
2016		**16**	**1.5**	**1.66**	**1857910**	**924795.5**	**2782705.5**
2020		**44.1**	**3**	**14.7**	**6031275**	**2302976.5**	**8334251.5**

4.1.5 Suggested harvesting Techniques for the surface Runoff

No doubt that, the optimum utilization of harvesting techniques in the study Wadi plays an outstanding role in avoiding the damages of the infrastructures and giving the chance to replenish the shallow aquifers. According to the results in the investigated Wadi, the suggested tools of harvesting techniques have been located and recommended (Fig. 8).

5. Conclusion and Recommendations

This work presents urgent solutions and alternatives, especially in the northwestern part of the Gulf of Suez in the El Ain El Sokhna area. This study area is a pressing concern as it undergoes the government's strategic plan 2020-2030 for sustainable development projects, and the optimum use of water resources in this area is a matter of immediate importance. According to the above discussion, the following recommendations must be taken into consideration:

- A significant amount of runoff water from Wadi Gheweiba flows through the main channels of this Wadi and is directed to the Gulf of Suez, causing occasional flash floods. Implementing advanced harvesting techniques for surface runoff and its maintenance is crucial to prevent the damage caused by these flash floods. This will not only protect the local communities and infrastructure but also ensure the efficient use of water resources.
- A diversity of dams should be constructed along the Wadi tributaries, especially in the upstream and middle portions of the Wadi, to decrease the runoff velocities for feeding the groundwater aquifers and diverting flood water to be distributed to agricultural lands.

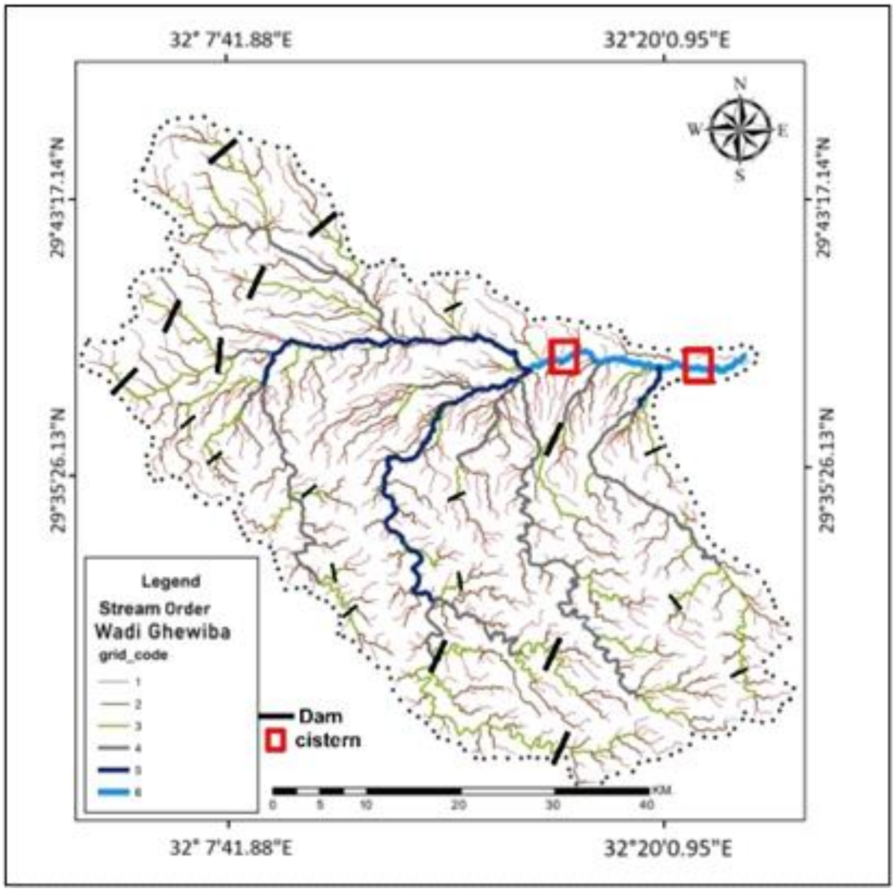

Fig. 8. The suggested tools of harvesting techniques.

- Construction of cisterns at various places, especially downstream of Wadi, to collect rainwater for drinking and other uses.
- Installation of meteorological stations on the top of mountains around the Wadi is essential since there is a great lack of meteorological data in this area. This will help in water resources studies, flood analysis, and rainfall prediction.

References

Abd Allatief, T.A., Galal, G.H. and Youssef, A.M., (1997): “Structural and lithological impacts on the groundwater occurrence along Wadi El Noqra-Wadi Badaa area” Egypt Geol. Surv. Proc. Of the 15th Ann. Meet., March 1997, pp. 107-124.

Abdel Mogheeth, S., (2008): “Geoelectrical study on the groundwater occurrence at wadi Gheweiba, west El-Ain Sukhuna”. Internal Report. DRC.

Abdel Samie, S. G. and Elewa, H. H., (2005): “Hydrogeochemical and environmental isotopic evaluation of groundwater of the area located to the northwest of the Gulf of Suez coast, Egypt”, Egyptian Journal of Geology, v.49, pp.109-131.

Andrawis, W. M., (2007): “Study of Groundwater Resources in the Northern Part of Suez Gulf”. Environment Sci. Thesis. DDC. No. 10544335. 66 P.

Chorley, R.J., Malm, D.E.C., Pogorzelski, H.A., (1957): “A new standard for measuring drainage basin shape”. Am. J. Sci. v.255, pp. 138 –141.

Continental Oil Company (CONOCO). (1987). Stratigraphic lexicon and explanatory notes to the geologic map of Egypt 1:500000 (Edited by Maurice Hermina, Eberhard, & Franz K. List).

Davis, J. C. (1973). Statistics and data analysis in geology. John Wiley & Sons, Inc.

DRC (Desert Research Center) (2007): “Geoelectrical study within the area lying between the outlets of Wadi Gheweiba and Wadi Bada along the western side of the Gulf of Suez”. Internal Report.

El Hazek, A.N., Abdelmageed, N.B., Mekhemer, H.M. and Amin, D.H., (2020): “Groundwater Evaluation and Management in Ain Sukhna, Egypt”. Asian Journal of Engineering and Technology (ISSN: 2321 – 2462) v.8.

Faniran, A., (1968): “The Index of Drainage Intensity – A Provisional New Drainage Factor”. Australian Journal of Science, v.31, pp. 328-330.

Geriesh, M.H., EL-Rayes, A.E. and Fouad, A. (2004): “Runoff control and water management in Wadi Gheweiba hydrographic basin, Northwest of Gulf of Suez region, Egypt”. Proc. 7th Conf. Geology of Sinai for Development Ismailia, pp. 53-67.

Gravelius, H., (1914): Flusskunde. Goschen Verlagshan dlung Berlin. In: Zavoianu I (ed) Morphometry of drainage basins. Elsevier, Amsterdam.

Gregory, K. J., Walling, D. E., (1973): “Drainage basin form and process”. John Wiley and Sons, New York, 456 p.

Hack, J.T. (1957): Studies of longitudinal stream profiles in Virginia and Maryland. USGS professional paper, 94 B, US Geological Survey

Hagget, P., (1956): “Locational analysis in human geography”, Edward Arnold Ltd, London, 339 p.

Hamed, M.F.A. and Mahmoud, H.H., (2009): “Impact of sea water intrusion on groundwater in El Ain El Sokhna Area-Gulf of Suez, using geoelectric exploration”.
Horton, R. E. (1932). Drainage basin characteristics. Transactions of the American Geophysical Union, 13, 350–361.
Horton, R. E. (1945). Erosional development of streams and their drainage basins. Geological Society of America Bulletin, 56, 275–330.
Ismail, H. M. (2017). Assessment of water resources in the area north of El Galala El Baharya.
Kohnke, H. (1980). Soil physics: Soil scientist (pp. 28–34). Purdue University, McGraw-Hill Publishing Company Ltd.
Majure J J, Soenksen P J, (1991): Using a geographic information system to determine physical basin characteristics for use in flood-frequency equations, in Balthrop BH, Terry JE eds., U.S. Geological Survey National Computer Technology Meeting Proceedings, Phoenix, Arizona, November 14-18, 1988: U.S. Geological Survey Water-Resources Investigations Report 90-4162:31-40.
Melton, M.A., (1957):” An analysis of the relation among elements of climate ‹surface properties and geomorphology”, Office of Nav. Res., Dep. of Geol., Columbia Univ., New York.Tech. Rep. II, 102 p.
Miller, N.C., (1953): “A quantitative geomorphic study of drainage basins characteristics in Clinish mountain area, Virginia and Tenssesse”, Columbia Univ. Geol. Dept., Tech. Report no.3, 30 p.
Mueller J.E., (1968): “An Introduction to the Hydraulic and Topographic Sinuosity Indexes”. Annals of the Association of American Geographers, v. 58, pp. 371- 385.
Moustafa, A.R., El Badrawy, R. and Gibali, H., (1998): “Pervasive E-ENE oriented faults in northern Egypt and their effect on the development and inversion of prolific sedimentary basins”. In: 14th E.G.P.C. Petrol. Conf. pp. 51-67. Cairo, Egypt.
Nasr, M.I., (2004): “Geophysical exploration for groundwater aquifers in Wadi Ghawaiba area, West Gulf of Suez,” Journal of Faculty of Educational, v. 29, pp. 131 –145.
Philip, J. R. (1957a). The theory of infiltration II. Soil Science, 34, 83–85.
Philip, J. R. (1957b). The theory of infiltration III. Soil Science, 34, 163–257.
Raghunath, H. M. (1990). Hydrology: Principles, analysis, and design. Wiley Eastern Limited.
Schumm, S.A., (1956): “Evaluation of the drainage systems and slopes in badlands at Perth Amboy”, New Jersy. Geol. Soc. American Bull. v. 67, pp. 596-646.
Sewidan, A. S. (1999). INFILTEST: Computer program of infiltration test calculation. Hydrology Dept., Desert Research Center, Cairo, Egypt.
Smart, J.S., Surkan, A.J., (1967) The relation between mainstream length and area in drainage basins. Water Resour Res 3(4):963-973.
Strahler, A. N. (1957). Physical geography. Wiley International.
Strahler, A.N., (1952): “Hypsometric (area altitude) analysis of erosional topography”, Geol. Soc. American Bull, v. 63, pp. 1117-1142.
Strahler, A.N., (1953): “Revision of Horton’s quantitative factors in erosional terrain”, Paper read before hydrology section of Am. Geophys. Union, Washington D.C.
Strahler, A.N., (1964):” Quantitative Geomorphology of Drainage Basin and Channel Network”, Handbook of Applied Hydrology, pp 39-76. Woldenberg, N.J (1967), Geography and Properties of Surface‖, Handward Paper in Theoretical Geography, v. 1, pp. 95-189.