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Methods to Reduce the Risk of Flash Floods for Wadi El Ibrahimi, Eastern Desert, Egypt

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ABSTRACT

The hydrological regime of Wadi El Ibrahimi, located in the Eastern Desert, Egypt, is characterized by repeated flash floods, causing extensive damage to infrastructure, villages, and major roads, as well as several fatalities. Therefore, the main objective of this research is to find methods to reduce the damages caused by flash floods. In this study, data for a time period from 2000 to 2023, which had four storms, was used. The SMADA 6.3 program was used to create hydrographs for the four storms with varying rainfall depths (29.63, 34.94, 11.56, and 18.11 mm) and return periods (2.4, 1.71, 1.5, and 1.33 years), respectively, in order to determine the maximum flow and runoff volume. The volume of runoff obtained varies from 0.243 million m^3 to 0.07 million m^3. Using ArcMap-software 10.3, Wadi El Ibrahimi was divided into six subbasins. David's method was used to determine hazard degrees for the detected subbasins of Wadi El Ibrahimi. The hazard degrees can be divided into four categories: basins of very low hazard degree (subbasin 5); basins of moderate hazard degree (subbasin 3); basins of high hazard degree (subbasin 2, subbasin 4, and subbasin 6); and basins of very high hazard degree (subbasin 1). Recommended Construction of detention dams at the outlets of the main channels to allow recharging of groundwater aquifers and reduce the amount of lost water that runs to the Nile River. Also, the installation of cisterns at the exits of the main channels allows for the storage of large quantities of surface water, as well as the installation of well-turbulent rain stations for more accurate estimates.

Keywords: Eastern desert; Flash flood; Hazard degrees; Morphometric parameters; Return pierod; Wadi El Ibrahimi.

1. Introduction

The rapid occurrence of flash floods makes it more challenging to predict in advance and give enough warning time (Sharma and Mahajan, 2020). Condensed rainfall causes floods, often in arid regions, endangering property and human lives as a result of environmental deterioration (Abdel-Fattah *et al.,* 2017). Traditional construction techniques such as ditches, bypass channels, culverts, and ponds are simple and effective ways to reduce the chance of unexpected flooding (Kumar *et al.,* 2017; Shah *et al.,* 2018). Geomorphological parameters have a direct effect on the potential and danger of flash floods, in addition to topography, climate, geological structures, human processes, drainage systems, and rainfall features. Measurable morphometric screening takes into account a variety of linear aspects of the drainage system, such as stream order, stream length, number of streams, and bifurcation ratio. In addition, aerial and relief aspects of the watershed, such as basin relief, relief ratio, ruggedness number, gradient ratio, basin slope, and relative relief, are considered (Strahler, 1964; Arulbalaji, and Padmalal, 2019). The establishment of small dams with diversion channels in the way of mainstream channels with high elevation and high stream orders was suggested for mitigating flash flood dameges (Gebril *et al.,* 2022).

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2. Study area

East of the Assiut governorate, next to Abnoub city, lies Wadi El Ibrahimi, this is situated in the middle part of the Eastern Desert, as shown in Fig. 1. It is located between latitudes 27° 15' and 27° 35' N and longitudes 30° 30' and 31° 30' E. The Wadi catchment has a total area of about 394.8 km^2, and it lies north of Wadi Assuiti. The limestone plateau of the Lower Eocene overlooks the research area. The arable area lies between the eastern scarp cliffs that enclose the Wadi and the River Nile. Similar to other desert regions, Wadi El Ibrahimi has unique hydrological characteristics and limited water resources. The hydrological regime of Wadi El Ibrahimi has characteristics of great rates of evapotranspiration, flash floods, a lack of base flow, and great variability in the temporal and spatial distribution of rainfall (Abushandi, 2011).

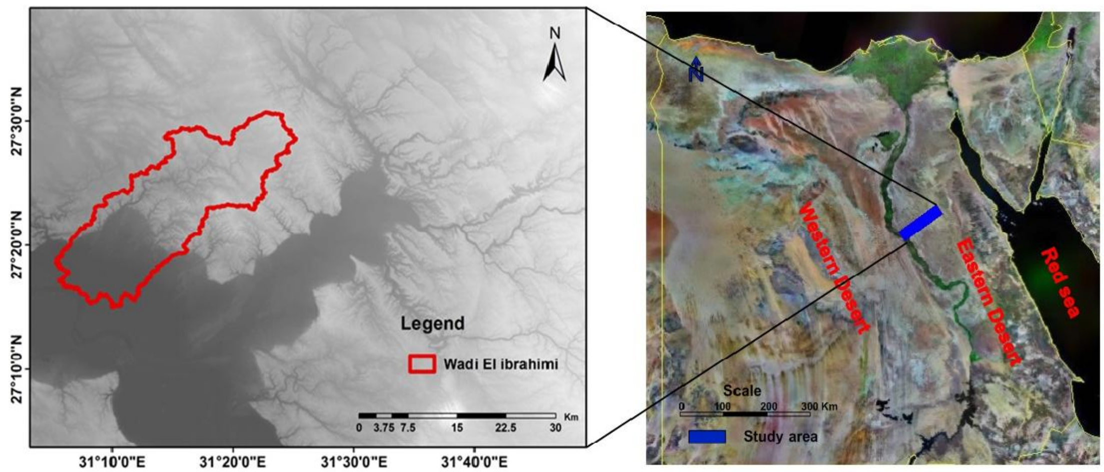

Fig. 1: Location map of Wadi El Ibrahimi, Eastern Desert, Egypt.

Geologically, according to Said 1960, 1981, Bishay 1961, El-Nagger 1970, Youssef et al.,1977, and others, based on the geologic map Assuit scale 500000: 1 (Conoco, 1987), The sedimentary sequence exposed in the study area is composed of the Tertiary rocks (Eocene and Pliocene) and the Quaternary alluvium (Fig. 2a). The Eocene rocks occupy the upstream and midstream areas of the Wadi El Ibrahimi basin, composed of limestone and dolomites (Minia formation). The Pliocene rocks extend spatially from Esna in the south to Manfalut in the north (Soliman, 2015). This formation consists of bedded travertine with minor conglomerate lenses (the Issawiya Formation). The quaternary alluvium is composed of mobile sediments, wadi deposits, fanglomerates, and Nile silt. Neonile sediments consisting of silt and clay occupy the top layer of the flood plain of the modern Nile and are also found outside this plain in the form of benches that fringe the valley at elevations ranging from 1 to 12m above the modern flood plain (Bakheit, 1983). This deposit belongs to the late Pleistocene. The wadi deposits are composed mainly of coarse sandy loam mixed with cobbles, gravels, and rock fragments derived from Eocene exposures. These deposits dominate tributaries of desert wadis and channels. Nile silt, which consists of fine sands, quartz grains, and some heavy minerals, is widely distributed and varies in thickness from one place to another, with an average of 9 m.

Structures, the study area are a part of the Nile Valley and lies within the stable shelf of Egypt, Said (1961, 1962). The main fault systems are NW, NE, and N-S (Youssef 1968 and El Shemi 1999).

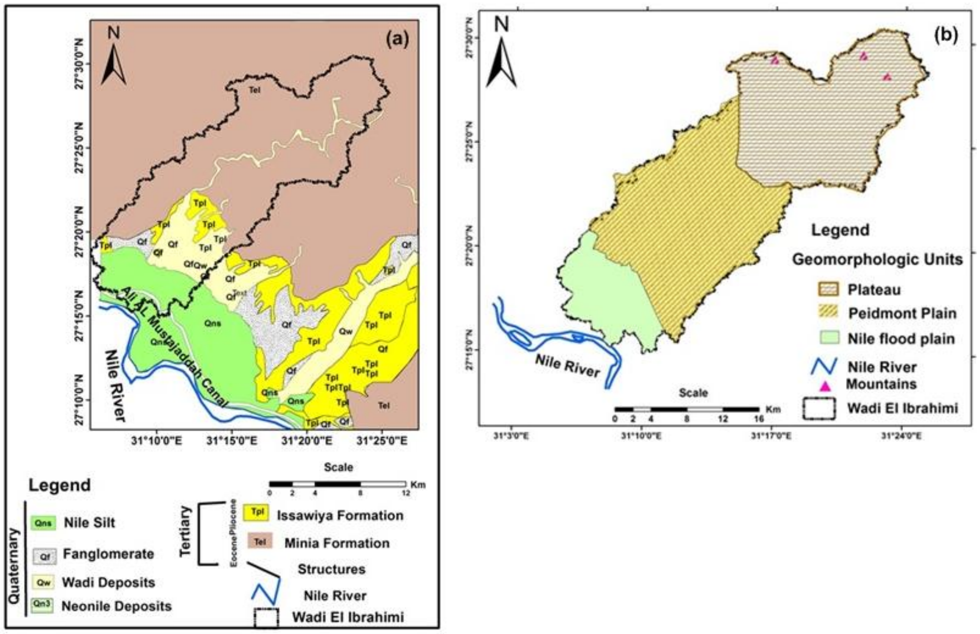

Fig. 2: a) Geological Map (modified from CONOCO, 1987); b): Geomorphological map of the Wadi El Ibrahimi, Eastern Desert, Egypt.

Geomorphologically, according to Soliman (2015) and Yousef (2008), the Wadi El Ibrahimi comprises three main geomorphological units: the structural plateau, which represents about 162.2 km^2 of the area of the basin and constitutes a part of the great Maaza Plateau. It is made up of hard limestone belonging to the Eocene period. It has an elevation between 200 m and 340 m above sea level. It contains most of the mountains of the area, such as G. Al Fant (303m) and G. Al-Ghuzuh (312 m). The plateau is corrugated with isolated mesas and buttes of limestone in different formations. It has an irregular surface owing to the effects of weathering and structures. Dense and well-developed drainage systems sever the plateau's surface, with Wadi El Ibrahimi being only one of several wadi systems that run westward. The second unit is Piedmont Plain, which is about 183.5 km^2 of the area of the basin. Its elevation ranges from 60m to 200m above sea level. It occupies the foot slope of the limestone plateau, which is composed mainly of cobbles, boulders, and gravels with sands and clays. The third unit is the Nile Flood Plain, which lies on the east of the River Nile, forming the flat alluvial floor of the cultivated lands bearing the River Nile channel from the east and dissected by irrigation canals and drains. It is almost flat and slopes from south to north. It has an area of about 57.3 km^2 of the area of the basin and occupies most of the downstream portion of the wadi at an elevation of 60m above sea level. It is made up of a silty clay layer belonging to the Holocene that caps the Pleistocene sandy and gravel deposits (Fig. 2 b).

Hydrogeologically, The Quaternary aquifer has a wide geographical distribution in the Nile valley and the adjacent desert fringes. It is composed of graded sand and gravel with occasional clay intercalations. The aquifer is considered unconfined to semi-confined. The aquifer is partially overlain by semi-permeable silty clay layers, where it is considered semi-confined. The Quaternary aquifer thickness varies from about 300 m in the north to 200 m in the south (Morsi el.at, 2018). The total dissolved solids (T.D.S.) of groundwater of the Quaternary aquifer vary from about 350 ppm to about 1800 ppm (Megahed, and Hanaa 2020). According to (Yan el.at, 2004), and Khalil (1988), the main source of recharge of the Quaternary aquifer is from the direct rainfall which falls over the catchment area and the deep upward leakage from the Nubian sandstone aquifer through deep major faults. The flow direction of the groundwater aquifer is towards the southwest, i.e. directly towards the mouth of the main valley on the Nile.

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3. Methodology

Globel Satellite Mapping of Precipitation (GSMaP) was used to estimate the accumulated precipitation that occurred between 2000 and 2023 at Assiut Station. GSMaP is a website the Japan Aerospace Exploration Agency (JAXA) developed that offers climatological precipitation for tracking extreme weather and global climatic events. From the available precipitation data (2000–2023), the distribution of daily maximums ranges between 1.7 and 34.9 mm with a mean value of about 10.62mm and a standard deviation of about 9.13 mm. While the distribution of annual rainfall ranges between 4.8 to 78.4 mm with a mean value of about 28.72 mm and a standard deviation of about 19.49 mm (Fig.3a and 3b). Also, Weibull's plotting location formula (Chow, 1964) was used to determine the return period and the probability of maximum daily precipitation (Fig.3c and 3d) for the same period (2000–2023) in the study area.

The methodology flow for assessing the hazard degrees, volume runoff, and strategies to lower the risk of flash floods in Wadi El Ibrahimi is shown in Fig. 4. Wadi El Ibrahimi and its six sub basins (Fig. 5a) were defined using topographic maps (scale 1:50,000) and the Shuttle Radar Topographic Mission Digital Elevation Model (SRTM, 30m) (Fig. 5b). Twenty-two geomorphometric characteristics were identified using GIS software and the geomorphometric mathematical formulas (Table 1, Table 2). These parameters include linear, aerial, and relief aspects. The dynamic changes in landform development due to geological and geomorphological processes over time can be understood using these morphometric parameters (Sharma and Mahajan, 2020).

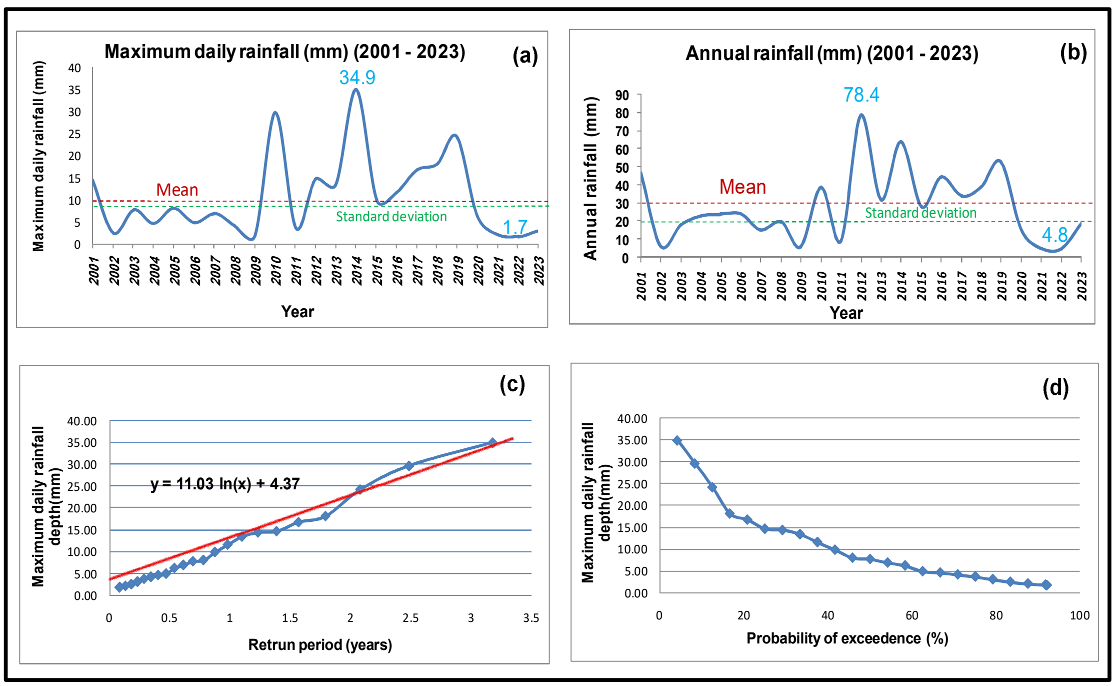

Fig. 3: (a) Maximum daily rainfall, (b) Annual rainfall, (c) Return period of the maximum daily rainfall and, (d) The probability of the maximum daily rainfall (Duration period 2000-2023).

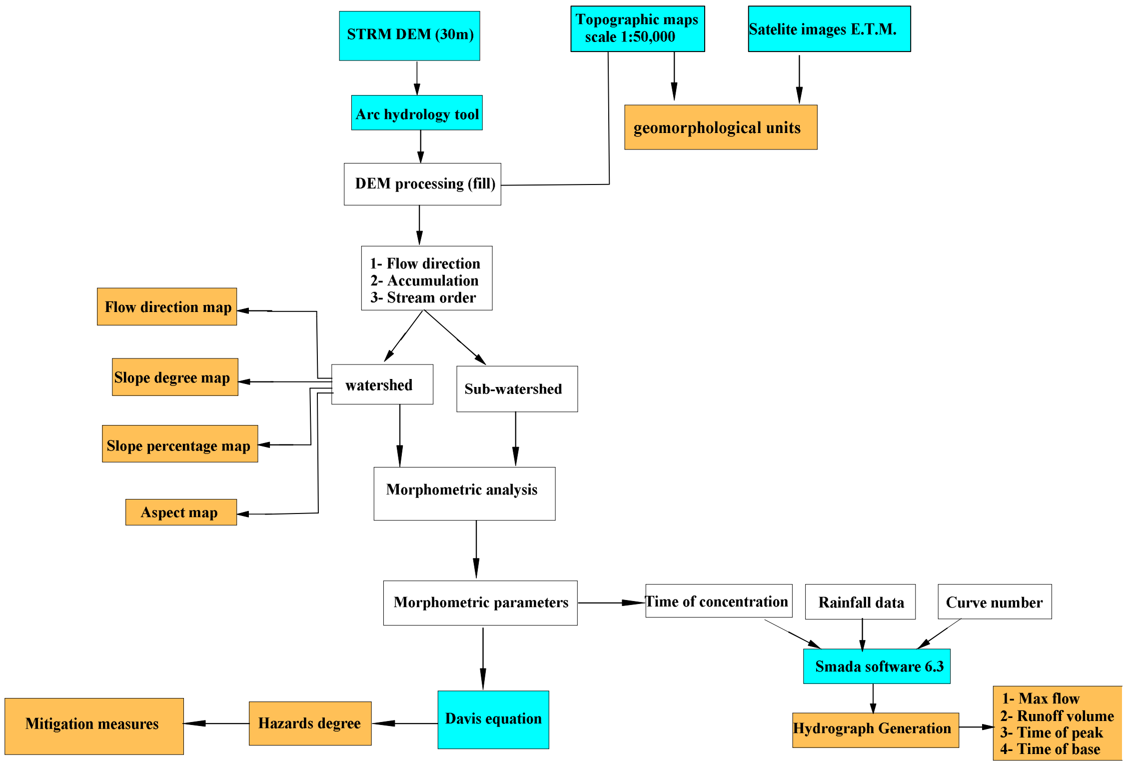

Fig. 4: Flow chart showing the methodology used for evaluated methods to reduce the risk of flash floods for Wadi El Ibrahimi, Eastern Desert, Egypt.

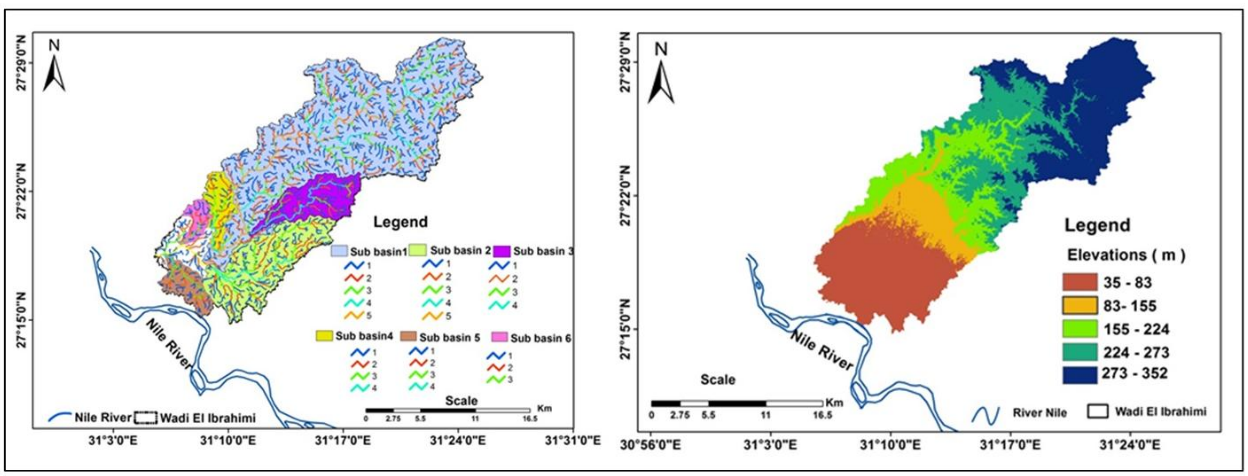

Fig. 5: Sub Basins, (a and b) digital elevation model of Wadi El Ibrahimi

Table 1: Basic Data of Wadi El Ibrahimi and its subbasins

Parameters / Name		Wadi Ibahimi	sub basin1	Sub basin2	sub basin3	sub basin4	sub basin5	sub basin6
Area (A) (Km2)		394.8	229.7	62.5	33.1	15.6	15.62	8.04
Perimeter (P) (Km)		144.6	104.98	53.1	36.3	26.5	25.4	16.8
Basin Width (w) (km)		10.3	8.7	4.7	2.3	1.91	2.29	1.6
Order of trunk channel		6rd	5rd	5rd	4rd	4rd	4rd	3rd
Direction of main trunk		**North east-South west**	**East-west**	**East-west**	**East-west**	**North west-south east**	**North west-south east**	**South - north**
First order	**Stream No.**	1134	665	171	97	46	49	23
	Length (km)	463.5	269.7	79.3	35.8	14.6	18.1	10.7
Second order	**Stream No.**	240	137	40	26	10	11	4
	Length (km)	240.6	127.9	46.4	15.5	13.1	8.6	6.5
Third order	**Stream No.**	53	31	10	4	2	2	1
	Length (km)	15	75.4	25.4	9.3	6.6	8.1	3.8
Fourth order	**Stream No.**	15	10	2	1	1	1	-
	Length (km)	68.6	30.5	14.1	16.3	5.3	1.98	-
Fifth order	**Stream No.**	2	1	1	-	-	-	-
	Length (km)	45.1	36.7	0.8	-	-	-	-
Sixth order	**Stream No.**	1	-	-	-	-	-	-
	Length (km)	7.1	-	-	-	-	-	-

Table 2: Morphometric Parameters of Wadi El Ibrahimi and its subbasins

Parameters / Name	Unit	Wadi Ibrahimi	sub basin 1	sub basin2	sub basin3	sub basin4	sub basin5	sub basin6
Sum of stream numbers ($\sum N_u$.)		1445	844	224	128	59	63	28
Sum of stream lengths ($\sum L_u$)	Km	960	540.3	166	76.9	39.6	36.78	21
Valley Length (L_v)	Km	59.9	43.7	19.5	18	11.4	9.4	6.9
Basin Length (L_b)	Km	38.6	28.1	19.5	18	8.1	7.5	5.1
Texture Ratio (Tr=Nu/P)	Km^{-1}	9,986	8.04	4.218	3.526	2.226	2.48	1.667
Sinuosity Ratio (S_i L_v/L_b)		1.6	1.56	1.4	1.43	1.41	1.3	1.43
Form Factor Ratio (FFR=(A/L_b2)		0.265	0.291	0.164	0.102	0.242	0.278	0.309
Compactness Ratio (SH=P/2(VπA)		2.053	1.953	1.894	1.78	1.87	1.81	1.67
Shape Index (Ish= 1.27A/L_b^2)		0.34	0.37	0.21	0.13	0.30	0.35	0.39
Circularity Ratio (Rc=4∏A/P^2)		0.238	0.263	0.28	0.317	0.286	0.306	0.36
Elongation Ratio (Re=(2√A/π)L_b		0.581	0.609	0.457	0.361	0.555	0.564	0.627
Bifurcation Ratio Rb=($\sum N_u/\sum N_{u+1}$)		4.7	5.6	3.8	4.7	3.9	3.9	4.9
Weighted Mean Bifurcation Ratio WMRb=(∑Rbu/Rbu+1) (Nu + Nu+1) /(∑Nu+1)		4.8	4.8	4.3	4.24	4.6	4.9	5.5
Drainage Density (D=($\sum L_u$/A)	Km^{-1}	2.4	2,352	2.656	2,323	2,491	2.355	2.312
Stream Frequency (F= ($\sum N_u$/A)	Km^{-2}	3.7	3,674	3,584	3,867	3.711	4.033	3,483
Upstream Elevation	m	352	352	272	297	224	65	207
Downstream Elevation	m	41	70	40	69	50	41	43
Relief((R)	m	311	282	232	228	174	24	164
Relief Ratio (R=R/L)	m/m	0.008	0.01	0.012	0.013	0.021	0.003	0.032
Ruggedness No. (Rn=R*D)		0.756	0.663	0.616	0.53	0.188	0.53	0.188
Length of overland Flow (Lo = 1/2D)	Km	1.20	1.18	1.33	1.16	1.25	1.18	1.16
Slope index SI=((E85-E10) /0.75VL)		0.462	0.0086	0.0158	0.0168	0.0204	0.0034	0.0228

The Programme of Storm Water Management and Design Aid (SMADA6.3) were used to generate the regional hydrograph of the study area. The program complements the hydrology packages, which include several separate executable files (the watershed characteristics and the rainfall event characteristics) that allow for drograph generation. To apply this software, the following files are considered:

a) Watershed file database

Watershed file contains characteristic parameters of the watershed (slope, overland flow, and drainage area) that were previously determined using GIS techniques (Table 2). Using the geological map, the impervious drainage area and the percentage of impervious area that is directly connected were determined.

b) Curve number

The Soil Conservation Service (SCS) (1972, 1986) developed the curve number to help in infiltration estimation during rainfall events. According to the SCS (1986) classification of hydrologic soils, the Quaternary deposits in the study area were classified as type A soils with a curve number of 63, and the Teriary as type A with a curve number of 77. Calculated the weighted curve number for mixed soil using the following equation:

$$CN = \frac{\sum_{i=1}^{K} AiCNi}{\sum_{i=1}^{K} Ai} \quad \text{.............................(1)}$$

Where, CNi corresponds to the appropriate CN for the part of the watershed that has an area Ai. The respective assignment of the curve number of Wadi El Ibrahimai, based on equation (1), is summarized in Table 2.

Table 3: Assignments of curve numbers for different land types in Wadi El Ibrahimi Eastern Desert, Egypt.

Name of Basin	Total area (km²)	Substrata		Type of soil group	Value of CN	Weighted CN
		Type	Area (km²)			
Wadi El Ibrahimi	394.64	Teriary	275.67	A	77	73
		Quaternary	118.96	A	63	

c) Time of Concentration

The time of concentration is the longest time required for a particle to travel from the basin water divide to the basin outlet. In the present study, Time of concentration is calculated by using the following equation (Subramanya, 1984):

$$Tc = \frac{0.0194L^{0.77}}{S^{0.385}} \quad \text{...........................(2)}$$

Where
Tc is the time of concentration,
L is Flow length (m), and
S is the average land slope.

d) Rainfall data:

Four storms with different return periods (Table 4) are used as input data in the SMADA6.3 program. Four scenarios for the rainfall-runoff relationship were carried out according to the different rainfall depths.

Table 4: Selected rainfall depths of different storms as input data in SMADA 6.3 program

Parameters / Date	Rainfall Depth (mm)	Total Rainfall Duration (hrs)	Return Period (years)	Probability of exceedence (%)
30/12/2010	29.63	1.00	2.40	41.67
09/03/2014	34.94	4.00	1.71	58.33
27/10/2016	11.56	1.50	1.50	66.67
15/11/2018	18.11	2.25	1.33	75

e) Hydrograph Generation:

The important step in the modeling process is the generation of a hydrograph. In the present work, a hydrograph is generated for Wadi El Ibrahimai for each rainfall depth using the SCS method. Final results are shown in Table (5) and Fig. (8).

f) Estimating hazard degree

Morphometric parameters were used to calculate the risk level for sub-basins of the Wadi El Ibrahimi. The risk level of the geomorphometric criterion in sub-basins was one (very low risk level) to five (very high risk level). The risk level for geomorphometric criteria was evaluated and calculated based on classic statistical equation method of Davis (1975), and Omar (2023):

$$\textbf{Hazard degree} = \frac{4(\text{X}+\text{Xmin})}{\text{Xmax}+\text{Xmin}} + 1$$ (In directly related morphometric parameters)………………. (3)

$$\textbf{Hazard degree} = \frac{4(\text{X}-\text{Xmax})}{\text{Xmin}-\text{Xmax}} + 1$$ (In inversely related morphometric parameters)……… (4)

4. Results and Discussion

4.1 Topographical parameters:

The Digitial Elevation Map (DEM) for the study area has been classified into five zones, for the elevation map, the maximum altitude is close to 352m in the north eastern part, while the minimum elevation is 35 m in the outlet of the basin (Fig. 5). As shown in Fig. (6), the slope degree map demonstrates the lowest slope range (0-3.2) with an area of 132.41 km^2 in the upstream and the downstream of the Wadi, while in the middle of the Wadi is the highest slope range (21.7 – 45.7) with an area of 5.02 km^2.

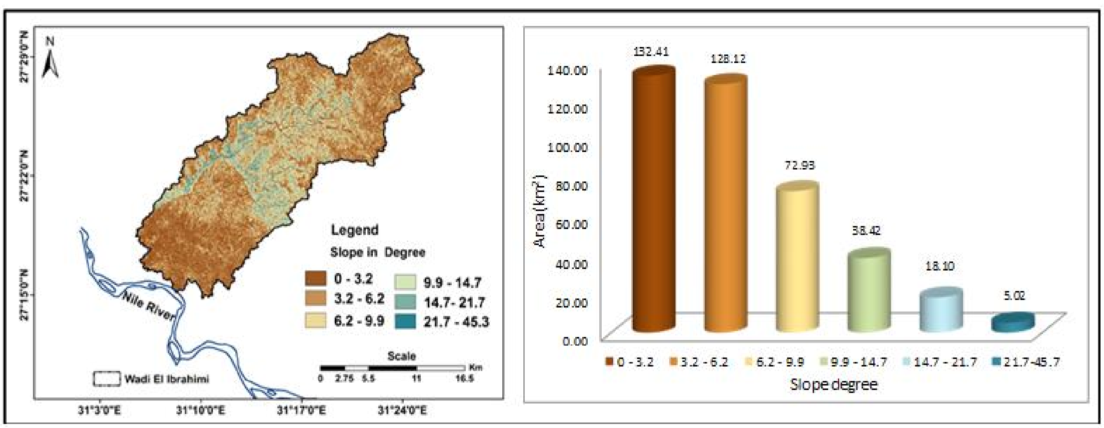

Fig. 6: Slope degree map and histogram of Wadi El Ibrahimi

The aspect may be called slope direction or aspect map. It is one topographic parameter for assessing landslide susceptibility mapping is this one. Clerici *et al.,* 2006 stated that aspects affect exposure to wind, sunlight, and precipitation, which in turn has an impact on other elements that cause landslides, like soil moisture, vegetation cover, and soil thickness. In the study area, the aspect map was classified into nine (9) classes, and these are flat, northeast, east, southeast, south, southwest, north, and northwest.

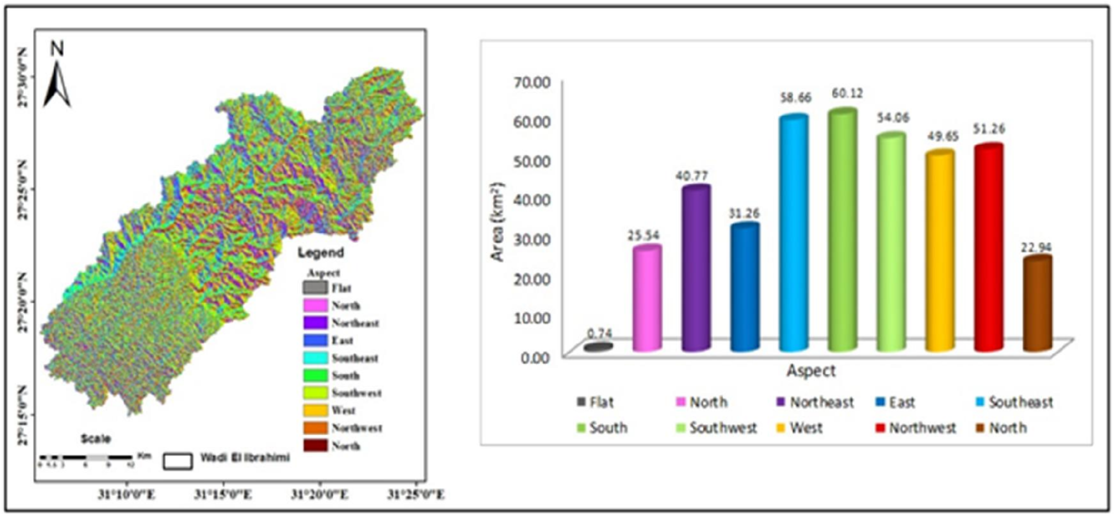

Fig. 7: Aspect map and histogram of Wadi El Ibrahimi

4.2 Morphometric parameters of Wadi El Ibrahimi

Based on the digital elevation model of the shuttle radar topography mission (SRTM, 30 m) resolution and the topographic maps (scale 1: 50000), different morphometric parameters, especially those that characterize the flood hazard degree of the basin, are determined. The morphometric parameters were measured and calculated using GISmap software, according to the concepts defined by Horton (1932 and 1945), Strahler (1957), and Schumm (1956), as shown in Table 1 and Table 2.

Bifurcation Ratio (Rb) and Weighted Mean Bifurcation Ratio (Rbw)

In general, in natural settings, Rb rarely approaches the theoretical minimum value of 2.0 (Joji *et al.,* 2013). According to Saad *et al.,* (1980), the bifurcation ratio influences the rate of drainage water and is correlated with the geometric shape of the basin, specifically its elongation and circularity. Because of their elongated structure and ability to let runoff pass through over lengthy periods, basins with high Rb have more opportunities to feed groundwater. Low-value RB basins, on the other hand, are circular and permit surface runoff to pass quickly, creating a sharp peak. The bifurcation ratio and weighted mean bifurcation ratio in Wadi El Ibrahimi and its subbasins range from more than 3 to more than 5. This means that Wadi El Ibrahimi and its subbasins have geologic structures that do not distort the drainage pattern; the high values indicate a decrease in the flash flood potential of the basin and subbasins and maximise the chance to feed the underlying aquifers.

Stream Frequency (F)

The number of segments of all orders per unit area is known as the stream frequency (F) (Horton, 1945). It illustrates how having more streams per unit area allows runoff to occur more quickly since the network of streams can carry a lot of water. According to Abdel Mogheeth *et al.,* (1985), a high stream frequency value (greater than 0.5) typically provides more opportunities for surface runoff to accumulate. The stream frequency values in the six sub basins under study range from 3.453 km^2 (Subbasin 6) to 4.033 km^2 (Subbasin 5), respectively. These values suggest that the sub basins are not flat, have a high relief, and contain nonpermeable subsurface materials (Ali *et al.,* 2021).

Drainage Density (D)

It reflects the type of surface layer, its permeability, and its relative roughness. It also expresses the proximity of tributaries to the basin and reflects the effectiveness of overland runoff and seepage. Horton (1932) found that in a mountainous region with impermeable rocks and high precipitation, the average drainage density was 0.93 km^{-1} and increased to 1.24 km^{-1}, while it decreased in drainage basins covered by Permeable rocks. Strahler (1964) stated that areas with highly resistant or highly permeable subsurface materials under dense vegetation and low relief form basins with low drainage density. In areas with weak or impermeable surface materials, scattered vegetation, and mountainous terrain, the basins have a high drainage density and have high flows. The drainage density in the Wadi El Ibrahimi and its sub basins ranges between 2.312 in sub basin 6 and 2.656 in sub basin 2 (Table 2). These values are considered high and therefore reflect high topography, impermeable subsurface materials, and reserve vegetation. It may also indicate the limited contribution of local precipitation to groundwater and the possibility of high flash floods.

Length of overland flow (OLF)

Length of overland Ffow is defined as the distance that water flows over the ground surface before it becomes concentrated in the drainage channel (Horton, 1945). The shorter the length of overland flow, the quicker the surface runoff will enter the stream (Horton, 1945). In the study area, it ranges between 1.16 km (Sub basin 3, and sub basin 6) and 1.33 km (Sub basin 2).

Circularity Ratio (Rc) and ElongationRatio (Re)

It is the ratio of the area of the basin to the square of the basin length. The circularity ratio approaches 1 if the basin shape is a circle, and it tends to zero if the basin is rectangular (Miller, 1953). In the study area, the subbasins' calculated values of the circularity ratio ranges from 0.263 (sub basin 1) to 0.36 (sub basin 6). This means that these basins have an elongated shape and low runoff.

Sinuosity (Si)

The sinuosity (Si) is defined by the length of the wadi path (VL) to the shortest distance between the mouth and the source of the stream (LB). As such, it represents the degree of meandering. The straight valley is more effective at flooding than the meandering one. The sinuosity ratio (Si) of the Wadi El Ibrahimi basin is about 1.6, which indicates that this basin has a good chance for groundwater recharge. The Si of study sub basins ranged from 1.3for sub basin 5 to 1.56 for sub basin 1, as shown in Table 2. This reflects that sub basin 1 has the shortest travel time for water flow to the outlet and is more effective in flooding. Sub basin 5 has the longest travel time and a good chance for groundwater potential.

Shape index (Ish)

According to Haggett (1965), the calculated value of (Ish) of the Wadi El Ibrahimi is about 0.34, while it ranged from 0.0034 for sub basin 5 to 0.0228 for sub basin 6. The higher value indicates that the basin length is long which resulted in a good chance for groundwater recharge. While the lower values indicate that the basin length is short which resulted in more flash flood hazard.

Relief ratio (Rr)

According to Schumm (1956), (Rr) is the relation between basin relief (Rf) and its length (LB). The high values of (Rr) indicate a steep slope and high relief, while the lower values may indicate the presence of basement rocks that are exposed in the form of small ridges and mounds with a lower degree of slope. Relief controls the rate of conversion of potential to kinetic energy as water drains through the basin. Runoff is generally faster in steeper basins, producing more peaked basin discharges and a greater erosion process. Both (Rr) and (SI) are directly proportional to flooding and inversely proportional to the time of concentration. The relief ratio in the studied sub basins ranges from 0.003 (sub basin 5) to 0.032 (sub basin 6).

Ruggedness number (Rn)

Rn is the product of extreme drainage density and basin relief; it usually combines slope gradient and length. Rn explains how soil erosion, slope steepness, and drainage density are likely to affect the landforms (Strahler, 1964). Table 2 shows that the sub basins Rn value ranged from 0.188 (sub basin 4, and sub basin 6) to 0.663 (sub basin 1). Flooding is a possibility in high-roughness sub-basins because of their dissection, peak discharge, and channel gradient (Singh and Mukherjee, 2020).

Texture ratio (Rt)

According to Schumm (1956), texture ratio is an important factor in the drainage morphometric analysis which depends on the underlying lithology, infiltration capacity, and relief aspect of the terrain. Smith (1958), classified the texture ratio of the basins into coarse (<6.4 Km^{-1}), intermediate (6.4-16 Km^{-1}), and fine (>16 Km^{-1}). The lower values of texture ratio indicate that the basin has a good chance for groundwater recharge, while the basins of high values, where they are composed of hard rocks that have no ability for water infiltration, have a good chance to produce flash flood (Pareta, and Pareta 2011a). The whole of the Wadi El Ibrahimi basin has a texture ratio of about, while the Rt of its sub basins ranges from 1.667 Km^{-1} (sub basin 6) to 8.04 Km^{-1} (sub basin1). The similarity of the texture ratios of the study basin and its sub-basins is due to the similarity of their lithology and geologic structure. The lower values of the texture ratio for Wadi el Ibrahimi and its subbasins indicate this coarse texture also has a good chance for groundwater recharge.

Slope index (SI%)

The slope is the most important and specific feature of the earth's surface form. The slope map is the most vital parameter of the drainage basin system, where the slope map of the wadi El Ibrahimi was created by using the Surface Analysis Tool in ArcMap10.3. The slope of the topography has a big control and direct influence on the surface runoff accumulation and the concentration-time of the generated hydrograph. Bains of low and mil gradients have a high possibility for groundwater recharge and yield a small volume of surface runoff hydrograph due to the slow velocity of overland flow. The Dominant slope ranges between 0° and 3.2° (33.52%) which means that the Wadi is almost flat. The (SI%) ranged from 0.003 for sub basin 5 to 0.023 for sub basin 6 (Table 2). This means that sub basin 5 has more groundwater recharge potentiality, while sub basin 6 has flash flood hazard potentiality.

4.3 Rainfall – Runoff relationship

The study area was exposed to many floods, the most famous of which were in the years 2010, 2014, 2016, and 2018. Using the SMADA 6.3 program, four scenarios were implemented for the relationship of rainfall and surface runoff according to different rainfall depths for the mentioned four storms. For each storm, the maximum flow, runoff volume, and aquifers recharge was determined Fig. (8), and Table (5).

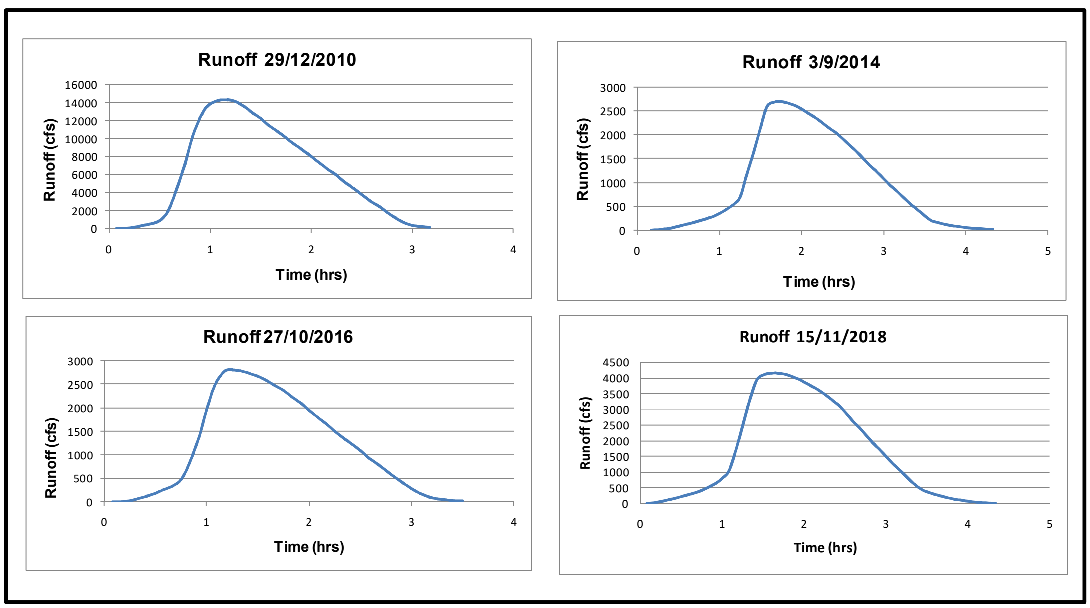

Fig. 8: Hydrograph of Wadi El Ibrahimi during the rainfall storms (2010, 2014, 2016, and 2018).

Table 5: Output parameters of Wadi El Ibrahimi for hydrograph generation using SMADA 6.3 based on SBUH method

Parameters / Date	Max flow (m^3/sec)	Runoff volume (m^3 x 10^6)	Time of peak (hours) (T_p)	Time of base (hours) (T_b)	Recharage (m^3x 10^6)
11/29/2010	405.472	0.243	1.08	3.17	1.006
9/3/2014	345.763	0.207	2.75	6	2.150
10/27/2016	79.371	0.047	1.17	3.5	——
15/11/2018	117.600	0.070	1.67	4.33	0.615

4.4 Evaluation of flash flood hazards

Application of equations (3) and (4) was used to determine the hazard degrees for each of the subbasin parameters of the Wadi El Ibrahimi. For each subbasin, the hazard degrees for its parameters sums to the final flood hazard of that subbasin (Table 6). As Table 6 illustrates, these values ranged from 19.64 for subbasin 5 to 30.62 for subbasin 1. Based on the computed values, the estimated subbasins hazard degrees can be divided into four categories: Basins of very low hazard degree (subbasin 5); basins of moderate hazard degree (subbasin 3); basins of high hazard degree (subbasin 2, sub basin 4, and sub basin 6); and basins of very high hazard degree (subbasin 1), as shown in Fig. 9.

Table 6: Hazard degrees of the effective parameters of sub basins of Wadi El Ibrahimi

Morphometric Parameters	Sub basin1	Sub basin2	Sub basin3	Sub basin4	Sub basin5	Sub basin6
Basin Area	5.00	1.98	1.45	1.14	1.14	1.00
Weighted mean bifurcation ratio	3.22	4.81	5.00	3.98	3.22	1.00
Drainage density	1.34	5.00	1.00	3.01	1.38	4.47
Slope index	2.07	1.07	3.78	4.50	**1.00**	5.00
Stream frequency	2.39	1.74	3.79	2.66	5.00	1.00
Ruggedness No	5.00	4.69	4.12	3.48	1.00	3.45
Texture ratio	5.00	2.60	2.17	1.35	1.51	1.00
Relife ratio	1.94	2.20	2.31	3.53	1.00	5.00
Shape index	4.65	2.20	1.00	3.71	4.39	5.00
Summation of hazard degree	30.62	26.29	24.62	27.36	19.64	26.92
Hazard degree	5	4	3	4	1	4
Basin relative hazard degrees (BRHD)	Very high	High	Moderate	High	Very low	High

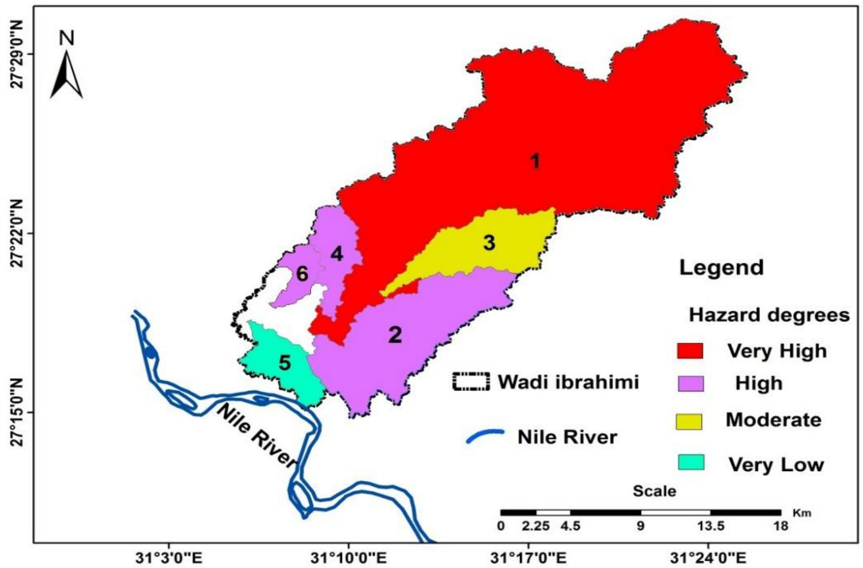

Fig. 9: Map of flash flood hazard degree for Wadi El Ibrahimi sub-basins

4.5 Recommendetions for reducing flash floods damages in the study area

The Wadi El Ibrahimi was exposed to many floods events, which led to the destruction of infrastructure, which requires more accurate measures and warning systems. The present study suggests and recommends some measures applied to mitigate or at least reduce the massive losses and destruction caused by torrential floods such as (Fig. 10):

1- Digging retention tanks along high-risk valleys is of outmost importance to reduce the destructive effects of flood waters accumulating downstream.
2- Establishing detention dams at the outlets of the main channels to allow recharging groundwater aquifers and reduce the amount of lost water flowing into the Nile River.
3- Installation of cisterns at the exits of the main channels allows for the storage of large quantities of surface water to be benefited in sustainable development, agriculture, and drinking.
4- Installing well-turbulent rain stations to obtain more accurate estimates.

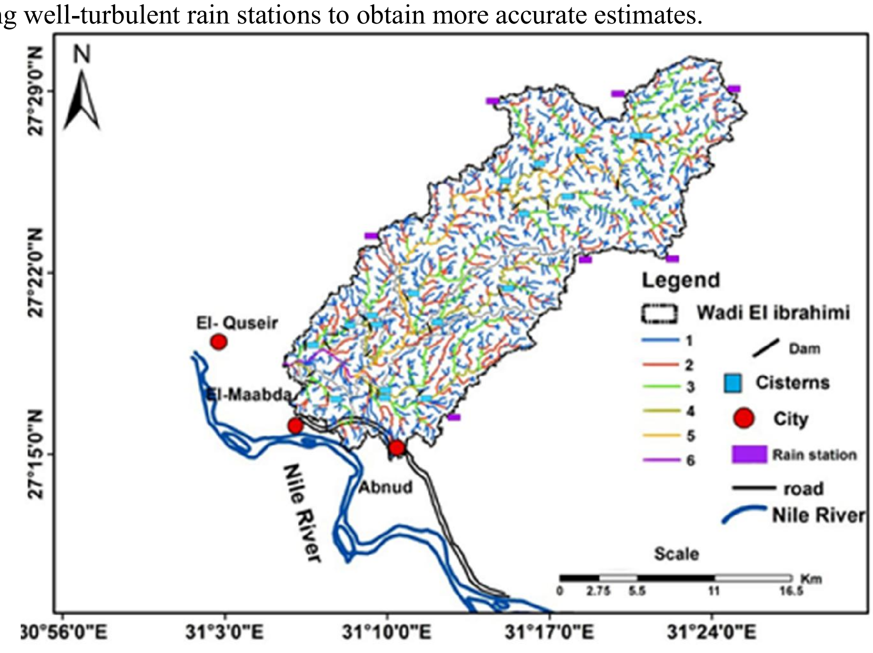

Fig. 10: Proposed dams and cisterns in Wadi El Ibrahimi

5. Conclusion

East of the Assiut governorate, next to Abnoub city, lies Wadi El Ibrahimi, this is situated in the middle part of the Eastern Desert. The sedimentary sequence exposed in the study area is composed of the Tertiary rocks (Eocene and Pliocene) and the Quaternary alluvium. The Wadi El Ibrahimi comprises three main geomorphological units: the structural plateau, Piedmont Plain, and Nile Flood Plain. The Quaternary and Pliocene water-bearing sediments are of particular importance in the area of the study. The Quaternary aquifer has a wide geographical distribution in the Nile valley and the adjacent desert fringes. The SMADA6.3 program was used to create hydrographs for the four storms with varying rainfall depths (29.63, 34.94, 11.56, and 18.11 mm) and return periods (2.4, 1.71, 1.5, and 1.33 years), respectively, in order to determine the maximum flow and runoff volume. The volume of runoff obtained varies from 0.243 million m^3 to 0.07 million m^3. Using ArcGis, Wadi El Ibrahimi was divided into 6 sub basins. David's method was used to determine hazard degrees for the detected subbasins of Wadi El Ibrahimi. The hazard degrees can be divided into four categories: basins of very low hazard degree (sub basin 5); basins of moderate hazard degree (sub basin 3); basins of high hazard degree (sub basin 2, sub basin 4, and sub basin 6); and basins of very high hazard degree (sub basin 1). Recommended Construction of diversion dams at the outlets of the main channels to allow recharging groundwater aquifers and reduce the amount of lost water that runs to the Nile River. Also, the installation of cisterns at the exits of the main channels allows for the storage of large quantities of surface water, as well as the installation of well-turbulent rain stations for more accurate estimates.

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