FLOOD RISK STUDY

MASDAR INFINITY POWER HOLDING 200MW WIND POWER PROJECT IN GULF OF SUEZ

AUGUST 2023

FINAL

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Executive summary

This report tackled a detail assessment of flood risk expected within the project site during rainstorms through some integrated models based on data related to; the physical characteristics of the region, the prevailing climatic conditions taking into account the global worming phenomena and its expected impact in the future especially the unexpected increase in rainfall intensity. The extent of the surface runoff passing directly in the drainage lines that cross the site and the highly dangerous places within the site will be determined. Develop all suggestions that would overcome and mitigate the negative impact of floods and how to protect facilities and people live in the event of heavy rainfall.

The data that used to complete this work included published data in different sources, the rainfall data recorded during the period (2016 – 2021) from the closest meteorological stations, climate satellite images of the region covered the period (2015 – 2021), SRTM satellite images of the project area, and intensive site visits.

ARC-GIS software has been used to design the flood risk assessment models based on morphometric analyses of the drainage basins, Satellite Visual Analysis especially climatic satellites, and rainfall data and maximum rain fall intensity data recorded in one day in the area. The severity and likelihood of the expected floods were determined based on two different approaches. The first; determination of severity and likelihood of the expected floods in the drainage basins crossing the project site compared with all Red Sea and Gulf of Suez basins, while the second was by comparing the drainage basins crossing the site with the nearby basins that lie under the same conditions. The outcomes of the constructed models were validated through site visits to observe the locations that show traces/remains of natural phenomena and indications on the intensity of rain, the floods occurrences, the extent of the capacity of these floods and their impact on the surrounding environment. Also, to confirm all the processed models and proposed mitigation measures on ground.

Analyses of climatic satellite images reveal an increase in the rate of change in the average expected precipitation on the study area due to the increase in the rates of passages of the strong rainstorms in the region which could be one of the consequences of climate change. The heavy accumulations of clouds that cause rain are concentrated in the central and eastern parts of the study area. The occurrence of torrential floods at the exits of the drainage basins is largely related to the amounts of accumulated clouds and the rain that falls on the elevated areas in the far west and southwest of the region (Red Sea mountain range). Rainfall on the middle part of the three studied basins crossing the project site does not cause torrential rains, which may threaten the facilities on the site. This is because the project site is far from the exits of the three basins.

Rainstorm model was designed based on the recorded rainfall data of the 6 years (2016 – 2021) of Suez and Bir Arida. It is important to note that, in October 2016 when the study area received heavy rainfall that resulted in strong flooding, the recorded rainfall at Bir Arida station (to the NW by about 120 km from the site), and Suez stations (to the N by about 200 km from the site) was 3.4 and 0.8 mm respectively. In the year 2020 when the above two stations recorded 9 and 25.4 mm rainfall depths, respectively, the area of study did not subjected to nay dangerous flooding. Global worming phenomena has been taken in consideration when designing the rainstorms and their returned periods through; 1) increase the amount of the recorded precipitation by about 25%, and 2) the calculation based on the maximum rainfall depths recorded in one day in the two stations (March, 2020) rather than the value recorded during the occurrence of floods (October 2016). The rainstorms of 1.21, 3.69, 6.88, 13, 19.6, and 28.4 mm precipitation have been expected with the returned periods of 2, 5, 10, 25, 50 and 100 year, respectively. The rain storm that recorded by 9 mm at Bir Arida and 25.4 mm at Suez station could be returned in a period of about 55 year. The rainstorm recorded during the occurrence of flooding in the study area at Bir Arida (3.4 mm) could be returned in 5 years.

After the catastrophic flood event of the year 2016 on the study area, set of mitigation measures were applied along the dangerous drainage basins in the area like, three successive dams along the main stream of Wadi Hawashyia, , group of successive dams with lining the road and placing many culverts underneath to prevent the flow of water above the road along Wadi Abu Had, a dam with artificial lake at the mouth of Wadi Al Darb, and Constructing concrete fences with a height of about 1 to 1.5 meters to protect the existing facilities in the tributaries that feeding the main stream from surface runoff along wadi Abo Had. All the above mitigations to great extent save the downstream cities (Ras Ghareb) and infrastructures (asphaltic roads, power stations, and power and communication towers) from the danger of floods and strong surface flow in the drainage lines distributed in the middle and upstream parts of the drainage basins.

Flood risk model based on the morphometric analyses of about 38 parameters of three studied basins using SRTM images processed by ARC-GIS. Tacking in consideration the historical floods recorded in the area. The expected severity and likelihood of dangerous flooding in three studied basins was calculated in the frame work of the whole Red Sea and Gulf of Suez basins. Then the three studied basins are of low flood risk severity. But, when calculating the flood severity of the three basins according to their morphometric parameters, the basins of Wadi Kharim and Al Darb could be expected surface flow of medium risk along the drainage lines crossing the project site, while, the basin of Wadi Abu Khashba falls into the category of low-risk runoff. The results of the model are reasonable as they are in line with most of the previous studies conducted on the drainage basins of the region.

The intensive and detailed site visits revealed that, the site is characterized by; the drainage lines (rainfall assembly drainages) of wadi Al Darb, Wadi Kharim and wadi Abu Khashba are shallow and wide. The locations for placing turbines are in the elevated areas away from any drainage lines. These area are very save no matter how intense the runoff. There are no indications on the ground showing the presence of severe surface flow, even in main streams of the drainage lines. There are no indications of the impact of this year rainy season on the site like severe erosion in the access paved roads along the site.

The most important recommendations of this study are:

1. Protection of site, turbines, and pylons: Onsite turbines and VPs are considered safe and are far from the expected areas of surface runoff (the drainage lines) during severe rainstorms. According to the locations of the turbines, which are mostly placed in elevated locations, they are considered naturally protected. However, this assessment should be refined during the detailed design to identify the specific turbines which may need additional or supplementary protection. This approach should also be conducted for the transmission line pylons to identify those which may require additional means of protection.
2. Site access paved or asphaltic roads: As for the protection of site access roads, the drainage lines in which surface runoff may occur are very wide and shallow reflecting the weak to medium runoff intensity, not concentrated in narrow and specific paths. Therefore, impacts on the paved and asphalt access roads within the site is not significant as there is no evidence of violent drifts in the paths of the roads crossing drainage lines. Therefore, in some places, simple cement culverts with a diameter of one meter at most

can be placed below the road crossing these valleys in specific places to accommodate the surface flow and prevent its flow up the road.

3. Electricity cables: Cables need to be buried underground at a depth of one meter, while taking measures for protection against subsurface infiltrated water by ensuring that adequate insulation is installed on all subterranean cables.

1. Introduction

The project site is situated in Ras Ghareb area on the Gulf of Suez, approximately 18 km to the west of the city. This area is part of a coastal strip that acts as a barrier between the Red Sea mountain range to the west and the watercourses of the Red Sea and the Gulf of Suez (refer to Figure 1). It is characterized by layers of clastic sediments, resulting from the erosion and weathering of exposed rocks in the mountain range, primarily transported by rainfall. The region extends around 35 km from the Gulf coast to the western foothills, gradually sloping eastward at a slower rate compared to the mountainous terrain.

Due to the clastic composition of the sediment covering this area and the significant difference in elevation between this region and the mountainous areas to the west, coupled with the impermeable nature of the rocks comprising the mountain ranges, rainwater tends to accumulate in numerous basins. This accumulation leads to surface runoff, forming multiple Wadies that flow towards the Gulf of Suez and the Red Sea. The intensity of surface runoff is influenced by several factors, including the size of the drainage basin, the length of the Wadi, the slope gradient, the characteristics of the rocks and sediments, and the intensity of rainfall. In certain basins and Wadies, this flow can develop into severe floods known as flash floods, posing significant risks to both life and infrastructure located along the course of these Wadies or at their outlets

Figure 1: Location of the project site in the coastal area between the Red Sea Mountains and the Gulf of Suez[1].

In the area surrounding the project site, there are many dry wadies that represent different drainage basins in natural and morphometric characteristics, which led to a variation in the intensity of floods that occurs during rain storm (Figure 1). Wadi Hawashyia, Wadi Abu Had, and Wadi Al-Darb are among the most dangerous Wadis in the area, as many flood events were recorded in these wadies, prompting the government to establish many applications and measures to mitigate the flood hazards. The government construct three successive dams with with artificial lake along wadi Hawashyia, one dame at the outlit of wadi Al Darb, and lining of the asphalt road passing through Wadi Abu Had, with the construction of many diversion culverts to protect the road in many locations. Protect the communication and electricity towers from the surface flow by constructing a concrete fence around the bases of them. Due to the presence of these wadies and the dangerous floods that have been recorded in area, a detailed study has been conducted to assess the risks of the expected floods in the project site, taking into account the consequences of global climatic changes.

2. Scope of Work

The primary objective of this report is to conduct a comprehensive study on the anticipated floods within the project area during rainstorms. The aim is to assess the level of risk associated with surface runoff that directly passes through the project site via the drainage lines intersecting it. Furthermore, it is crucial to identify high-risk areas within the site. The

[1] Note the numerous drainage lines running to the Gulf water crossing the whole area and the most obvious drainage are Wadi Hawashyia, Wadi Abu-Had and Wadi Al-Darb.

report will provide recommendations and strategies to mitigate the adverse effects of floods, safeguarding both infrastructure and residents in the event of such occurrences. A model will be developed to evaluate flood risk by considering the natural characteristics of the region, prevailing climatic conditions during the current climatic cycle, and accounting for dynamic climate changes and their resulting impacts, particularly the unforeseen escalation in rainfall intensity.

3. Methodology

In carrying out the assessment, the consultant carried out the following activities:

a. **Previous work and literature review:** Collection and review of available published articles, internal reports ... etc within the area, on climate, rain, etc., and the flash flooding records. (

b. Shuttle Radar Topography Mission **Satellite Visual Analysis:** Satellite visualizations provide a suitable means for estimating the amounts of rain that fell anywhere on the surface of the Earth by tracking satellite images, especially climatic satellites. This helps in monitoring various climatic phenomena, including the phenomenon of rain. So in addition to the 6-year records that will be collected from the active weather stations in the area (Suez and Ber Arida), the rainfall data will be extracted from climate satellite images by Neural Network Models.

   The analysis of climate satellite images allows obtaining data of various elements such as rain, as the sources provide data and measurements of the amount of rain on a daily, weekly, monthly, and yearly basis. This data is used after extracting it to track the movement of rainstorms and draw a hydrograph of rain, as well as the possibility of determining both the volume of rain and the intensity of rain according to mathematical equations. This model is based on calculating rainfall using GridSat-B1 infrared data and adjusting it using the monthly global climate data product. The extraction process will be done through the following steps:

- Download climate satellite data for the previous ten years

- Rain monitoring and tracking in the area was achieved through the utilization of CPC (Cartesian Perceptual Compression) and NOAA (National Oceanic and Atmospheric Administration) satellite images. The following procedures are involved:

▪ Gathering monthly average rainfall data for the study period and creating corresponding maps that illustrate the amount of rainfall for each month.
▪ Tracking severe rainstorms experienced in the region by analyzing the rainfall depth and intensity of each storm.
▪ Utilizing the gathered data to determine the probability and recurrence intervals of severe rainstorms.
▪ Estimating the potential magnitude of future rainstorms.
▪ Generating hydrographs to depict hydraulic drain values within the basin.
▪ Calculating hydrological factors of the basins and determining the water budget of the wadies, including evaluating their potential hazards.

c. **Installed level gauges data:** Collection of real rainfall during the period (2016 – 2021**) of Suez and Bir Arida stations from the General Authority of Meteorology.**

The integrated record of the rainfall history represents the area of the project site that is collected from two meteorological stations: Bir Arida station, which is located on the Kuraimat Zafarana road and Suez station. While a third station, namely, San Antonio station is also located in the close to the project location, it has been discontinued since 1986. Therefore, the Suez and Bir Arida stations were relied upon as the two closest weather stations to the area (Figure 2). The data obtained from the General Authority of Meteorology represent records of the past 6 years records from Suez and Bir Arida stations concerning the following rainfall parameters for the 6 rainy months (Jan, Feb, Mar, Apr, Oct, Nov and Dec.):

- The number of rainy days
- Rainfall intensity
- Deluge

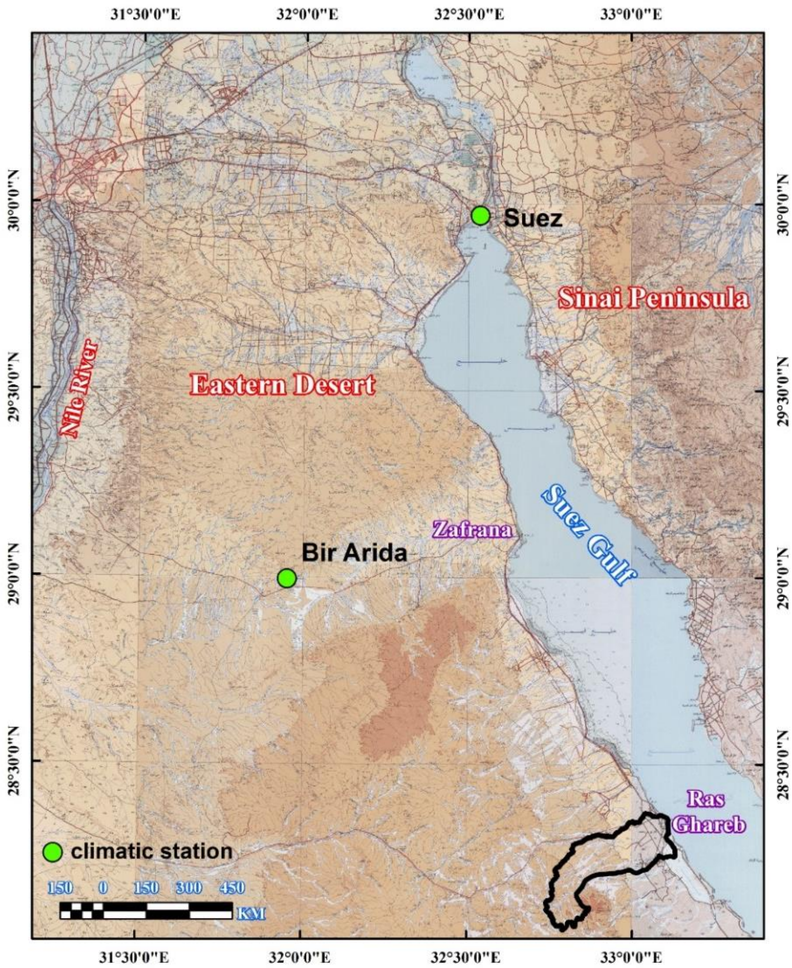

Figure 2: The weather stations closest to project site

d. **Topographic and Morphometric Analysis** of the drainage basins in the area was carried out based on the Shuttle Radar Topography Mission (SRTM)/ The Digital Elevation Model (DEM) of the area satellite images of Egypt, using ARC-GIS software, and maximum rain fall intensity data recorded in the area. Then the severity and likelihood of the expected floods was determined.

e. **Validation field visit** to encounter any natural phenomena in the area that indicate the intensity of rain, the places where floods occur, the extent of the capacity of these floods and their impact on the surrounding environment. Also, to validate all the processed models and proposed mitigation measures on ground.

f. **Flash Flood Risk Assessment Model**: The model is carried out using the inputs from Satellite Visual Analysis for climatic data, real rainfall data collected from the Suez and Bir Arida Meteorological stations and Morphometric analysis of the SRTM.

g. **Model advantages, limitations/sensitivities**

Flash flooding is considered one of the most severe natural disasters, and is responsible for sizeable social and economic losses, as well as injuries and death. Flood Risk assessment, which assesses areas susceptible to flooding, has proved to be an effective tool for managing and mitigating flash floods.

The study aims to introduce the methods to determine the weights of the risk severity and likelihood. In this regard, the Consultant proposed a methodology to assess flash flood risk in a GIS environment, through the analyses of the climatic satellite images, analyses of the actual recorded rainfall data, examining the building up thunderstorms at different return periods based on the maximum received rainfall in one day and taking into consideration the impact of climate change on the rainfall intensity, and morphometrical analyses of the drainage basins. Historical flood records over the area were also referenced. The validation against the historical flash flood data indicated a high reliability of this method for comprehensive flash flood risk assessment.

Both qualitative and quantitative validation of the assessment results were used. To begin the qualitative verification, the Consultant normalized the historical data of flash flood events, and then summed the normalized values to generate the historical flash flood in the area. The qualitative verification analysis was realized by comparing the expected rain fall from the historical satellite images, and the historical recorded data. Hence, the quality of climatic satellite images and real data as well as remote sensed data is critical to flash flood assessment.

In addition, the proposed approach has some limitations/considerations such as:

1. The accuracy of the models are highly dependent on the reliability of the climatic satellite and DEM images. To overcome this limitation, the Consultant downloaded internationally recognized climatic data .
2. Models are only as good as the inputted rainfall data, which should obtained from local meteorological authority.
3. Not adopting unidentified softwares in the work of the flood assessment models.
4. Varied trusted sources need to be used to obtain historical flood records, like published scientific articles, local authorities, public consultations … etc.
5. Detailed field work should be done after modeling processes to validate the output of the models.
6. The maximum rainfall intensities used in modeling process was slightly overestimated due to the unexpected impact of climate change on the rainfall intensity. This is also part of the reason why the risk in economically developed areas is overestimated.

When compared to other alternatives, the proposed methods have greater reproducibility and applicability, and can obtain relatively good evaluation results based on basic theories and simple operation processes. There are reasons to believe that this method will offer preferable assessment results with the support of high accuracy and abundant data.

4. Location

The project site is located on the western bank of the Gulf of Suez, about 155 km north of Hurghada. The nearest settlements to the site are Ras Ghareb City to the east by about 18 km, where Zafarana city is located at about 120 km north of the site (Figure 3). The available site area is about 80 km^2 at an altitude of about 450 m (amsl). The northern end of the Red Sea elevated mountains run in NW-SE at distance of about 8 km to the western boundary of the project site at an altitude of about 1100 m (amsl) with a slpe pattern of about 0.8.

Figure 3: Location of the project site

5. Climate

The climate of Ras Ghareb area is semi-arid, characterized by hot dry summers, moderate winters and very little rainfall (Salah etal., 2021). The climatic data in this study was collected from the world meteorological weather organization and from Hurghada Weather Airport Station (the nearest weather station to Ras Ghareb).

5.1 Temperature

The mean maximum temperature over a 30-year period (1971-2000) is recorded as 46°C, with an average maximum temperature of 27.0°C. Additionally, the mean minimum temperature is documented as 18.74°C (Table 1).

Table 1: The meteorological parameters during the period 1971-2000 at Hurghada, the nearest weather station to Ras Ghareb (Salah etal., 2021)

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Av. annual
Av. Highest temp. °C	30	32	35	40	43	46	44	42	43	43	35	32	46
Av. lowest	11	11.4	14	17.8	21.9	24.8	26.4	26.2	24.2	20.9	16.6	12.5	18.74

temp. °C													
Av rainfall mm.	0.4	0.02	0.3	1	0.04	0	0	0	0	0.6	2	0.9	5.26
Av RH%	48	46	46	43	42	41	45	46	48	53	51	51	46.67
Sun rise Hs	279	290	310	300	341	360	403	372	330	310	270	279	3844

The range of temperature was 7°C during January and 46°C in May 2016 and the mean monthly temperature was 26°C (Table 2). The mean high temperatures reached 26 °C, while the average minimum temperatures were 21°C in 2016. Year 2016 was particularly chosen since it was a year that witnessed violent torrents occurred that hit Ras Ghareb, and as a result, dams were built in Wadi Hawashia, Abuhad, and Al-Darb.

Table 2: The values of temperature, wind speed, rate of precipitation, and pressure at sea level during the months of 2016 as recorded in the weather station in Hurghada International Airport(Salah eal., 2021).

Parameter	Max	Avg	Min	Sum
Max temperature	46. °C	32 °C	17 °C	
Mean temperature	32 °C	21 °C	7 °C	
Min temperature	32 °C	21 °C	7 °C	
Heating degree days (base 65)	10	1	0	199
Cooling degree days (base 65)	60	15	0	5561
Growing degree days (Base 50)	75	30	5	10859
Dew point	29 °C	11. °C	-22 °C	
Precipitation	40.9 mm	0.1 mm	0.0 mm	40.89 mm
Wind speed	74 km/h	19 km/1	-	-

5.2 Wind

The highest wind speed recorded during 2016 at Hurghada weather station was 74 km/hr, with an average of 19 km/hr (Table 2).. The prevailing winds blowing on Ras Ghareb in the Red Sea Governorate are the N or NE winds summer and autumn or S in winter[2]

5.3 The Relative Humidity

The mean annual Relative Humidity % fluctuated between 41% and 51% during the period of 1971-2000, with a total average of 46.67% (Table 1). Notably, the air humidity experiences a significant decrease when the country is exposed to the Khamaseen winds, which typically occur from March to June. These winds are characterized by being hot, dry, and dusty, often causing the stirring of fine sand to the extent of obscuring visibility. Moreover, during this period, the humidity levels are notably low. The decrease in humidity is often associated with weather

[2] GAENS 2009 Hurghada International Airport Meteorological Station

systems such as depressions from the Mediterranean and North Africa, or weather conditions that lead to instability during the spring season.

5.4 Sunshine

Hegazy and Effat (2010) reported that the mean range of the monthly percent of sunshine hours was 65% to 70% in winter months and 80–85% in summer months as given for the period 1987-1996 at Suez Marine Meteorological Station. It was also mentioned that their investigated area, which included Ras Ghareb, has a high solar radiation intensity ranging from 1.900 to 2.600 Wh/m^2/year. The mean sun shine during the period 1971-2000 at Hurghada was 320.33hr/month (Table 1).

5.5 Rainfall (Precipitation) and Evaporation

Based on data obtained from the meteorological station at Hurghada International Airport, it was observed that the highest monthly total annual rainfall was recorded at 40.89 mm during October 2016. In contrast, most months of the year had a mean lowest rainfall of 0.1 mm (Table 2). On the other hand, the mean annual rainfall over the period 1971-2000 amounted to approximately 2 mm/year (Table 1).

Additionally, the annual evaporation rate was measured at 300 mm, with the highest evaporation rates occurring in June and July, as reported by the Suez Marine Meteorological Station between 1987 and 1996.In recent years, there has been a noticeable increase in the frequency of flash floods in Egypt, resulting in loss of life and significant damages. The occurrence of destructive flash floods has been documented between the years 1972 and 2016, as depicted in Table 3.

Table 3: Historical records of flash floods along the coastal areas of the Red Sea

Date	Area	Recorded Damages & References
October, 2016	**Ras Ghareb**	**Death of tens of people as well as damage to infrastructures and properties (El Nazer etal., 2017)**
Feb. 2015	**Sinai, Red Sea region**	**Road damages**
May, 2014	**Zafarana, G. Zeit, Taba, Sohag, Aswan, Kom Ombo Safaga**	**Dam failure at Sohag, road damages El Wafd Newspapers**
2013	**South Sanai**	**2 deaths, road damage**
2012	**W. Dahab , Catherine area**	**Dam failure, destroyed houses**
17-18 January 2010	**Along the Red Sea**	**Water Resources Research Institute (WRRI)-Nature of damage is not known**
Oct. 2004	**Wadi Watier**	**Road damage**

May 1997	Safaga and El Qusier	- Information and Decision Support -- - Center in Red Sea Governorate, 2009. --The National Authority for Remote Sensing and Space Sciences (NARSS) – Red Sea Governorate, 1997. The impacts were erosion and cuts in the main roads.
November 1996	Hurghada and Marsa Alam	
November 1994	Dhab, Sohage, Qena, Safaga, El-Qusier	
August 1991	Marsa Alam	- Reports of Red Sea Governorate, 1994. - Red Sea Environmental Profile, 2008
20 October 1990	Wadi El Gemal between Marsa Alam and Shalateen	
23 October 1979	Marsa Alam and El Quseir	
Jan. 1988	W. Sudr	5 Deaths
Oct. 1987	South Sanai	1 Death, Roads Damage
May., Oct. 1979	Aswan, Kom Ombo, Idfu, Assiut, Marsa Alam, El-Qusier	23 deaths and demolished houses
Feb. 1975	W. El-Arish	20 deaths, road problems
1972	Giza	Destroyed houses, roads and farms

6. Geomorphology and Topography

6.1 Geomorphology

The project is located in an area with many drainage basins and dry wadis flow to the Gulf of Suez at and to the south of Ras Ghareb city. The area belongs to three drainage basins, namely the Wadi Al-Darb basin, Wadi Kharem basin and Wadi Abu Khashba (Figure 4).

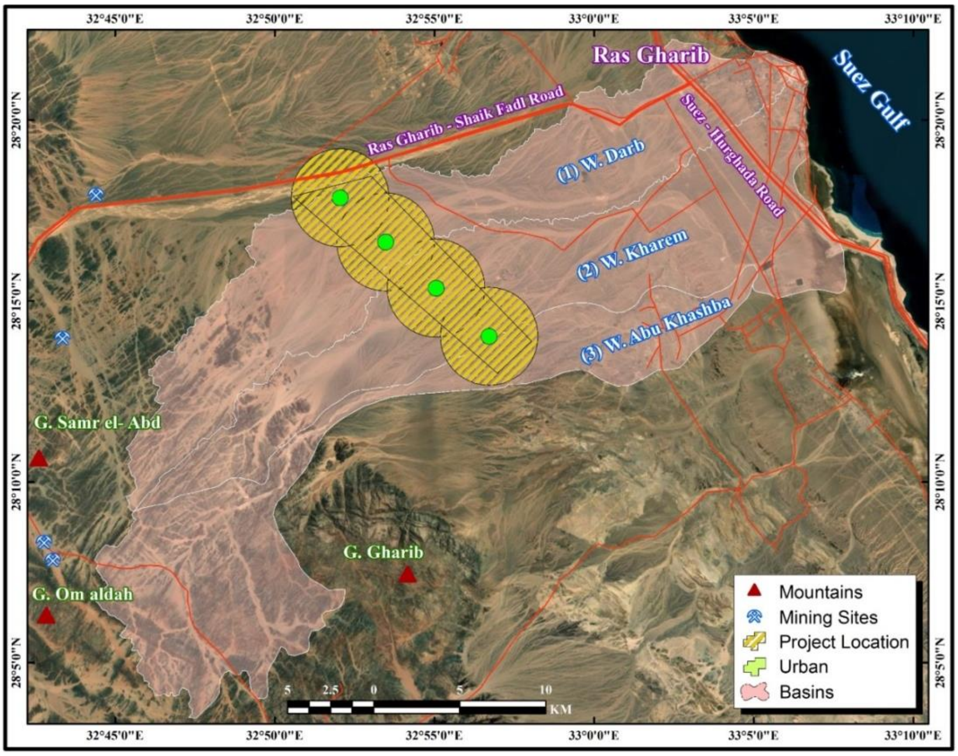

Figure 4: Map indicating the location and morphology of the three basins to which the project site belongs, as it is crossed by many drainage lines of those three basins

From the north, the area is bordered by the water divide area with the Abu Had basin, while from the south it is bordered by Wadi Ghareb basin, from the southwest by Wadi Qena basin, from the west by Wadi Tarfa basin, and from the east by the Gulf of Suez. Astronomically, the study area extends between latitudes 20.6˝ 3' 28˚ - 29.6˝ 22' 28˚ North and longitudes 9.7˝ 44' 32˚ -1.3˝ 8' 33˚ East, (Figure 4).

6.2 Topographic Setting of the Area

The project site is located in Ras Ghareb area along Ghareb-El Sheikh Fadl Road to the west of Ras Ghareb city by about 25 km. The site is at the middle part of three drainage basins which are from north to south; Wadi Al Darb basin, Wadi Kharem basin and Wadi Abu Khashba (Figure 4). The diversity of terrain characteristics is well explained in the following:

6.2.1 The Digital Elevation Model of the area (DEM) based on SRTM images

Based on the topographic maps of the area at a scale of 1: 50,000 and 1: 250,000, the digital elevation models provided by the US Geological Survey (with a spatial discriminatory accuracy of 30 m), (Landsat-8 (OLI) 2022) satellite images, and previous studies, a digital elevation model for the was built for the specific project area (Figure 5).

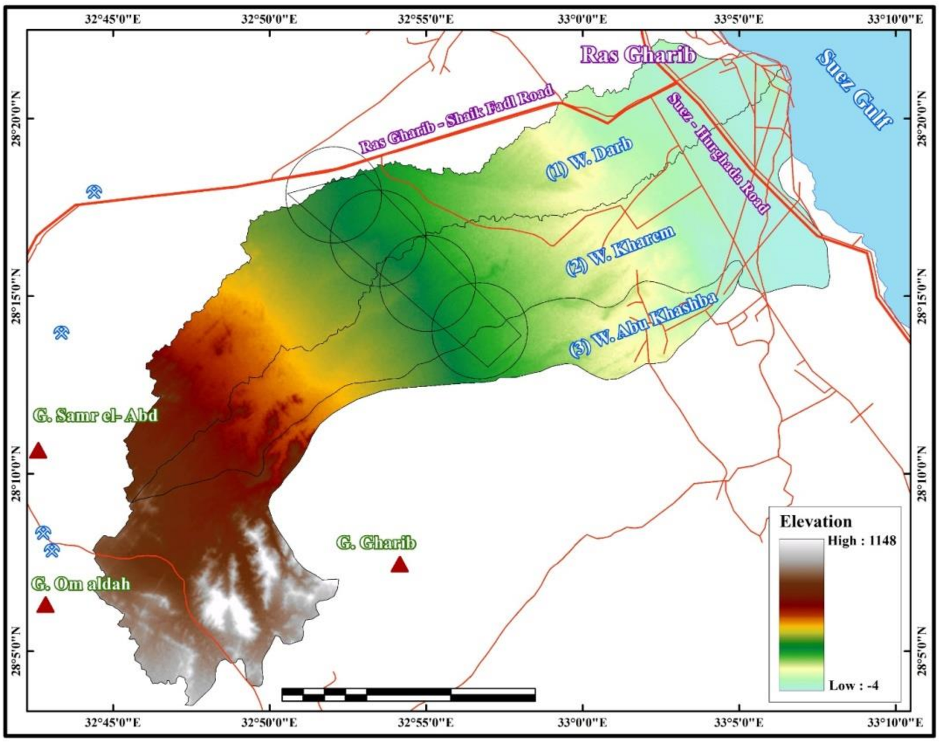

Figure 5: The surface topography of the area

6.2.2 Topographic Data Obtained from Model

6.2.2.1 Overview

Some information drawn from the model include the following:

a. The ground surface elevation of the whole area ranges from -4 meters southeast of the study area at the end of Wadi Al-Darb in the coastal plain of the Gulf of Suez, and 1148 meters where the high peaks are north-south of Wadi Abu Khashba in the heights of Jabal Ghareb (Table 4 and Figure 6).
b. The surface of the study area is graded in terms of height from west to east, as in the Red Sea region and the Gulf of Suez in general, where the surface descends from the mountain peaks in the west towards the coastal plain region in the east.
c. It is estimated that about 110.8 km^2, or about 21.5% of the total area, is located below the level of 100 m. This area constitutes the coastal plain of the Gulf of Suez, as well as the lower reaches of the drainage basins. While 145.6 km^2, or 28.2% of the total area is located above the level of 500 meters as the highest parts of the study area, all of which are located in the western parts of the basins of the region.

Table 4: The level categories of the area

Elevations	W. Al Darb		W. Kharim		W. Abu Khashba	
	Area (Km^2)	(%)	Area (Km^2)	(%)	Area (Km^2)	(%)
<100	62.9	33.9	42.8	23.8	5.1	3.4
100-200	36.7	19.8	27.2	15.2	26.3	17.4
200-300	33.3	18	31.1	17.3	15.6	10.3
300-400	20.8	11.2	31.8	17.7	3.7	2.4
400-500	11.9	6.4	17.6	9.8	3.4	2.3

500-600	11.8	6.4	16.2	9	4.9	3.2
600-700	6.7	3.6	11.4	6.4	19.7	13.1
700-800	1.2	0.7	1.5	0.8	32.5	21.5
800-900					30.9	20.5
900-1000					6.3	4.2
1000-1100					2.2	1.5
>1100					0.3	0.2
Total	185.3	100	179.6	100	150.9	100

d. The elevation categories from 100 to 200 meters cover about 17.5% of the total area, which is the lower parts of the mountain slopes, which represent the lower sector of these slopes.
e. The elevation categories of 200 meters or more cover about 61.0% of the total area of the studied basins. These categories are concentrated to the west of the study area, where the northern Red Sea Mountain ranges.

f. The areas with elevation more than 1000 m cover about 0.5% of the region's and appear in the far west of the region, where the slopes of the main mountain masses such as Jabal Ghareb, Umm Alada and Samar Al-Abd.

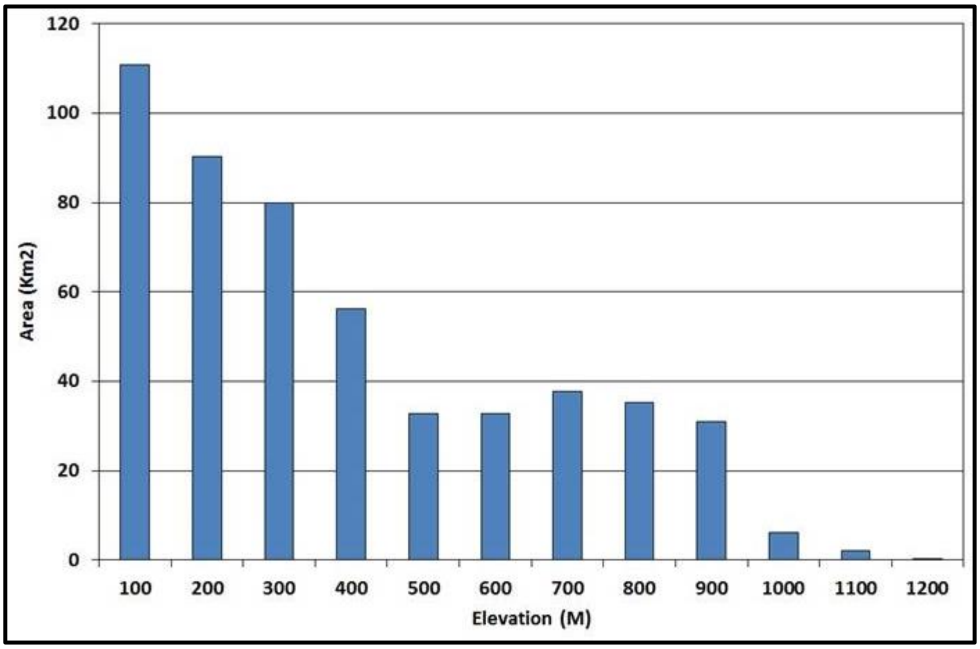

Figure 6: Elevation categories in the study area

6.2.2.2 <u>Surface slope patterns of the area</u>
Surface slope patterns of the area indicate the degree of gradient, which is the angle between the sloping surface of the ground surface and the horizontal plane. The project site is located in areas with gentle slope to sub-horizontal categories, with degree of less than 2.

The change in the shape of the slope gradient from place to another is useful in analyzing the shapes of the surface (Table 5 and Figures 7 & 8) are as follows:

Table 5: The degree of the main surface slope patterns

Slope degree	W. Al Darb		W. Kharim		W. Abu Khashba	
	Area (Km^2)	(%)	Area (Km^2)	(%)	Area (Km^2)	(%)
0-2	66.7	37.1	65.7	35.5	24.2	16
2-5	91.9	51.2	96.9	52.3	56.8	37.6
5-10	15.2	8.5	17.6	9.5	31.8	21.1
10-18	3.2	1.8	3.4	1.8	19.8	13.1
18-30	1.7	0.9	1.1	0.6	14.1	9.4
30-45	0.9	0.5	0.6	0.3	3.6	2.4
>45					0.6	0.4
Total	185.3	100	179.6	100	150.9	100

a) **Horizontal and sub-horizontal lands**: they are areas of ground surface with slope less than two degrees. This category covers about 156.6 km^2 with a rate of about 30.4% of the total area of the three basins. These lands appear in the coastal plain area and the mouths of dry wadies and their drainage lines below the mountain edges.
b) **Gently sloping lands:** They are those surfaces whose degree of slope range between (2-5 degrees) and cover about 245.6 km2 with a rate of 47.6% of the total area of the three basins. These lands appear as more or less horizontal plains on the sides of the drainage lines and cover most of in the west of the study area.
c) **Medium-slope lands:** The ground surface slope of these ranges between (5 -10 degrees) and cover about 64.6 km2 with a rate of about 12.5% of the total area. These lands appear at the west where the foot slopes of the dissected hills to east of high elevated areas.
d) **The lands above medium slope:** These areas are of surface slope ranges between (10-18 degrees) where they cover about 26.4 km2, with about 5.1% of the total area. These lands appear on the sides of the western heights in the region and along the slopes of the sides of the dry wadis at the western part of the area.
e) **Steep slope lands:** These are the surfaces whose slope varies between (18-30 degrees) and cover about 16.98 km2 with a rate of 3.3% of the total area. These lands appear to the west and represent the foot slopes of the Red Sea Mountains.
f) **Very steep slope lands**: they are the lands whose slope degrees range between (30-45 degrees) and cover about 5.2 km2 with a rate of about 1% of the total area. These lands appear on the sides of the mountainous heights peaks at the west.
g) **Escarpment lands:** those lands whose slope is more than 45 degrees and are represented in the areas of highland peaks surrounding the region from the west and southwest, which have an area of 0.6 km2, or 0.1% of the total area of the three basins.

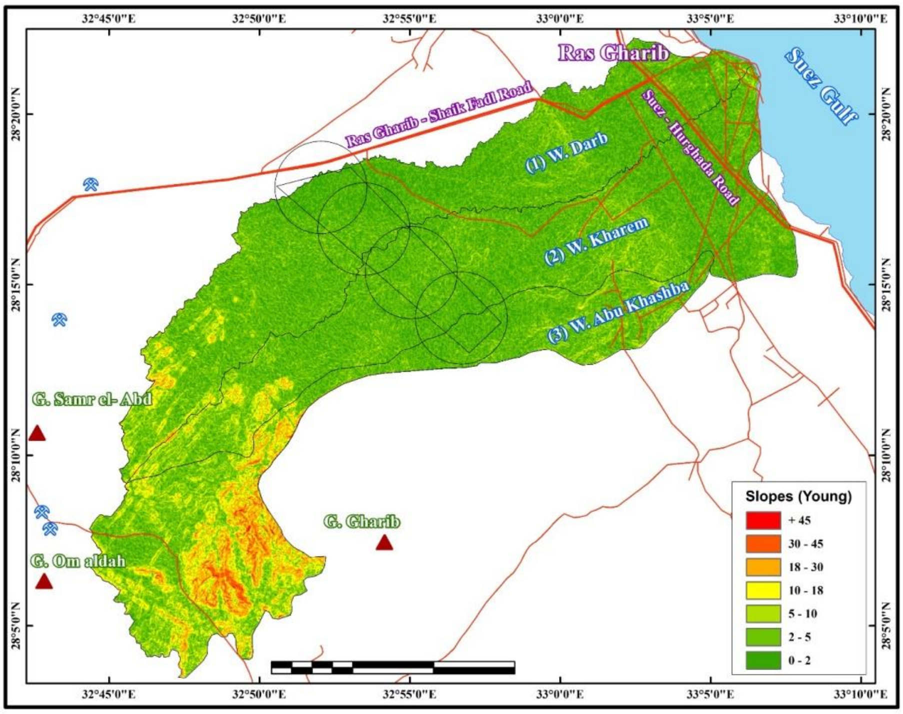

Figure 7: Surface slope pattern of the area

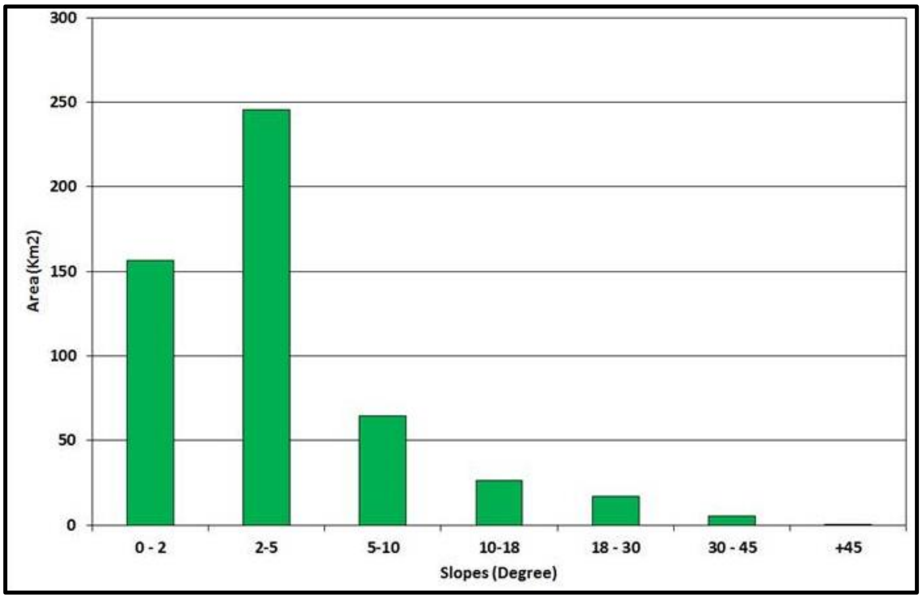

Figure 8: Slope patterns of the study area

6.2.2.3 The direction of slope

The data represented in Table 6 and Figures 9 and 10 reveal the following:

a. **Flat lands:** Flat lands means the lands do not take any slope direction. These lands cover about 13.3 km 2, of about 2.6% of the total area of the study basin. It exists in the coastal plain area and the lower parts of the main streams of the wadies.
b. **North direction**: Lands that have a slope angle ranging between (0 - 22.5 degrees) and cover about 76.1 km^2 with a rate of 14.8% of the total area. These lands appear clearly in

the southern sides of the main streams as well as the northern slopes of Jabal Ghareband Samar al-Abed.

c. **Northeast direction:** Lands that have a slope angle ranging between (22.5 - 67.5 degrees), and cover about 92.5 km^2, with a rate of about 17.9% of the total area. This direction represents the direction of the drainage lines which descend from the southwest towards the northeast.
d. **East direction:** Lands that have a slope angle ranging between (67.5 – 112.5 degrees) and cover about 81 km^2 with a rate of about 15.7% of the total area of the study area. These lands appear on the eastern side of the slopes of the area.
e. **Southeast direction:** Lands that have a slope angle ranging between (112.5-157.5 degrees) and cover about 72.8 km 2 with a rate of about 14.1% of the total area. They appear on the southern slopes of the western highlands.
f. **South direction:** Lands that have a slope angle ranging between (157.5-205.5 degrees) and cover about 50.5 km^2, of about 9.8% of the total area. These lands appear on the southern slopes of the western heights, especially in the southwestern part of the region.
g. **Southwest direction:** l7Lands whose slope angle ranges between (205.5 - 247.5 degrees) and cover about 35.8 km^2, with a rate of about 6.9% of the total area. These lands appear in the southwestern sector of the region.
h. **West direction:** The surface slope angle ranges between (247.5-292.5 degrees) and cover about 36.6 km^2 with a rate of about 7.1% of the total area. These lands appear in the western sector of the region and some parts in the middle and eastern sector.
i. **Northwest direction:** Lands whose surface slope angle ranges between (292.5-337.5 degrees) and these lands cover about 57.2 km^2 with a rate of about 11.1% of the total area. These lands appear in the center and northwest of the study area.

It is clear from the elevation category of the ground surface of the three basins crossing the project site that the site is in the area of moderate elevation gradient (200 to 300 meters). The height varies across the site boundaries from 250 in the west to 200 in the east within a distance exceeding 3000 meters with slope angle of about 0.5 degree. This means that the site is located in sub-horizontal to gentle slope area. The direction of the drainage lines crossing the project site is mainly in the East and North east toward the Gulf.

Table 6: The slope directions in the study area

Slope degree	Wadi Al Darb		WadiKharim		WadiAbu Khashba	
	Area (Km^2)	(%)	Area (Km^2)	(%)	Area (Km^2)	(%)
Flat	5.7	3.2	5.2	2.8	2.4	1.6
North	28.4	15.8	25.8	13.9	21.9	14.5
North East	34.7	19.3	33.7	18.2	24.1	16
East	28.9	16.1	31.1	16.8	21	13.9
South East	23.9	13.3	28.4	15.3	20.5	13.6
South	16.8	9.4	17.5	9.5	16.2	10.7
South West	10.8	6	11.8	6.4	13.2	8.7

West	10.8	6	12.1	6.5	13.7	9.1
North West	19.6	10.9	19.7	10.6	17.9	11.9
Total	179.6	100	185.3	100	150.9	100

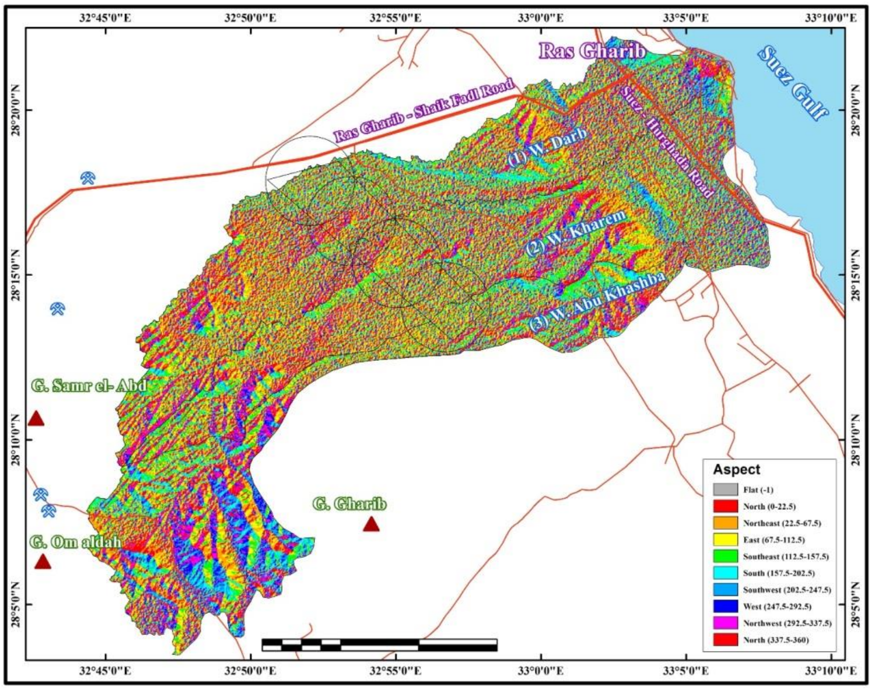

Figure 9: The direction of surface slopes of the basin

Therefore, the project site is in an area with a low slope rate, where the elevated areas with an elevation of more than 1000 meters do not exceed an area of 0.5% of the total watershed areas of the three basins passing through the project. This indicates that the quantities of water that are collected in these basins are limited compared to the large basins in the region, such as Wadi Hawashyia basin, Wadi Abu Had basin or even Wadi Dara to the south.

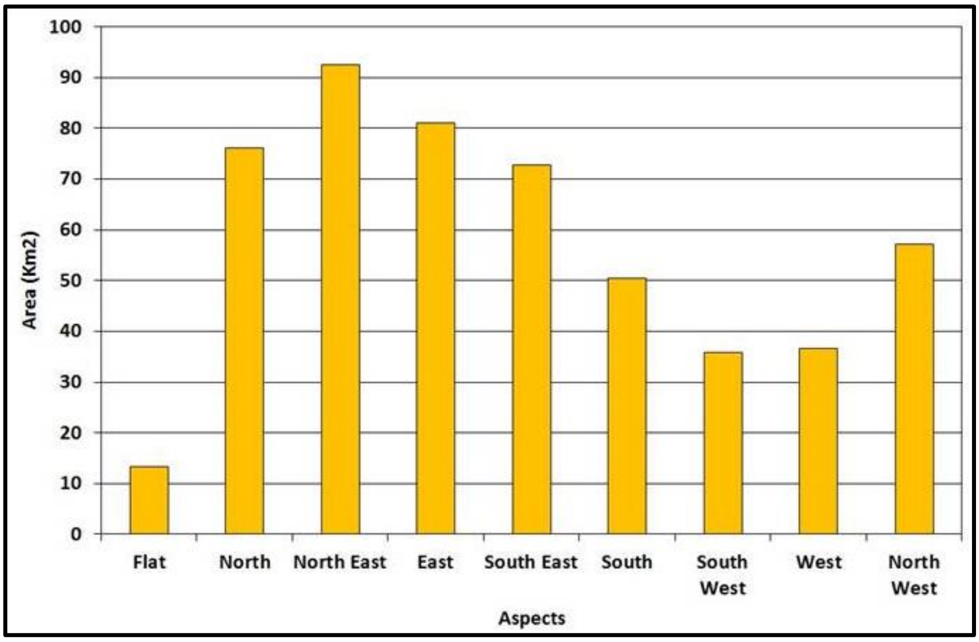

Figure 10: The intensity distribution of slope directions in the area

7. Surface Geology

The project site is a part of Ghareb plain (Figure 11). The plain extends NW-SE parallel to the Gulf of Suez and bounded from the west by high mountainous range, the northern part of Red Sea mountainous series, which composed of igneous and metamorphic rocks, and from the east by western coast of the Gulf of Suez.

Geologically, the area is located in the sedimentary basin called West Bakr that has many productive petroleum wells. Based on Conoco and the Egyptian General Petroleum Company (EGPC) 1987 and Conoco 1989, the basement (Igneous and metamorphic rocks of Precambrian age) outcrops to the west represent the watershed of the dry wadies drained the area especially Wadi Abu Had and Wadi Al-Darb (Figure 11). Quaternary deposits (Post-Miocene) are the main exposed sediments covering the whole project area.

The Post-Miocene deposits which are composed of gravels and sands are represented by large thickness in study area. This thickness ranges from about 100 m in the west to more than 450 m in the east.

The Quaternary deposits (Post – Miocene) cover all the area of the project site (Figures 11, 12). The composition of the Quaternary deposits is mainly the weathering products of the surrounding exposed rocks. In the area around the project with the occurrence of the igneous rocks of the Red Sea mountain range in the far west and southwest, which consists mainly of granitic rocks rich in feldspars reddish in color, the soil cover in the area predominantly dark as it consists of fragments of granite and feldspars, the weathered products of granites (Figure 13).

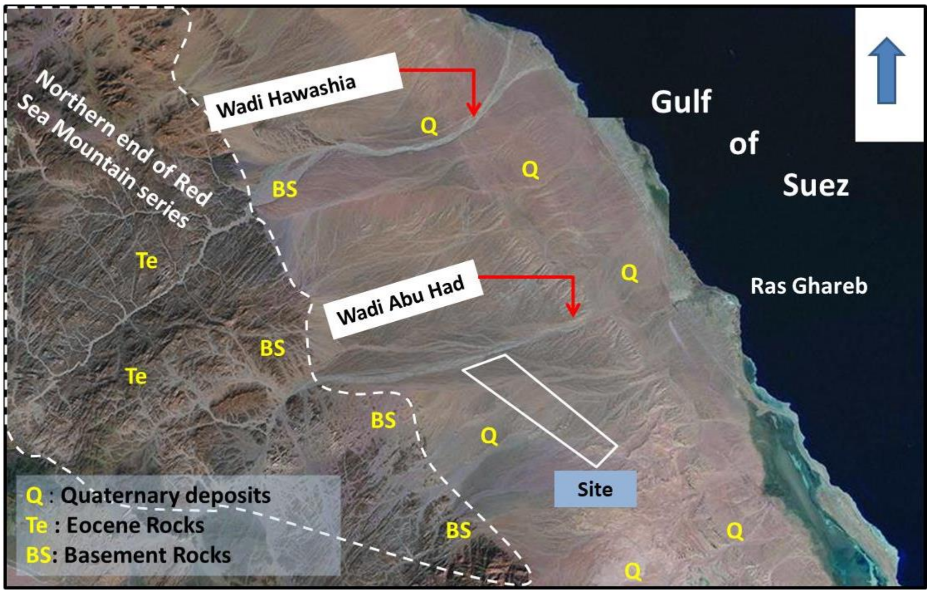

Figure 11: Land satellite image showing the location of the project site.

The Quaternary sediments are the main cover of the project area on which all construction works will be built. During the field survey, with the help of geological maps and aerial photographs, the different types of soil, characteristics and their location in the project area were investigated.

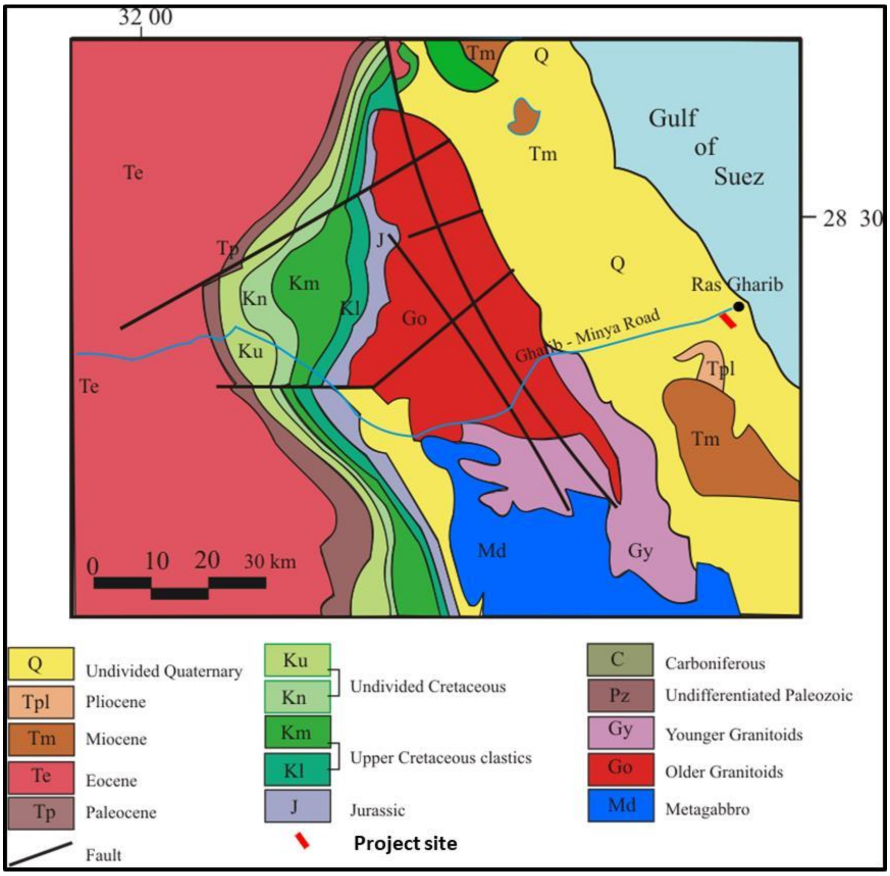

Figure 12: Regional geologic map of the area, modified from the geologic map of Egypt

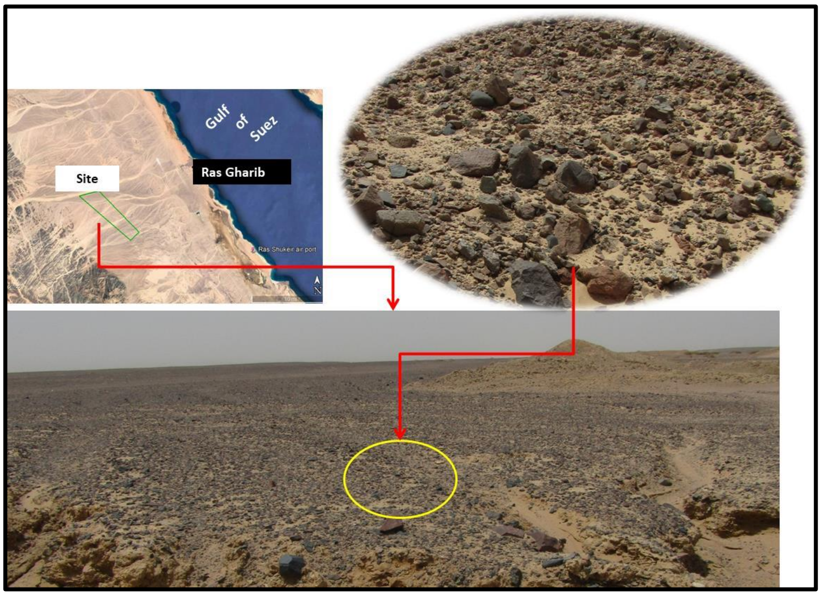

Figure 13: The Quaternary deposits common on the ground surface of the project area and all surroundings[3].

The soil covers almost all the projects area in the form of chains of alluvium terraces. Three alluvium terraces have been described in the project site during the site visit; T1, T2 and T3.

The type deposits and the size their components in addition to the potential of surface flow control the exposed height of the terrace. The terraces near the highlands in the west and south west are located at higher altitudes, and the components are very close to those in the source and their size is large. T1 (the oldest terrace) is located close to the elevated exposures close to the high mountains (Red Sea Mountains). Going to the east and northeast crossing the fine tributaries, the younger terraces formed on low lying successive levels, T2 and T3. The younger formed terraces characterized by a successive reduction in the grain size, level and elevation.

T1: The Oldest Terrace

These terraces represent the top of the elevated along the whole area of the project site (Figure 14). These old terraces have been dissected by numerous shallow and wide tributaries drain eastward to the Gulf of Suez. The maximum elevation of the terraces at the northwest part is about 280 m (a.m.s.l) while it attains about 240 m (a.m.s.l.) at the southwest part (Figures 14).

The height of the of the terrace above the ground level (the level of the following terrace) varies from 1 m to about 2 m at the northwest while it varies from 1 m to about 3m at the southwest. This terrace composed of very coarse chert nodules, cobbles and boulders of granite, basalt, impeded in fine clay and sand (Figures 14).

T2: The Intermediate Terrace

[3] Note the fragments of basement rocks; granite and feldspars (red color), basalt, serpentine (dark color) impeded in aeolian sand.

These terraces are exposed along the floor of the tributaries cutting through the terrace T1 (Figures 15, 16 &17). The height of the of the terrace T2 above the ground level (the level of the following terrace) varies from 0.5 m to about 1.5 m at the northwest while it varies from 0.5 m to about 2 at the southwest. This terrace composed of medium sized chert nodules, fragments igneous rocks impeded in fine clay and sand (Figure 15).

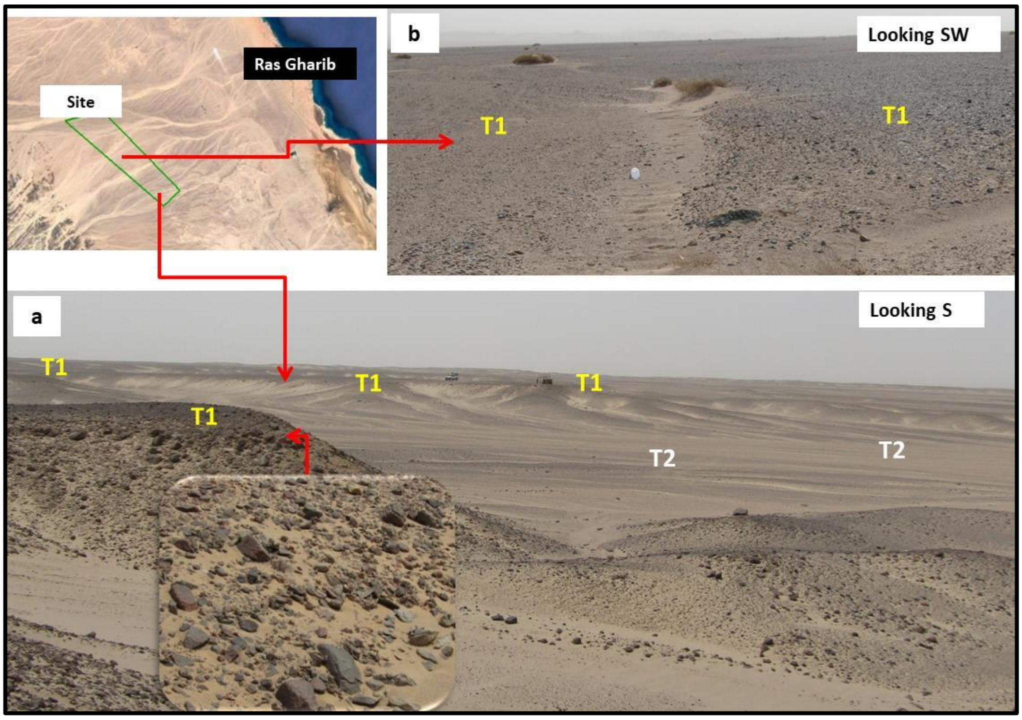

Figure 14: The distribution of alluvium terraces (T1, T2) along the whole project area.

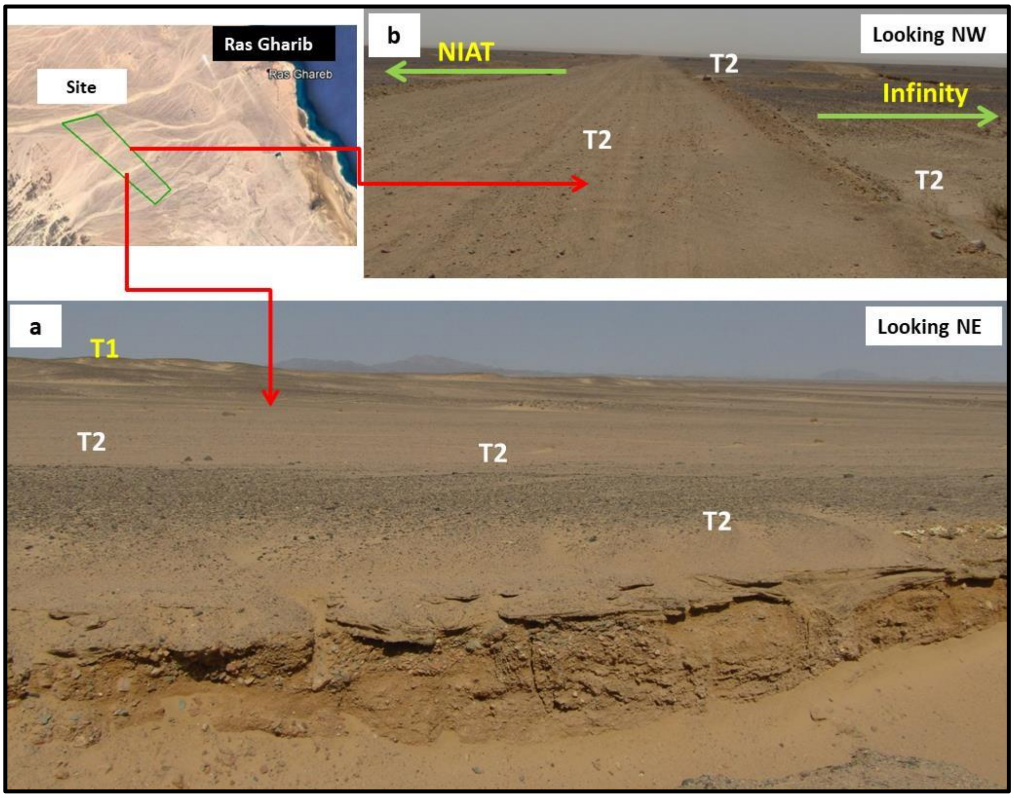

Figure 15: The exposed terraces T1, T2; a) at the southwest part, b) at the middle part.

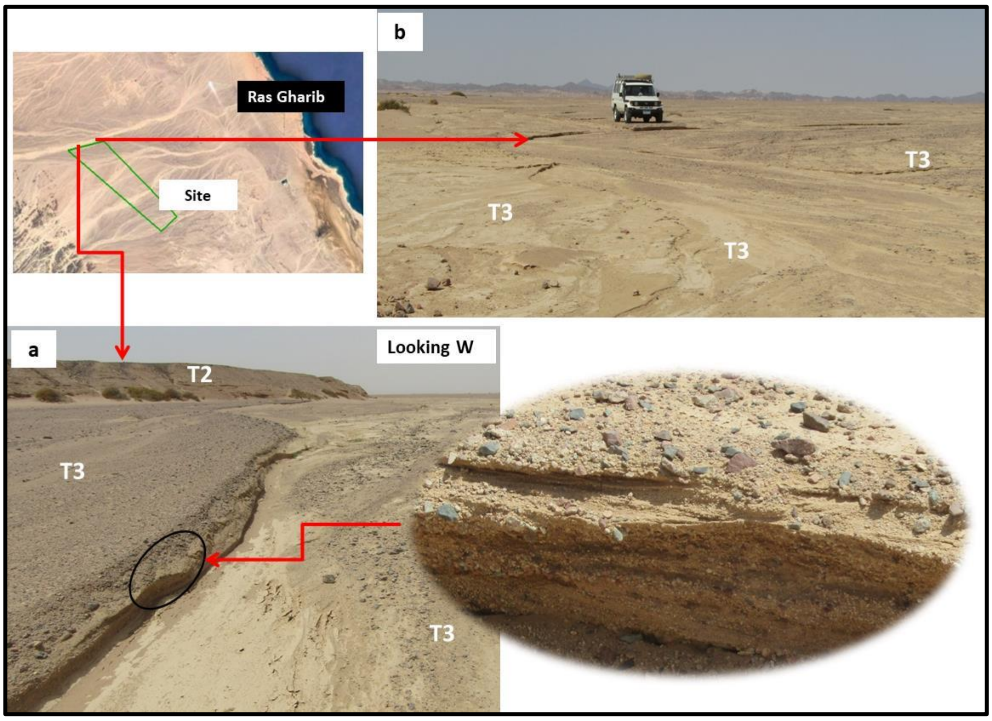

Figure 16: The exposed terrace T2, T3 in project site.

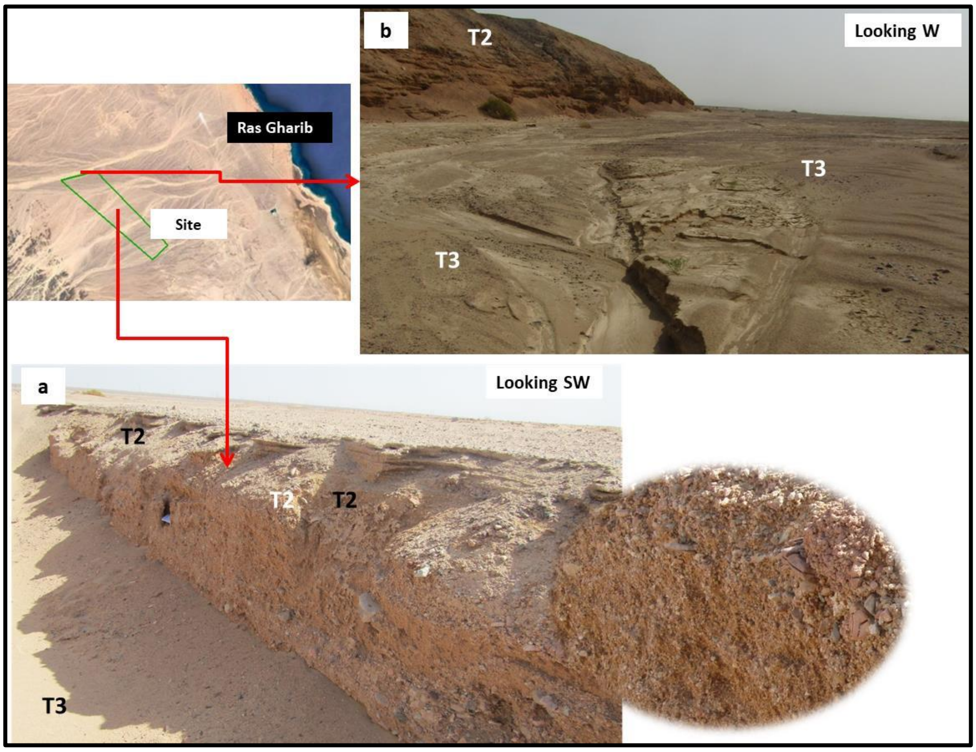

Figure 17: The exposed terrace T2, T3 in project site.

T3: The Youngest Terrace

These terraces are exposed along the floor of the tributaries cutting through the terrace T2 (Figure 18 &19). The height of the terrace T3 above the ground level (the level of the following terrace) varies from <0.5 m to about 2 m. at the northwest (Figure 18a), while it varies from 0.5 m to about 1 at the southwest. This terrace composed of small nodules, fragments of igneous rocks impeded in fine clay and sand (Figure 18). The fine clay and sand fraction are greater than that in the previous terrace T2.

In the Far east "completely out of the project site borders and going close to the city of Ras Ghareb" the thickness of the T3 terrace is increase and the fine sand and clay fraction dominated its composition (Figure 19 a,b). Going further east close to the Gulf water, the T3 terrace characterized the existence of wet lands due to the subsurface inland flow of sea water (Figure 19 c). Raised beaches of corals, shallow marine sand and evaporites are exposed along the shore line of the Gulf (Figure 19).

From the above discussion, it is clear that, the alluvium deposits that cover the whole area has a great thickness ranges from 100 m at the west to about 450m at the east. The alluvium deposits have high degree of porosity and permeability which resulted in infiltration of large volume of rainwater underneath the surface and recharge the aquifer. This means that the contribution of the sediments presents in the site and through the drainage lines that crossing the area in reducing the intensity of surface runoff is significant.

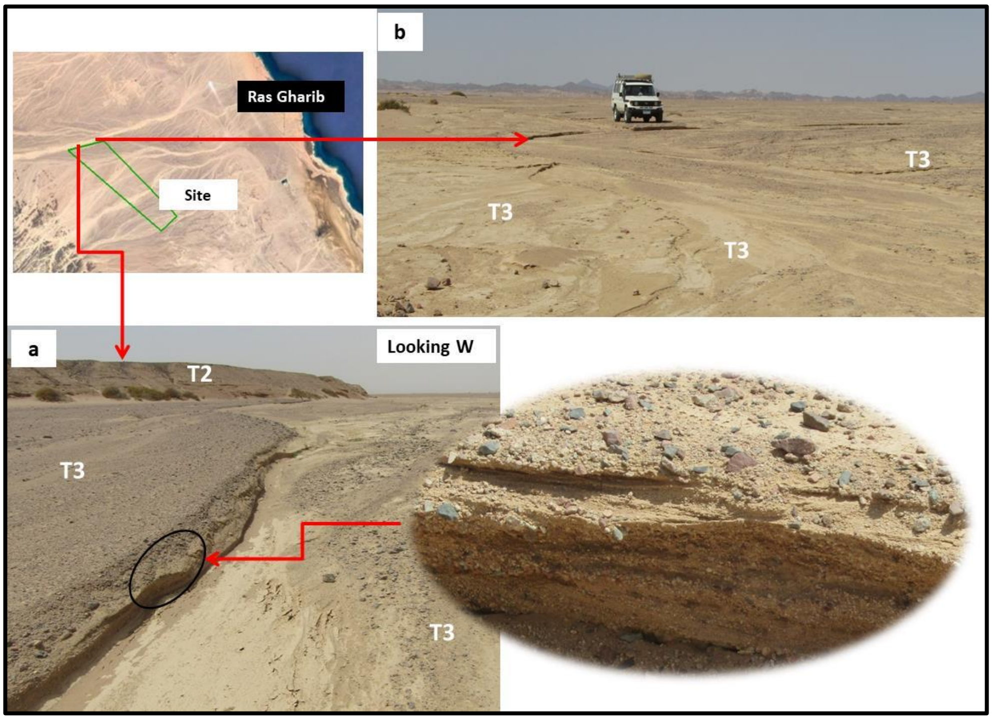

Figure 18: The composition of the terrace T3 deposited along the course of Wadi Abu Had to north of the project site.

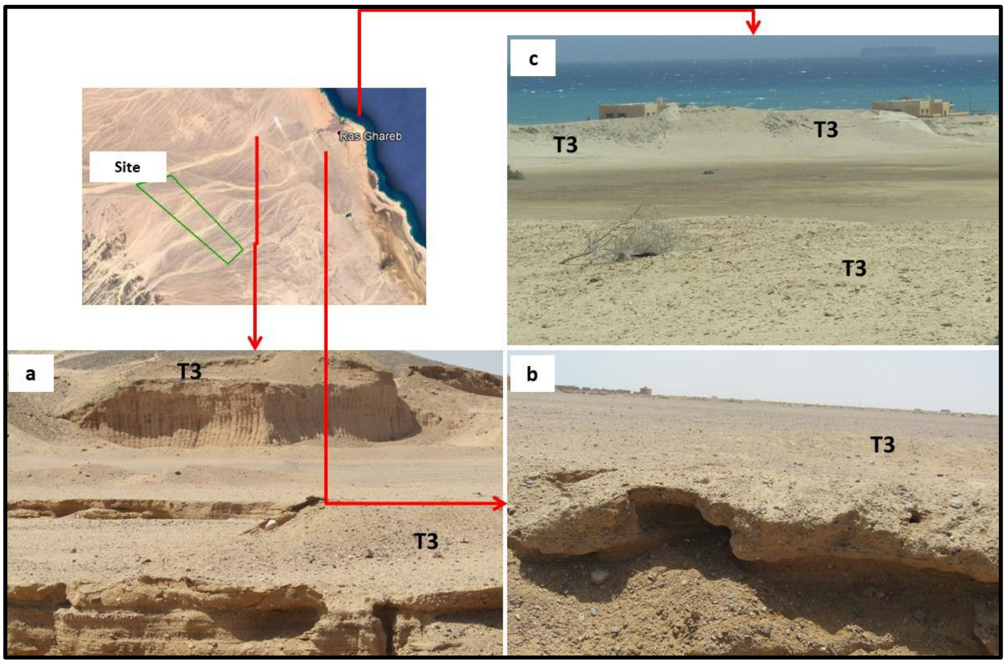

Figure 19: The composition of the terrace T3 faraway east from the project site.

Based on an in-depth analysis of prior research studies pertaining to the flash flood risks prevalent in the vicinity of the project site, coupled with a comprehensive on-site survey aimed at observing and documenting tangible manifestations of flash flooding, the findings regarding the magnitude of perilous floods experienced in this specific location can be succinctly summarized as follows:

1- With the global warming and climate changes, Ras Ghareb region began to experience dangerous floods in the rainy seasons during the last 15 years.

2- Rainwater collects in many dry wadis surrounding the area, especially Wadi Abu Had and Wadi Al Darb, which directly affect the city of Ras Ghareb.
3- The main stream of Wadi Abu Had runs outside the boundaries of the project site to the north and does not cause any danger on the infrastructure to be built on the site, even in the event of heavy rain and a violent surface flow along this wadi.
4- The site represents a part of the watershed area of Wadi Aldarb basin, in which rainwater collects through the small tributaries abundantly spread in the area in the form of a weak surface flow until it meets at the exit of the main wadi located to the east out of the site, causing a violent torrent that directly hits the city of Ghareb.
5- The sediments covering the project site have a high percentage of porosity and permeability, which leads to the sub-surface leakage of a large amount of rainwater, which reduces the surface flow, occurs at the site.
6- The entire project site is characterized by simple relief with a very gentle slope towards the east and north-east, and there are no signs of a severe surface flow that may cause a vertical deepening of the tributaries paths as the all drainage lines in the site are wide and shallow.
7- The surface sediments that cover the project site and drainage lines of different orders are multi-sized deposits. This means that the surface run off is weak and unable to carry large sized sediments. Once the surface flow from the fine tributaries reach the high ordered segments of the wadi (main wadi course) its intensity reduced dramatically leaving the fine sediments (clay & silt) deposited along the wadi course.
8- There is no sign of deep dray wadis crossing the concession site or even large alluvial fan deposits reflecting strong surface flow.
9- The drainage lines that drain the project site are very short, wide and shallow that reflects a complete absence of dangerous floods except at the outlet of wadi Al-Darb outside the project site to the east.

Recommendations

From the foregoing, it is clear that the project site is part of Wadi Al-Darb basin which is one of the basins that cause serious floods in the city of Ras Ghareb. Although the site is located in the watershed area, far from the main outlet of the wadi, and did not show clear evidence of dangerous floods, the infrastructures that could be established in the site may be affected by the severe surface runoff. Therefore, it is necessary to determine the intensity of this surface runoff, which may occur in the drainage lines pass through the project site, so that mitigation measures can be put in place to reduce the risk of this runoff.

Considering the potential effects of climatic variations and global warming, which are anticipated to result in escalated precipitation levels within the area, comprehensive flood risk assessment models have been implemented to ascertain the maximum magnitude of surface runoff projected for the project site. This evaluation utilizes up-to-date data and factors in the heightened likelihood of such occurrences in the future. Consequently, it is imperative to devise appropriate mitigation strategies aimed at minimizing the anticipated adverse consequences arising from intense surface flow on the project's infrastructure and foundations.

8. Rain fall study on the area

Rain is one of the main factors affecting the occurrence of run-off in the drainage basins on the coast of the Gulf of Suez. Based on the speed and quantity of the run-off, the dangerous effect of the flood that affect some areas of current and future development can be expected. Since the region has limited water resources, it is worth highlighting the positive aspects of the flooding and reducing its negative effects. For instance, by studying how to mitigate its dangers save the rainwater in some different areas of development.

Generally, rain in the study area is characterized by their scarcity. Despite that, rain often falls, causing flash flooding in the basins of the region. These torrents vary in strength, water quantity and speed depending on the amount of rain falling, which is characterized by its irregularity, temporal and spatial variation.

The amount of annual rain varies significantly from year to year, and also changes from one place to another within the study area. This means that there is a difference in the amount and timing, which are the distinguishing features of desert rain that leads to flooding.

In order to verify this, it was necessary to study the conditions of rain expected to fall on the study area based on the density of clouds that cross the area and its distribution through satellite data. Comparing this data with the intensity of rainfall recorded by meteorological stations, in addition to the extent to which these clouds are related to the torrential rains that occurred in the Ras Ghareb region, especially in the year 2016. Therefore, the future of floods in the region can be expected in light of the prevailing climatic changes.

8.1 Precipitation measurements from satellite images (Theoretical Precipitation)

Satellite images provide an important source of data that can be relied upon in studying of weather and climate elements. This is done through successive monitoring of these elements from remote sensing systems such as the NOAA satellites, the oldest remote climate sensing systems.

By using inputs from Satellites, mathematical models can be built to determine the distribution of pressure, temperature, the thickness and density of the atmospheric layers.

The movement of winds can be calculated through monitoring of the movement of clouds from static satellites using high-powered telescopes in both visible and thermal ranges, where the temperature gradient is recorded. Inside the cloud layers, it is possible to compare them and obtain simple preliminary results.

The study included in this section of the report relied on the data of the PERSIANN (Precipitation Estimation from Remotely Sensed information using Artificial Neural Network) project made by the Center for Meteorology, Hydrology and Remote Sensing at the University of California, which extracts rain data from satellite images by using Neural Network Models. The data of the type PERSIANN-CCS (Precipitation Estimation from Remotely Sensed information using Artificial Neural Network – Cloud Classification System) is a high-resolution spatial data with a cell size of 4 km x 4 km. The study period extends through the period (2015-2021), during which these digital files were analyzed and modeled to determine the spatial and temporal changes in the amount of rain expected to fall during the study period. The following sections present the results of the spatio-temporal analysis of these data sets.

8.1.1 The average annual precipitation evaluation in the study area

The following table displays the possible annual averages of precipitation in the area. The average annual precipitation is estimated to be about 9.59 mm per year. So, it is expected that the three studied basins will carry about 5 million m^3 rain water annually, by 1.7 million m3 in Wadi Al Darb, 1.8 million m3 in Wadi Kharim and 1.5 million m3 in Wadi Abu Khashba. This amount increases in some years with high precipitation rates, and it also increases in some months in which the rates of rain storms increase in quantity and quality. Figures (20, 21) depict the annual change in the amount of potential precipitation in the study area. It reveals that the year 2018 is the highest year in terms of the amount of rain likely to fall with an average of about 16.14 mm.

Table 7: The annual change in rain expected to fall on the studied area basin during the period (2015-2021).

Year	2015	2016	2017	2018	2019	2020	2021	Ave.
Year Ave. (mm)	7	8	10.52	16.14	14.9	4.41	6.66	9.59
Total Rain (mm)	84	96	103.2	193.63	169.1	52.93	79.9	115.11
Change (%)	-	14.3	35.6	48.7	-12.7	-68.7	50.9	44.1

Source: the analyses of the PERSIANN-CCS data during the period 2015-2021

This rainfall intensity results in a quantity of water up to about 8.4 million m3 received by the watersheds of the studied three basins. It is noted from the attached table that the amounts of rain expected to fall on the three basins fluctuate during the study period (2015-2021).

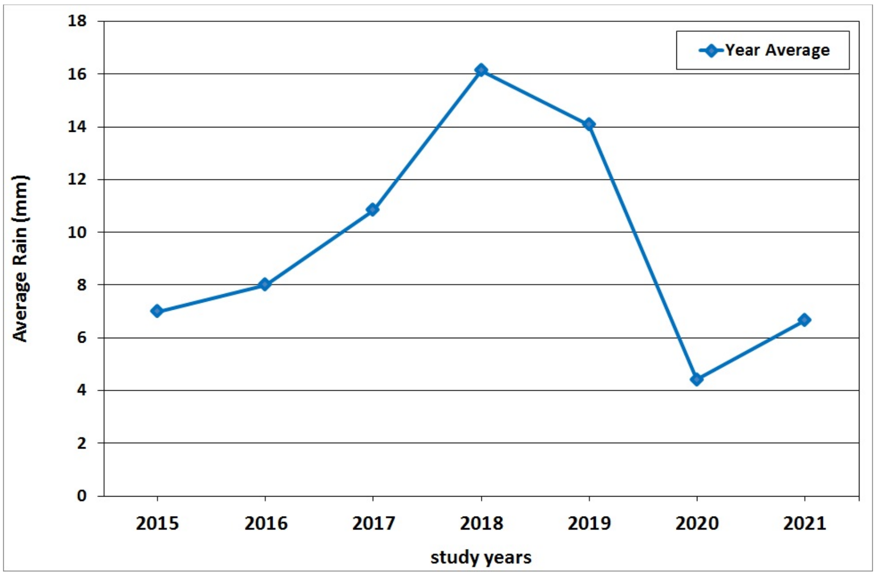

Figure 20:The annual averages rain expected to fall on the studied basins during the period (2015-2021)

The general curve for the distribution of rainwater increased during the period (2015-2018) due to the passage of an abundance of rainstorms. The most important floods recorded are; the rainstorm on (October 26-27, 2016), which caused many in Egypt. The rainstorm (Oct. 26-27, 2016) caused the occurrence of torrential flows in Ras Ghareb region from the basins of Wadi Abu Had, north of the study area, Wadi Al-Darb, Wadi Kharim and Wadi Abu Khshba.

It is also noted that the amounts of rain decreased during the period (2018-2020), then gradually increased again in the year 2020 where the general average of possible rain was 6.66 mm. This was due to the passage of a number of rain storms during the year 2020. The most important one is the Dragon Storm in the days 11, 12 and 13 March 2020. This storm resulted in dangerous runoff in the northern part of the Eastern Desert, in which the study area is located, as well as the rainstorm on November 2, 2020.

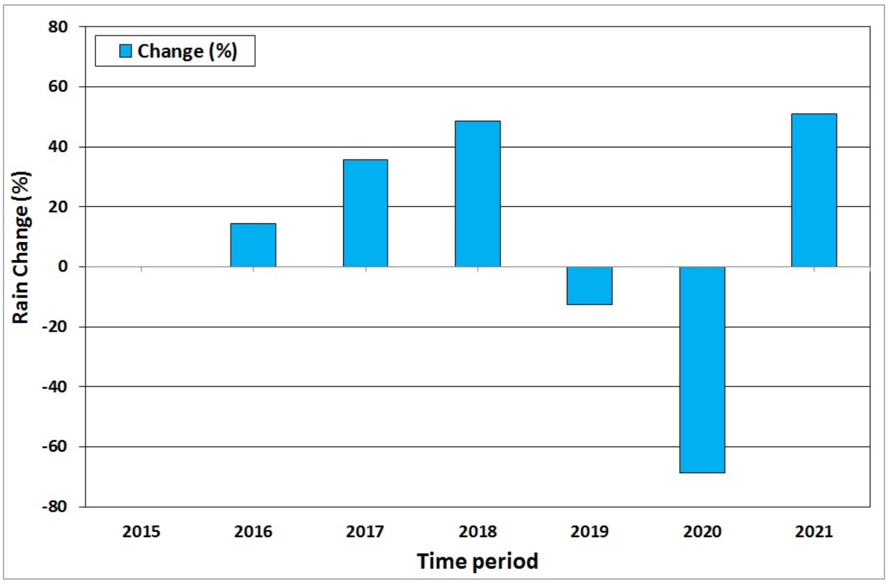

Figure 21: The annual change in the rainfall quantity expected to fall on the watersheds of the studied basins.

In general, the rate of change in the average expected precipitation on the study area amounted to 44.1%. This is due to the increase in the rates of passages of the strong rainstorms in the region, which is attributed to clear changes in the number and strength of rainstorms in Fall and Spring seasons of each year. Figure (22) shows that the large amount of precipitation was concentrated on the middle and lower parts of the basins during the years 2015 to 2021. But in the year 2016 the heavy expected precipitation was concentrated on the high mountainous slopes at the west and south west. This year witnessed severe torrential rains in Ras Ghareb. Consequently, it can be said that when the rains fall heavily on the high areas in the far west and southwest of the region, the possibility of dangerous torrential rains is greater than in the case of rains falling on the middle and downstream parts of the basins. It is also noticed in the years 2017, 2018, 2019 and 2021, despite the great amounts of rain expected to fall in these years as a result of the accumulation of large amounts of clouds, but no dangerous torrential rains were recorded that threatened the region. This may be due to the topographical situation of the central and eastern regions of the basins in terms of the gentle slope of the earth's surface and the widening of the drainage lines rather than the western regions with large elevations and steep slopes that allow the collection of rainwater in the main streams of the wadies and its flow at a high speed to collect at the downstream parts in a short time which causes dangerous floods.

From the aforementioned study of the amounts of rain expected to fall in the region according to climate satellite data, the following can be concluded:

1. The expected change in the rate of rainfall over the region during the seven years (2015-2021) is 44.1%. This means that according to the prevailing climatic changes during the study period, the accumulation of clouds causing rain increases over the study area, Table No. 1.
2. The heavy accumulations of clouds that cause rain are concentrated in the central and eastern parts of the study area. This may be due to the effect of winds on these dense clouds and moving them to the east.
3. The occurrence of torrential rains at the exits of the Wadies is largely related to the amounts of accumulated clouds and the rain that falls on the elevated areas in the far west and southwest of the region (Red Sea mountain range).

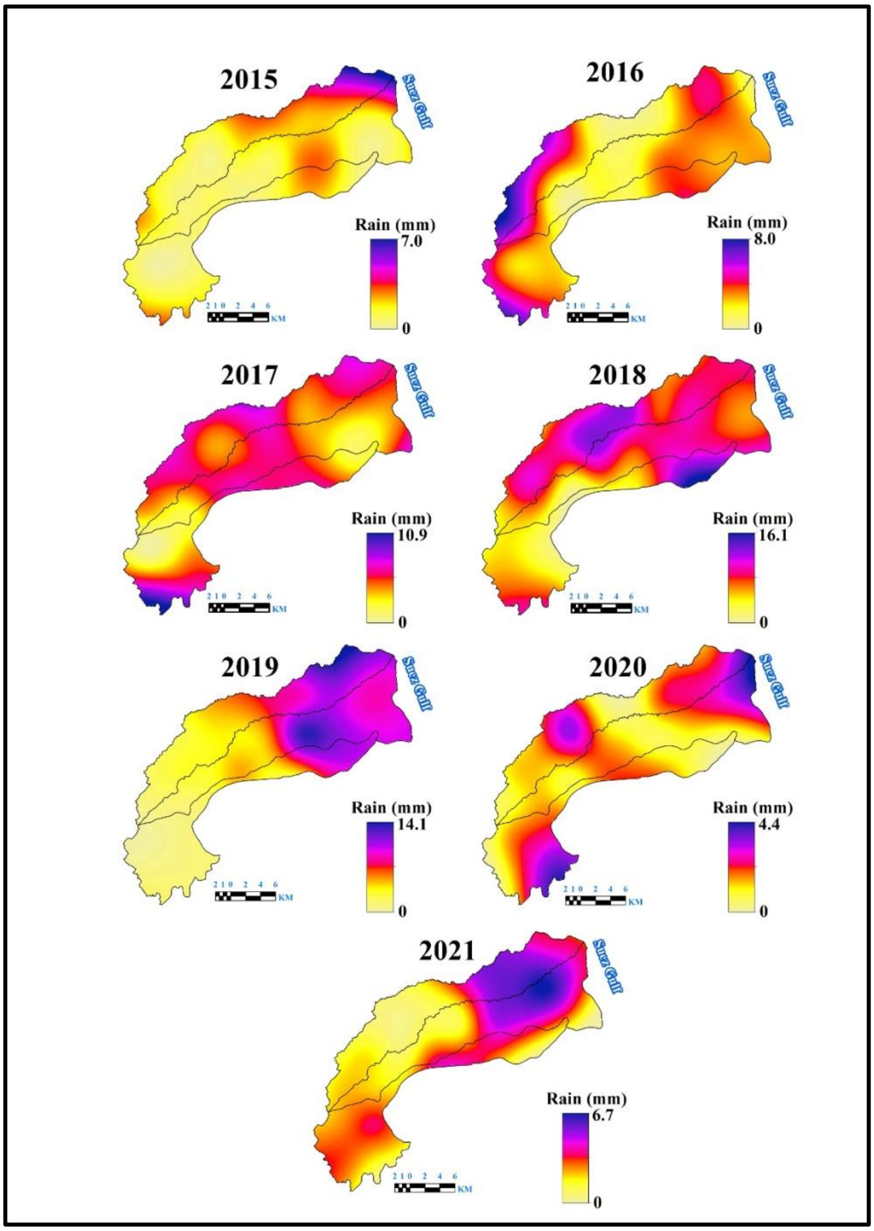

Figure 22: Spatial and temporal changes in the amount of rain expected to fall on Wadi Arabia basin during the period (2015-2021)

4. Rainfall on the middle part of the three studied basins, in which the project site is located, even if it is heavy, does not cause torrential rains, which may threaten the facilities on the site. This is because the project site is far from the exits of the three Wadies passing through it. However, it may result in a surface runoff in the tributaries that cross the site, which are wide and shallow drainage and have no traces of violent surface flows so far.
5. With this positive trend in increasing the amounts of clouds accumulating in the middle and eastern parts of the region as a result of climate changes, the volume of surface runoff may increase, which requires the application of some necessary measures to protect any facility that may be located in these drainage lines.

8.1.1 Average expected monthly precipitation in the study area

Table (8) and Figure (23) display the probable monthly averages of rainfall in area during the period (2015-2021). **April** is the highest month of the year in terms of the potential precipitation rate about 21.31 mm. This month is the middle of spring which coincides with the spring weather fluctuations and the simultaneous blowing of warm winds from the south to fill the air depressions that pass on the northern coasts and are attracted by the Red Sea mountain ranges towards the south.

April recorded large amounts of expected rain during the years 2017 of about 53.5 mm which increased to about 60.1 mm in 2019.

February comes in the second category in terms of the highest months of the year in terms of potential precipitation rates. This month represents the middle of the winter season, as the rates of atmospheric depressions increase on the northern coasts. Then the chances of rain increase, especially when some depressions change their direction towards the south through the Red Sea Mountains, which increases the chances of rain in the basins of the Ras Ghareb region. The monthly average precipitation in February was about 17.67 mm. This month witnessed high expected precipitation rates during the year 2018 as it expected to be about 60.2 mm, and 27.3 mm in 2019.

Table 8: Probable monthly averages of rainfall in the area during the period (2015-2021).

Months	**Jan.**	**Feb.**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ave**	**Total**
Average	13.5	17.67	15.6	21.13	15.6	0.67	0	0	1.89	8.5	5.54	14.9	9.59	124.7

Source: the analyses of the PERSIANN-CCS data during the period 2015-2021

In the third category comes the months of March and May, with an expected average precipitation of about 15.56 mm each. January and December come in the fourth, with an average of 13.5 and 14.9 mm, respectively. October and November are the fifth category with an average of 8.5 and 5.54 mm, respectively. As for the lowest months of the year in terms of precipitation rates, they are represented in the months of June, July, August and September, which represent the months of the summer season and the beginning of the autumn, which are characterized by high temperatures. The predominance of dry conditions and the lack of opportunities for precipitation in a very large way, except for some ascending rain resulting from the high temperature in the presence of a source of evaporation represented in the Gulf of Suez, which is very rare, low-quantity rain and has no effect on the process of runoff. Figure (32) shows the changes in the amount of monthly precipitation in the studied three basins during the period 2015-2021, which reveals that the high rates of potential precipitation were expected in the months of winter, spring and autumn, and decrease in summer.

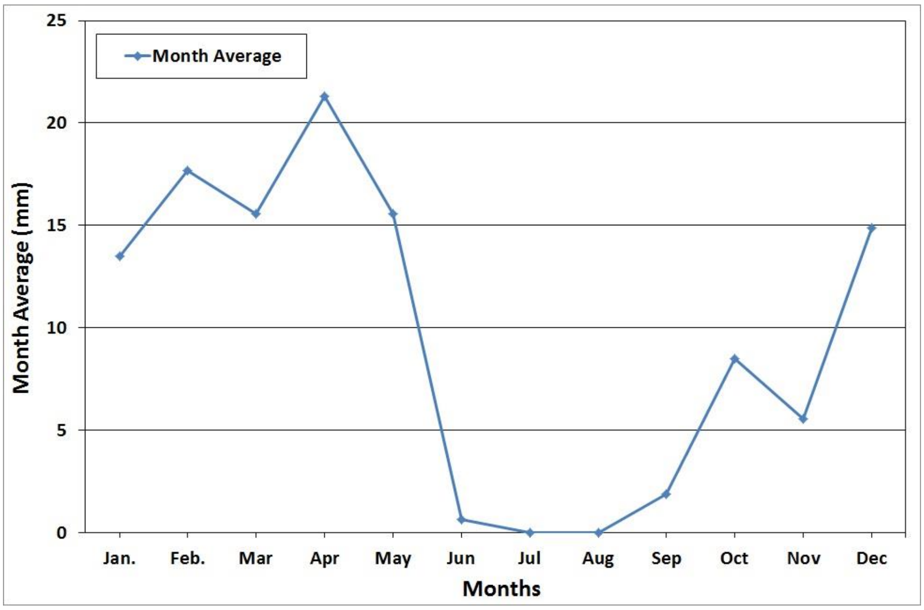

Figure 23: The monthly change in the amount of precipitation expected area during the period (2015-2021)

8.1.2 Average seasonal precipitation in the study area

Table (8) and Figure (24) exhibit the possible seasonal averages of rainfall in the studied basins during the period (2015-2021), which show that winter is the highest season of the year in terms of the amount of rain expected to fall with an average of about 15.58 mm during the study period. This quantity increased to reach 29.97 mm in the winter of associated with cloud cover activity and frequent weather fluctuations. It also reached 24.74 mm in the winter of 2018. The increase in the amount of rain expected in this season is due to the passage of atmospheric depressions in the northern part, whose impact may extend to the interior parts of the northern eastern desert and the Red Sea Mountains which will result in an increase in the expected precipitation rates.

Table 9: Probable seasonal averages of rainfall on area during the period (2015-2021)

Months	2015	2016	2017	2018	2019	2020	2021	Average
Winter	17.93	18.87	6.97	24.74	29.97	7.13	3.63	15.58
Spring	2.63	5.3	19.97	26.1	24.87	5.2	3.53	12.51
Summer	1.3	0	0	3.1	0	0	0	0.63
Autumn	6.13	8.03	16.47	10.6	1.53	5.31	19.47	9.65

Source: the analyses of the PERSIANN-CCS data during the period 2015-2021

The spring season comes in the second place in terms of the amount of rain expected to fall, which averaged 12.51 mm during the study period. This could be due to the weather disturbances represented in the passage of depressions in the northern part of Egypt resulted in the blowing of the Khamaseen monsoon and increase in the chances of rain. The amount of rain expected to fall on the basin of Ras Ghareb in the spring season reached its maximum value in 2018, which amounted to 26.18 mm, followed by 2019 of about 24.87 mm, while it reached its lowest value in 2015 of about 2.63 mm.

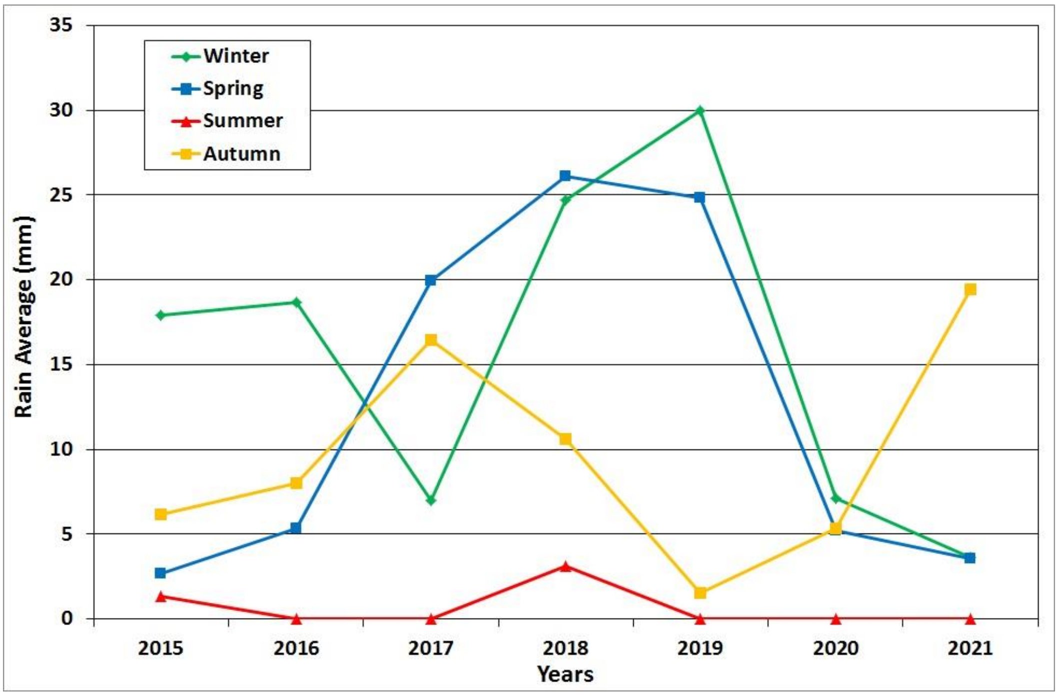

Figure 24: The expected seasonal average precipitation on study area during the period (2015-2021)

The autumn season comes in the third place in terms of the amount of rain expected to fall, with an average of about 9.65 mm during the study period. The autumn season represents a transitional period between the dry summer and the rainy winter. So, it witnesses some weather disturbances that result in rain falling in the study area. The amount of rain expected to fall reached its maximum value in the autumn season in the years 2017 of about16.47 mm, decreased to about 10.6 mm by the year 2018. These are the years in which the intensity of rain storms increased and resulted in many torrents in the Gulf of Suez region in general. One of the most dangerous floods that the Gulf of Suez region experienced was in the fall of 2016, specifically on October 26-27. The floods occurred in the basins of wadi Abu Had to the north of the site and Wadi Al-Darb that crosses the site, affected the city of Ras Ghareb resulted in loss of life and property.

Summer is the least season of the year in terms of rainfall, which averaged about 0.63 mm during the study period, as the study area is characterized by very hot, dry and high humidity summers.

8.1.3 The monthly average of the largest amounts of precipitation during the study period

Table (9) shows the expected monthly average precipitation of the largest quantity during the study period (2015-2021). April, May and December are the highest months of the year recording the largest amounts of precipitation expected during the study period. The expected average precipitation in these months was 35.14, 37.57 and 37.17 mm, respectively, where the maximum expected rainfall was in April 2019, May 2018 and December 2021 of about 98, 89 and 83 mm respectively.

No serious impacts of these torrents were recorded on the residential areas located at the outlet of the wadies on the infrastructures. This is due to two important factors; **the first:** is the design of many protection measures in all dangerous basins such as Wadi Hawashia and Wadi Abu Had north of the site and also at the exit of Wadi Al-Darb East of the site, **the second factor**: is that the heavy amounts of rain fell on areas with gentle slopes in the middle and eastern parts of the drainage basins. In May, 2018 the region witnessed torrential rains that led to the suspension of all roads leading to the Gulf of Suez, and the traffic stopped for more than a day as a result of the strong rainstorm, which was accompanied by severe surface runoff, without any damage to lives and infrastructures.

Table 10: Average precipitation of the largest amount of rain expected per month during the period (2015-2021)

Months	2015	2016	2017	2018	2019	2020	2021	Month Average
Jan.	32	4	19	1	100	27	20	29
Feb.	52	6	0	90	40	3	10	28.71
Mar	19	78	21	28	14	41	3	29.14
Apr	0	10	69	43	98	4	22	35.14
May	17	46	25	89	25	29	32	37.57
Jun	12	0	0	0	11	0	0	3.29
Jul	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0
Sep	22	0	0	27	0	0	0	7
Oct	25	021	0	59	3	1	42	21.57
Nov	16	30	25	25	9	12	21	19.71
Dec	16	2	77	46	13	27	83	37.71
Year Average	17.6	16.4	19.67	34	26.08	10	19.42	20.74

Source: the analyses of the PERSIANN-CCS data during the period 2015-2021

January, February and March come in second category in terms of the highest amount of rain expected to fall in the region, where the expected average rainfall was 29, 28.71 and 29.14 mm respectively. The maximum amount of rain expected in the three months was 100 mm in Jan, 2019, 90 mm in Feb, 2018 and 78 mm in Mar, 2016.

October and November come in third category in terms of the highest amount of rain expected to fall in the region, where the expected average rainfall was 21.57 and 19.71 mm respectively. The maximum amount of rain expected in the two months was 59 mm in Oct, 2018 and 30 mm in Nov, 2016.

Although the amount of rain expected to fall on the study area in the year 2016 is considered the least among the months of the year, the concentration of clouds in October was on the high elevated areas in the west and southwest, resulted in a strong rush of water in the main streams of the wadies as a result of the steep slope, which led to violent torrential rains hit the city of Ras Ghareb.

8.1.4 Annual analysis of the calculated average amounts of rain expected to fall during the study period.

From the analyses of the PERSIANN-CCS satellite data during the period 2015-2021, the calculated annual average precipitation that was expected in the area Table (10) and Figures (25, 26) revealed that:

1) **2015:** The expected annual average precipitation in 2015 was about 7.0 mm. This average increased to 27.2 mm in February, while it decreased to zero in August and July. The winter season is the highest season of this year in terms of the expected average precipitation, which amounted to about 17.93 mm, followed by the autumn season, which measured 6.13 mm (Table 10 and Figure 25).

Table 11: The calculated annual and monthly average precipitation in the study area during the period (2015-2021)

Months	2015	2016	2017	2018	2019	2020	2021	Month Average
Jan.	18.2	2.8	10.4	0.03	54.4	4.3	4.4	13.50
Feb.	27.2	2.2	0	60.2	27.3	1.1	5.7	17.67
Mar.	8.4	51	10.5	14	8.2	16	0.8	15.56
Apr.	0	3.7	53.5	26	60.1	2	3.9	21.31
May	6.2	12.2	6.4	52.3	11.5	13.6	6.7	15.56
Jun	1.7	0	0	0	3	0	0	0.67
Jul.	0	0	0	0	0	0	0	0.00
Aug.	0	0	0	0	0	0	0	0.00
Sep.	3.9	0	0	9.3	0	0	0	1.89
Oct.	10.7	14.8	0	14.4	0.9	0.03	18.7	8.50
Nov.	2.6	8.4	5.8	7.8	1.9	6.6	5.7	5.54
Dec.	5.1	0.9	43.6	9.6	1.8	9.3	34	14.90
Year Ave.	7.00	8.00	10.85	16.14	14.09	4.41	6.66	9.59

Source: the analyses of the PERSIANN-CCS data during the period 2015-2021

2) **2016:** The expected annual average amount of precipitation in this year was about 8.0 mm, increased to reach 51.0 mm in March. October witnessed dangerous flooding runoff in the central and southern part of the Gulf of Suez resulted in the sinking of most of the city of Ras Ghareb. Winter is the highest season of the year in terms of the expected precipitation rate, which reached 18.67 mm, followed by autumn with about 8.03 mm, then spring with about 5.3 mm (Table 10 and Figure 26).

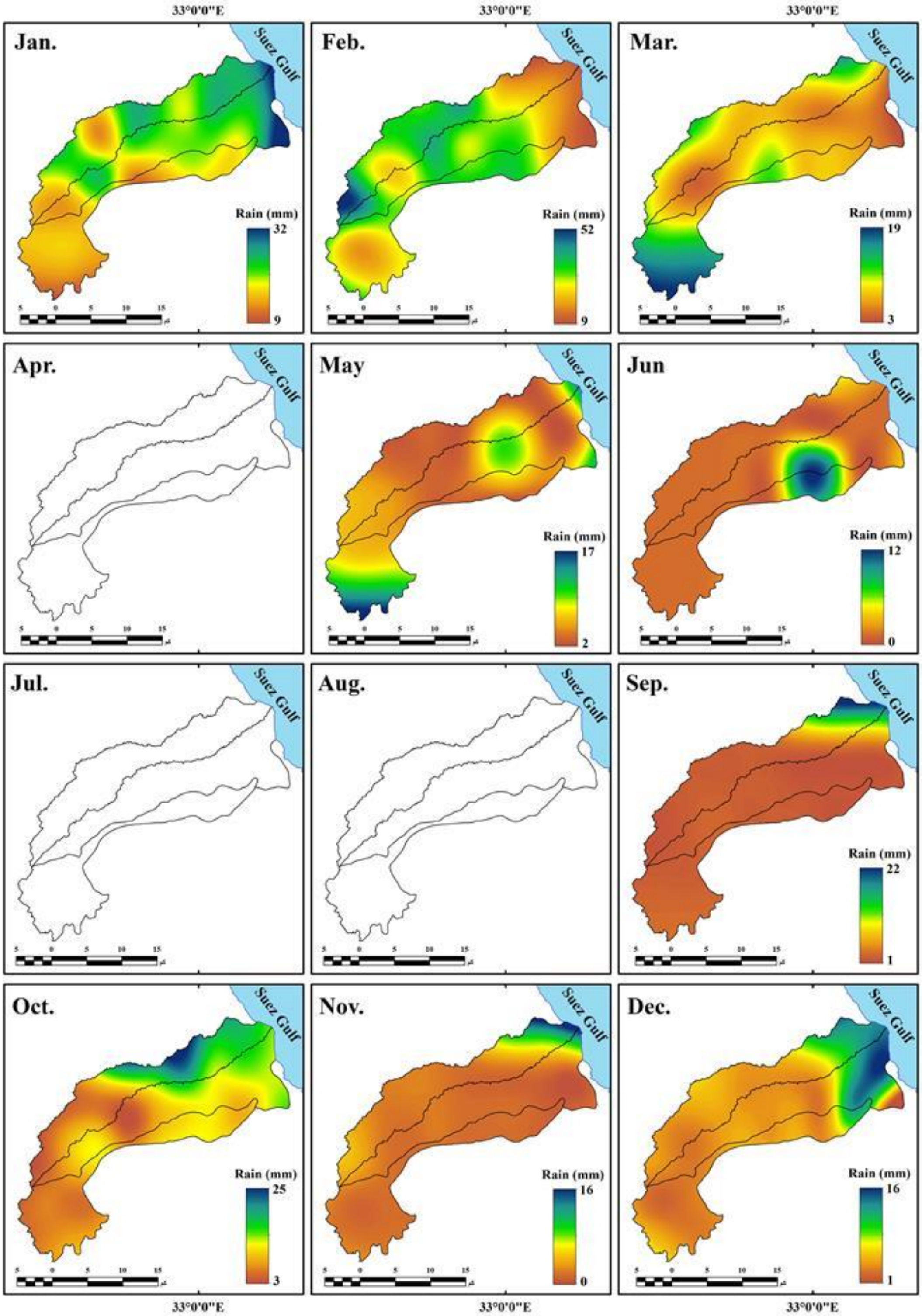

Figure 25: The expected monthly rainfall of the year 2015 on the area.

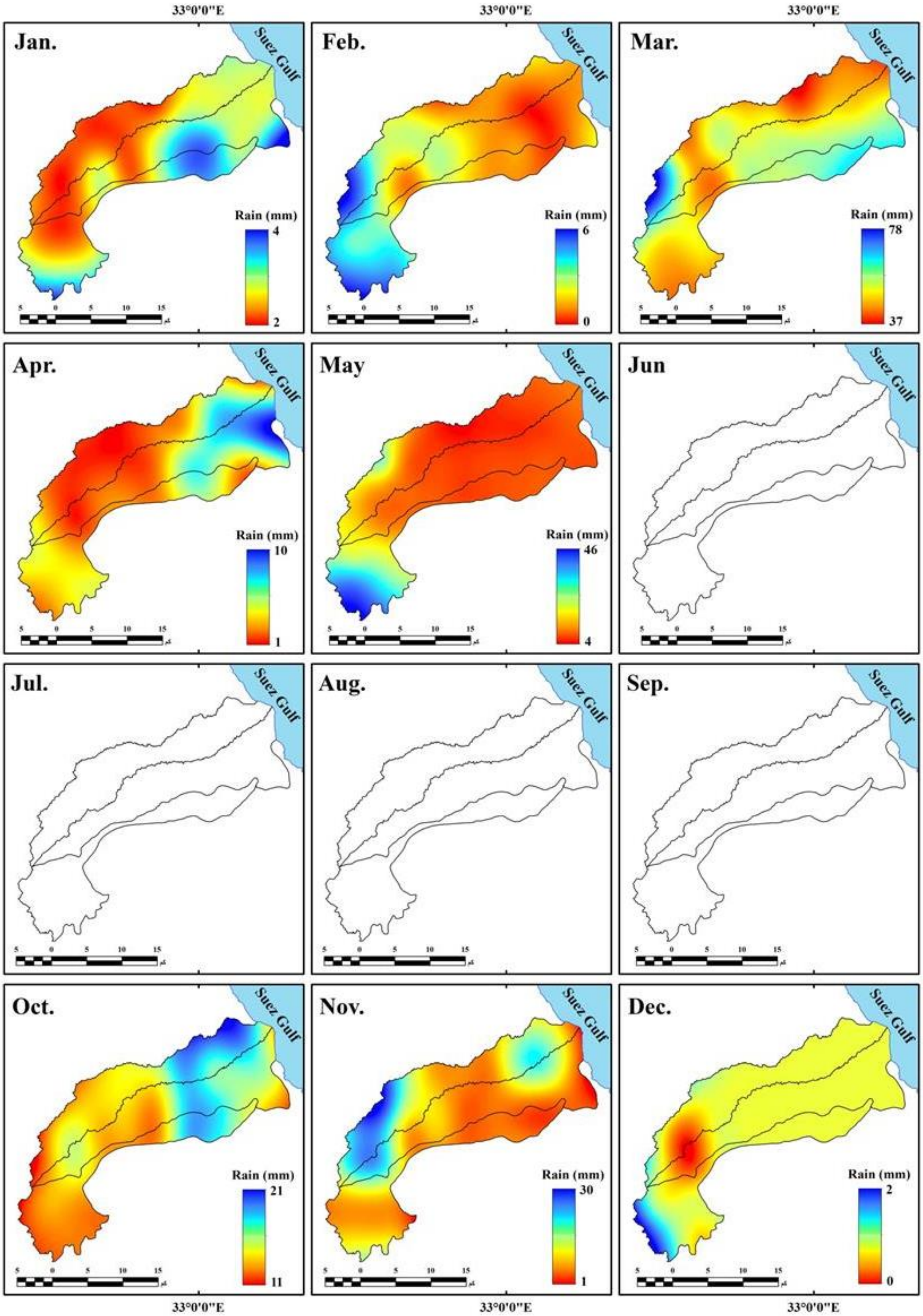

Figure 26: The expected monthly rainfall of the year 2016 on the area.

3) **2017**: The expected annual average amount of precipitation for this year was about 10.85 mm. This average reached its highest value in April, which recorded about 53.5 mm, followed by December with about 43.6 mm. The spring season came first in terms of the

expected rainfall rate of about 19.97 mm, followed by the autumn season with about 16.47 mm, then the winter season with about 6.97 mm (Table 10 and Figure 27).

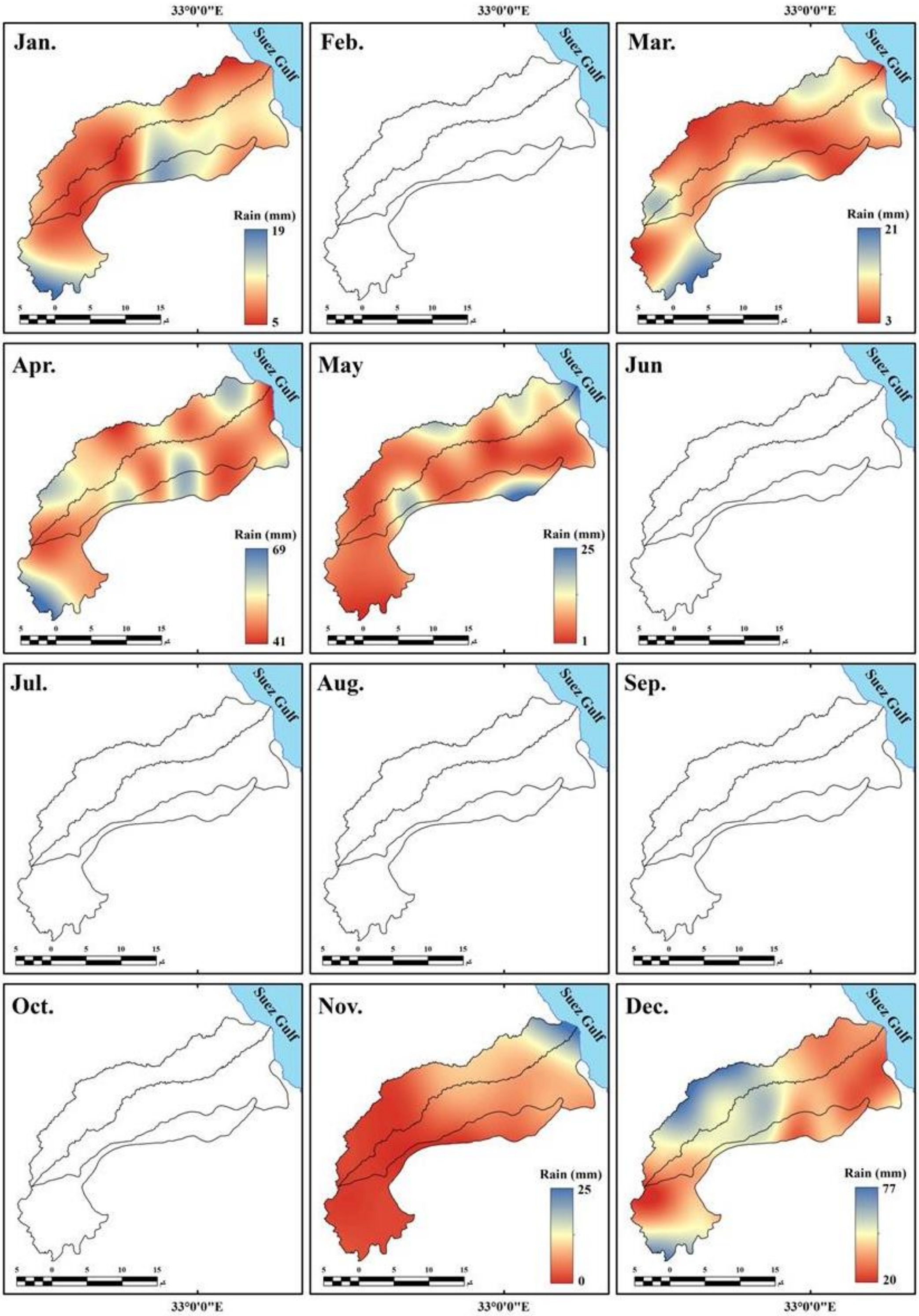

Figure 27: The expected monthly rainfall of the year 2017 on the area.

4) 2018: This year is the highest year in terms of expected rainfall rates obtained from satellite images with an average of about 16.14 mm. The highest value was in February (60.2 mm). In the 24th of February, a strong rainstorm passed, resulting in a large flow of water in the basins of the middle and south of the Gulf of Suez. May came in the second category in this year, reaching about 52.3 mm, as this month witnessed the passage of a

strong rain storm on May 25, which resulted in a large runoff in the basins of the northern and central parts of the Gulf of Suez. Spring was the highest season of this year with an average of about 26.1 mm, followed by winter with about 24.74 mm, and then autumn with about 10.6 mm (Table 10 and Figure 28).

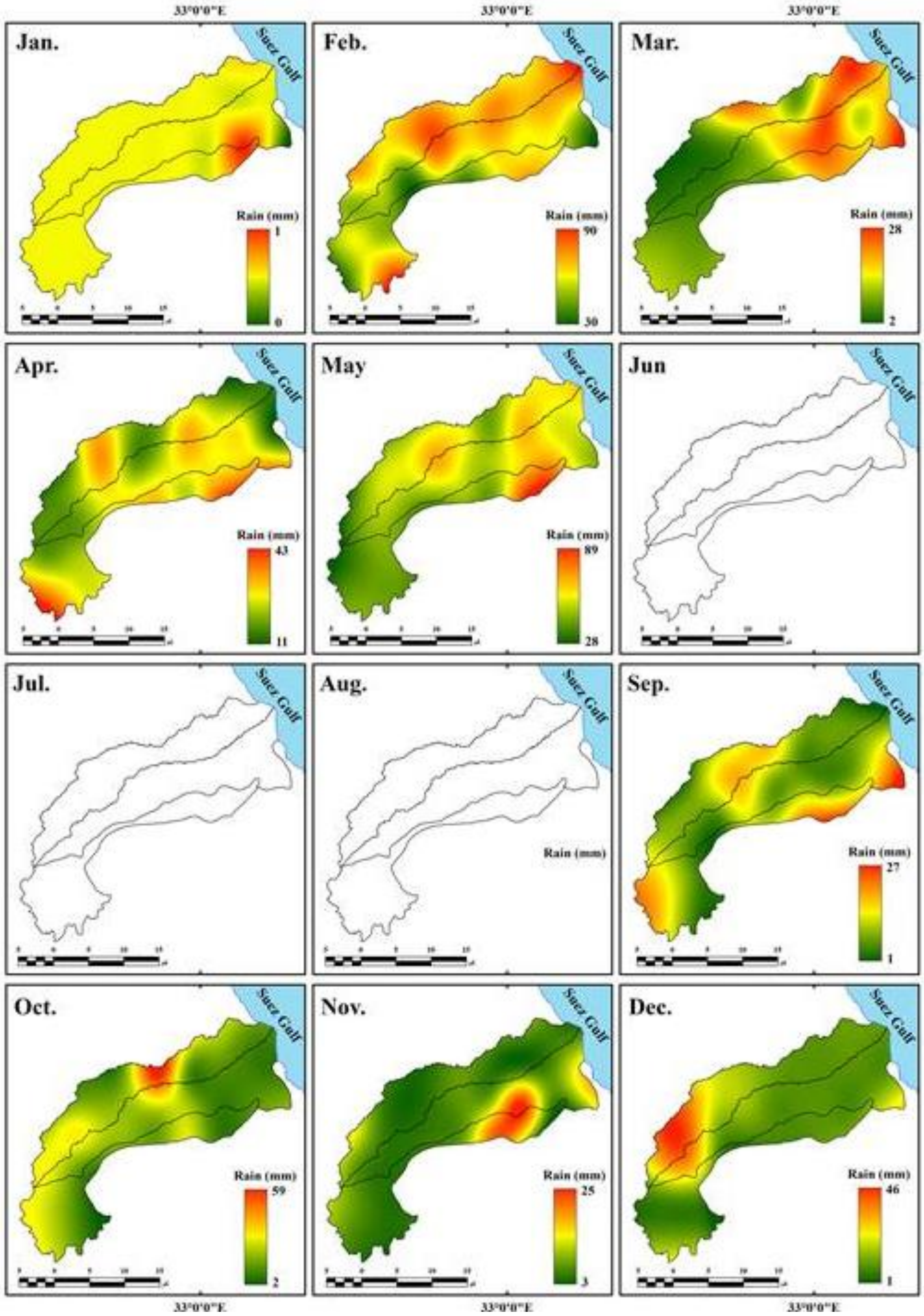

Figure 28: The expected monthly rainfall of the year 2018 on the area.

5) **2019:** The expected annual average precipitation decreased in this year compared to the previous year, as the annual average precipitation was about 14.09 mm, with a decrease rate of 12.7%. April is the highest month of the year with an average of about 60.1 mm, followed by January, with a precipitation rate of 54.4 mm. In terms of seasons, winter is the highest season of this year which amounted to about 29.97 mm, followed by spring

with an average precipitation of 24.87 mm, and then autumn with 1.53 mm (Table 10 and Figure 29).

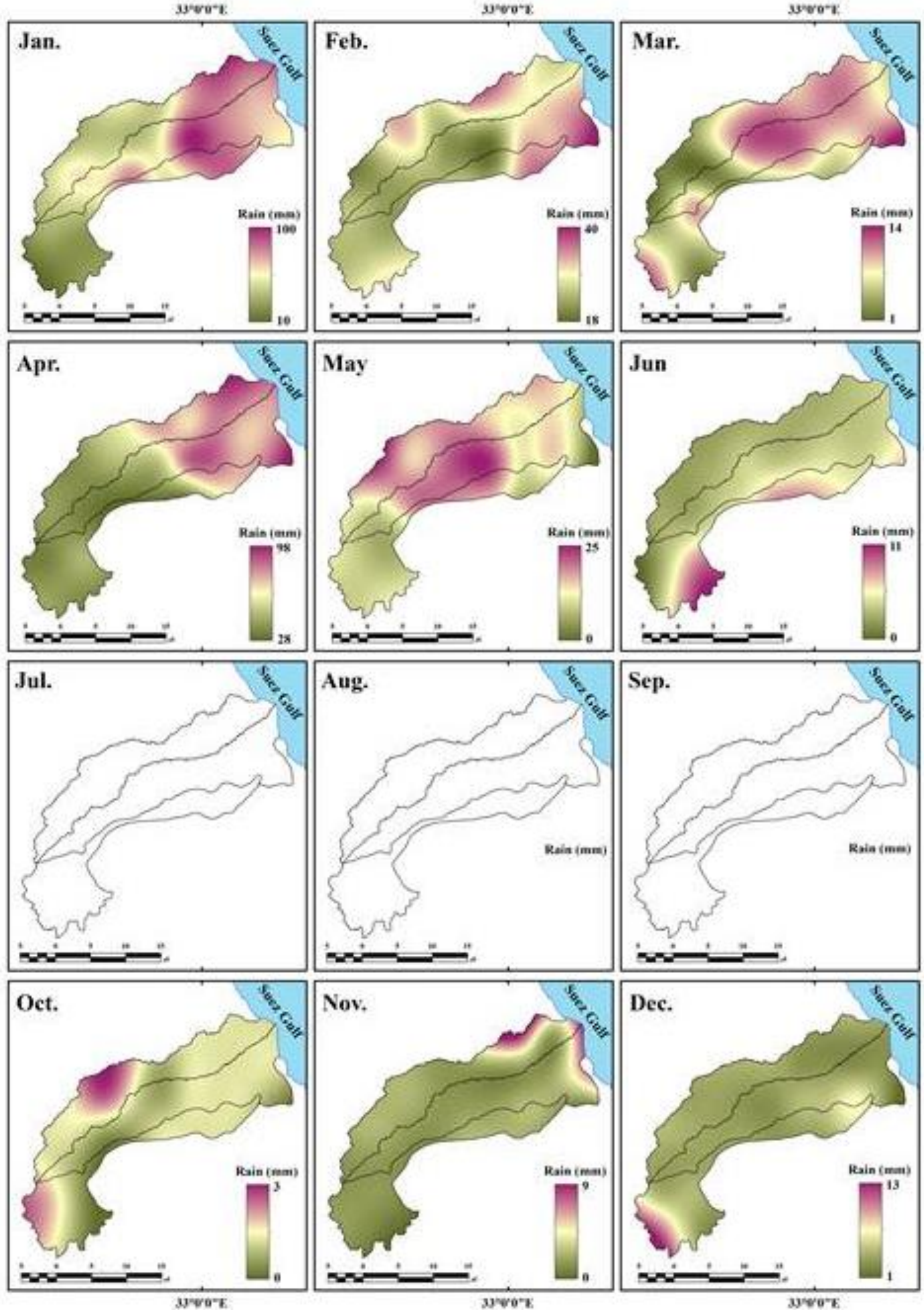

Figure 29: The expected monthly rainfall of the year 2019 on the area.

6) **2020**: The expected average of precipitation in this year was about 4.41 mm. It is thus considered the lowest year of the study in terms of the expected rate of precipitation. March is the highest month of this year with an average of about 16.0 mm. In terms of seasons, winter is the highest season of this year with an expected average of precipitation reached about 7.13 mm, followed by autumn (Table 10 and Figure 30).

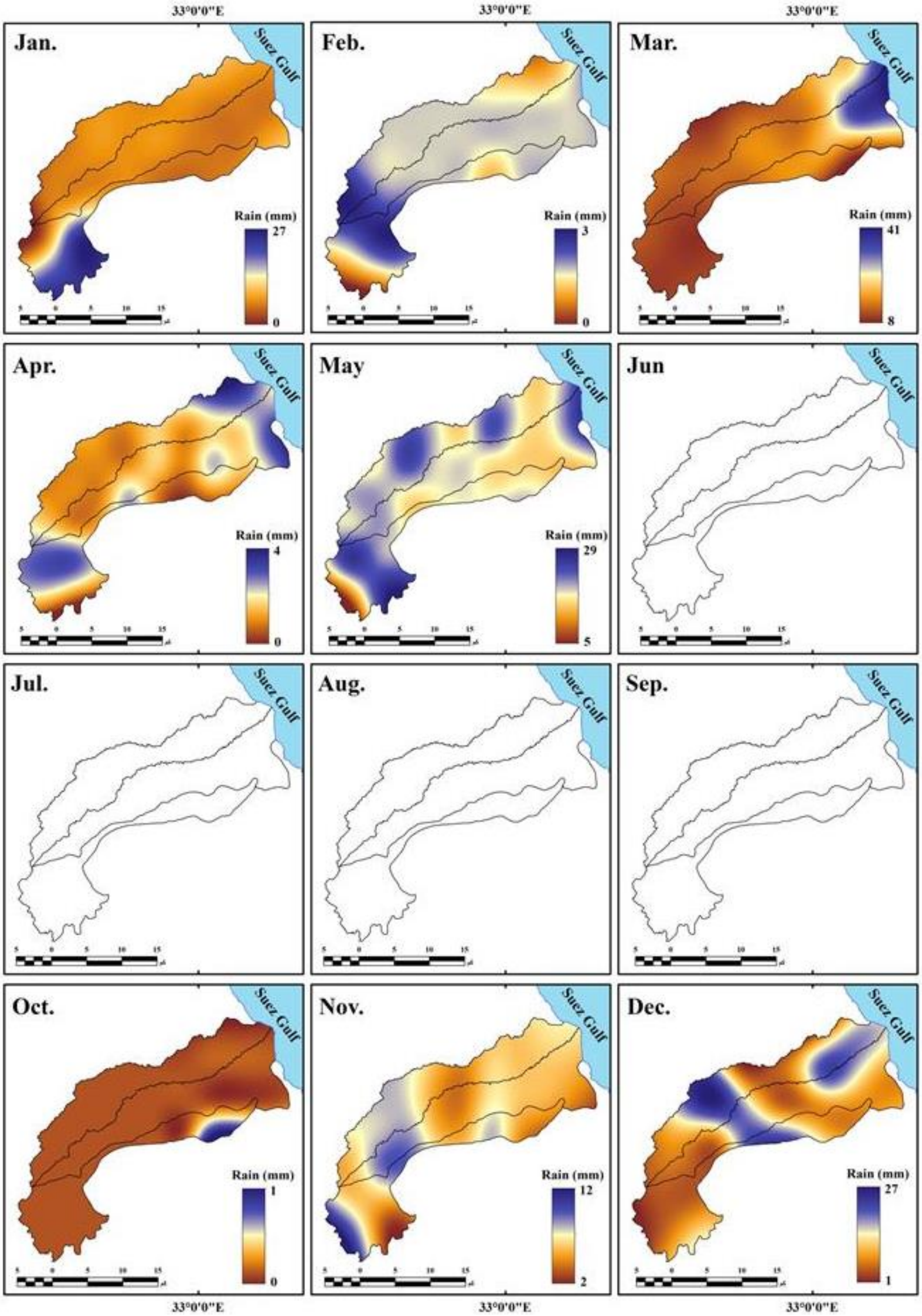

Figure 30: The expected monthly rainfall of the year 2020 on the area.

2021: The general average precipitation increased in this year, reaching 6.66 mm, with an increase rate of 50.9% over the previous year. December is the highest month of this year with a rate of about 34.0 mm, followed by October by about 18.7 mm. Spring was the highest season of expected precipitation with about 19.47 mm, followed by the winter and spring seasons, where the expected precipitation rates are about (3.63 - 3.53 mm) for each of them, respectively (Table 10 and Figure 31).

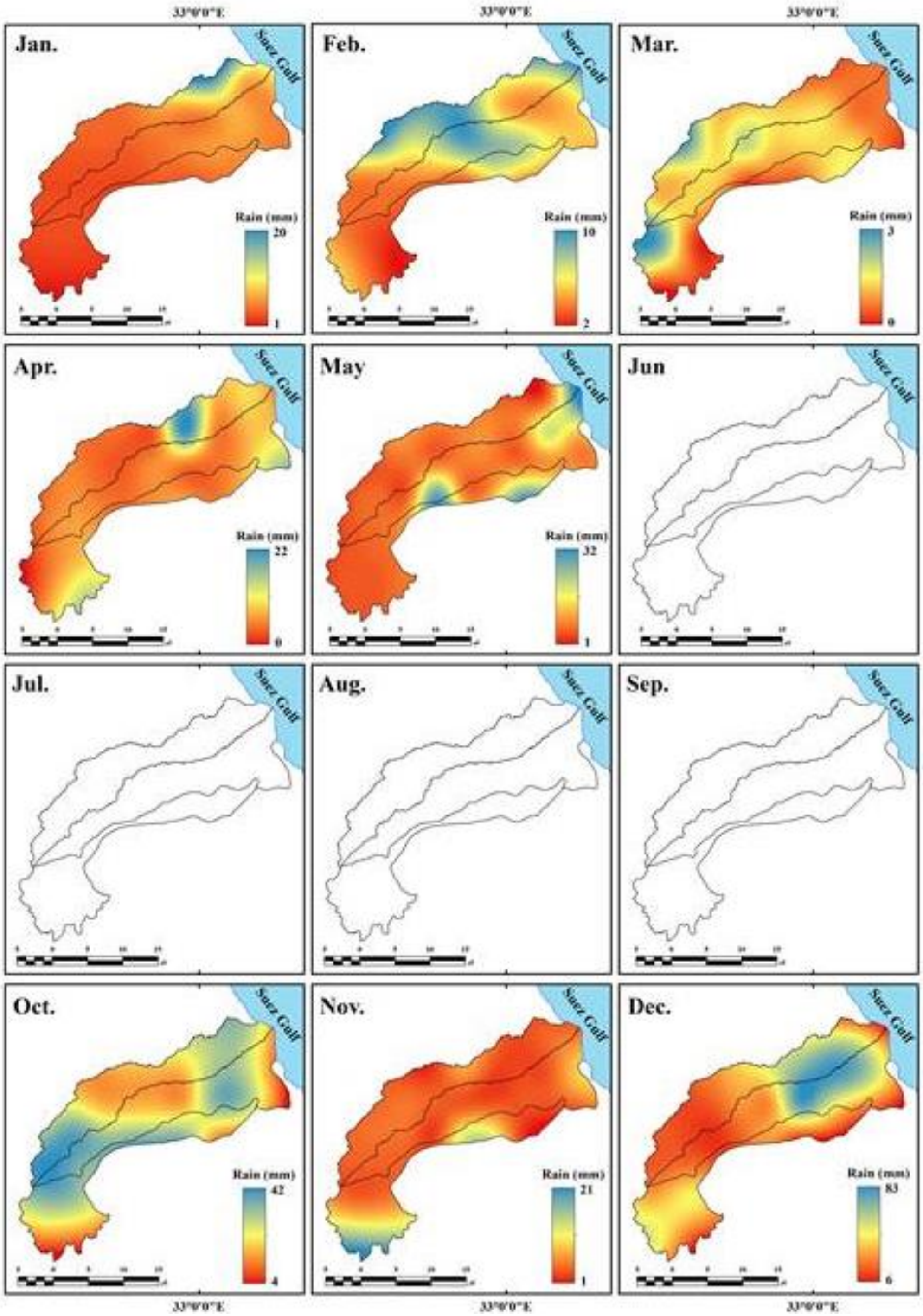

Figure 31: The expected monthly rainfall of the year 2121 on the area.

8.2 The measured Rainfall data and rainstorms design (Actual Data Measured)

The actual rain fall data used in this section was collected from Egyptian Meteorological Authority for the two closest meteorological stations to the study area which are Suez and Bir Arida stations (Figure 32). The collected data represent 6 years of records from 2016 to 2021, to be synchronous with the selected climate satellite images.

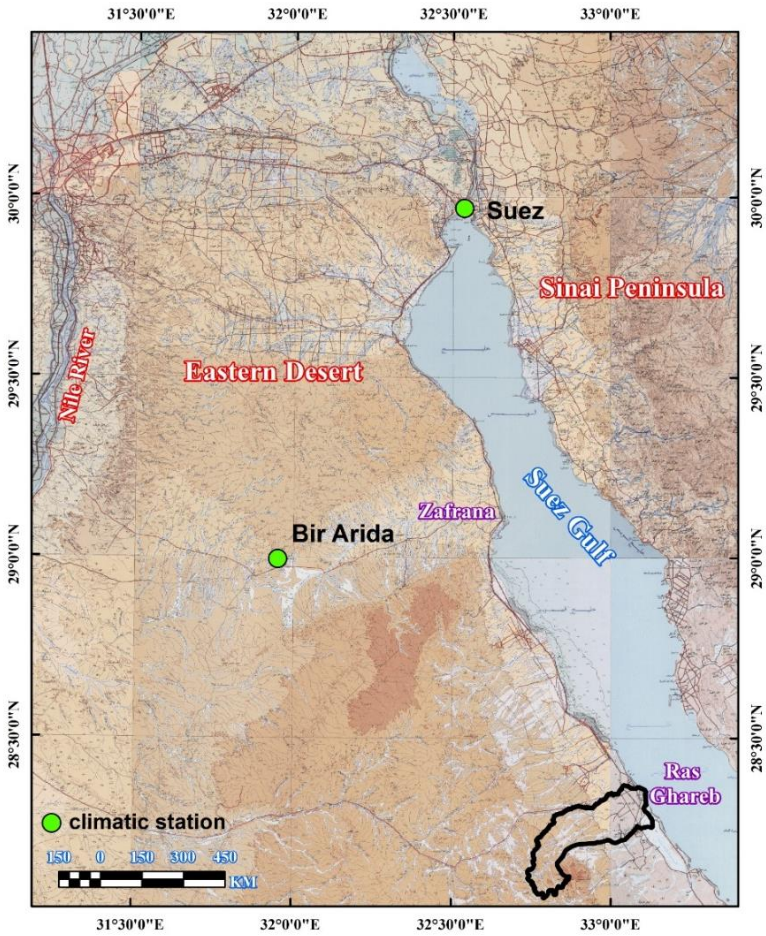

Figure 32: The weather stations close to the area basin

8.2.1 Recent rainfall data

The rain fall data of the 6 years (2016 – 2021) of Suez and Bir Arida Meteorological stations collected from the Egyptian Authority are shown in (Tables 11, 12).

Based on the comparison between the rainfall data expected from the satellite images and that actually measured (Tables 11, 12 and 13), important notes can be revealed:

- Concerning the year 2016 exactly in October, when the area of study subjected to heavy rainfall resulted in a dangerous flood hit the City of Rad Ghareb, the estimated rain fall depth from the satellite images expected to be 21 mm, where the actual measured rainfall from the closest meteorological stations was 3.4 mm at Bir Arida station and 0.8 mm at Suez station (Table 13).
- The actual rainfall depth could be representing about 16% of the expected rain intensity calculated from the satellite images.

Table 12: Monthly records of the rain fall data during the last 6 years of Bir Arida station

Parameter	Jan	Feb	Mar	Apr	Oct	Nov	Dec	year
No. of rainy days	2	-	1	-	1	-	1	2016
The quantity of rain (mm/month)	2	0	0.8	0	3.4	0	0.2	
The quantity of rain in one day (mm)	1.4	0	0.8	0	3.4	0	0.2	
The date of maximum rainfall	27	-	13	-	27	-	23	
No. of rainy days	-	1	1	-	-	-	-	2017
The quantity of rain (mm/month)	0	1.3	0.3	0	0	0	0	
The quantity of rain in one day (mm)	0	1.3	0.3	0	0	0	0	
The date of maximum rainfall	-	16	18	-	-	-	-	
No. of rainy days	1	2	-	1	-	-	1	2018
The quantity of rain (mm/month)	0.1	2	0	0.6	0	0	1.3	
The quantity of rain in one day (mm)	0.1	1.2	0	0.6	0	0	1.3	
The date of maximum rainfall	25	13	-	25	-	-	5	
No. of rainy days	1	1	1-	-	1	-	-	2019
The quantity of rain (mm/month)	0.1	0.1	1.8	0	1.6	0	0	
The quantity of rain in one day (mm)	0.1	0.1	1.8	0	1.6	0	0	
The date of maximum rainfall	20	15	30	-	22	-	-	
No. of rainy days	-	1	1	-	-	-	-	2020
The quantity of rain (mm/month)	0	4.8	9	0	0	0	0	
The quantity of rain in one day (mm)	0	4.8	9	0	0	0	0	
The date of maximum rainfall	-	24	12	-	-	-	-	
No. of rainy days	-	1	-	-	-	1	-	

The quantity of rain (mm/month)	0	2	0	0	0	1.6	0	2021
The quantity of rain in one day (mm)	0	2	0	0	0	1.6	0	
The date of maximum rainfall	-	4	-	-	-	4	-	

Table 13: Monthly records of the rain fall data during the last 6 years of Suez station

Parameter	Jan	Feb	March	April	Oct	Nov	Dec	year
No. of rainy days	2	-	1	-	1	-	-	2016
The quantity of rain (mm/month)	1.8	0	0.2	0	0.8	0	0	
The quantity of rain in one day (mm)	1	0	0.2	0	0.8	0	0	
The date of maximum rainfall	27	-	26	-	27	-	-	
No. of rainy days	-	-	1	-	-	-	-	2017
The quantity of rain (mm/month)	0	0	0.8	0	0	0	0	
The quantity of rain in one day (mm)	0	0	0.8	0	0	0	0	
The date of maximum rainfall	-	-	22	-	-	-	-	
No. of rainy days	1	1	-	2	-	2	1	2018
The quantity of rain (mm/month)	0.5	0.6	0	3	0	3.1	1.8	
The quantity of rain in one day (mm)	0.5	0.6	0	2.3	0	2.1	1.8	
The date of maximum rainfall	26	12	-	25	-	23	5	
No. of rainy days	-	2	1	-	1	-	-	2019
The quantity of rain (mm/month)	0	5.1	4	0	3	0	0	
The quantity of rain in one day (mm)	0	4.6	4	0	3	0	0	
The date of maximum rainfall	-	6	5	-	22	-	-	
No. of rainy days	-	1	2	-	-	-	-	
The quantity of rain	0	16.4	36.5	0	0	0	0	

(mm/month)								2020
The quantity of rain in one day (mm)	0	16.4	25.4	0	0	0	0	
The date of maximum rainfall	-	24	12	-	-	-	-	
No. of rainy days	-	2	-	-	-	1	2	2021
The quantity of rain (mm/month)	0	7.6	0	0	0	0.3	0.7	
The quantity of rain in one day (mm)	0	5.2	0	0	0	0.3	0.6	
The date of maximum rainfall	-	5	-	-	-	21	31	

- In April and December 2017, now actual rainfall was recorded in the meteorological stations, whoever the expected rainfall was 69 and 77 mm respectively (Table 13).
- In the year 2018, the expected rainfall was high in most of the rainy months reached 90 mm in February except January, while the maximum recorded rainfall at Bir Arida station was 2 mm in February and 3 and 3.1 mm in April and October. No flooding or even violent surface flow was recorded in the study area.
- In January and April 2019, the estimated rainfall depth was 100 and 98 mm, respectively, while the recorded rainfall at Bir Arida station was 0.1 and 0, respectively and no rainfall recorded at Suez station (Table 13).
- In February and March 2020, the expected rainfall depths were 3 and 41 mm, while the measured rainfall at Bir Arida station were 4.8 and 9 mm, respectively and at Suez station were 16.4 and 25.4 mm, respectively. However, the measured rainfall depth in March is high at the two stations, no recorded flooding or strong surface flow in the study area.
- Although the rain expected to fall on the area in December 2021 was 83 mm, no rain was recorded in the region in this month at Bir Arida station and 0.7 mm at Suez station (Table 13).

Table 14: The expected rainfall compared with the actual rainfall depths during the period (2016 to 2021)

Month	2016			2017			2018			2019			2020			2021		
	Ex.	M. BA	M. S	Ex.	M.	M. S	Ex.	M.	M. S	Ex.	M.	M. S	Ex.	M.	M. S	Ex.	M.	M. S
Jan.	4	2	1.8	19	0	0	1	0.1	0.5	100	0.1	0	27	0	0	20	0	0
Feb.	6	0	0	0	1.3	0	90	2	0.6	40	0.1	5.1	3	4.8	16.4	10	2	7.6
Mar	78	0.8	02	21	0.3	0.8	28	0	0	14	1.8	4	41	9	25.4	3	0	0
Apr	10	0	0	69	0	0	43	0.6	3	98	0	0	4	0	0	22	0	0

Oct.	**21**	**3.4**	**0.8**	0	0	0	59	0	0	3	1.6	3	1	0	0	42	0	0
Nov.	30	0	0	25	0	0	25	0	3.1	9	0	0	12	0	0	21	1.6	0.3
Dec.	2	0.2	0	77	0	0	46	1.3	1.8	13	0	0	27	0	0	83	0	0.7

Ex.: Expected precipitation based on analyses of the satellite images
M. BA: Measured precipitation data from the Bir Arida meteorological station
M. S: Measured precipitation data from the Suez meteorological station

8.2.2 Estimation of the rainstorms returns probability

To estimate the probability of the occurrence of floods in the study area and the time of their return, the data of the meteorological stations in the study area was relied on to obtain the highest amount of rain that fell in one day in these stations during the period (2016-2021). The maximum values 25.4 mm and 9 mm were recorded in the Suez and Bir Arida stations in the year 2020, respectively (Tables 11, 12). These values have been arranged in descending order so that the highest value of rain takes the first place, followed by the rest of the values, and so on (Rank) as shown in Table (13). The amount of rainfall over the Red Sea Mountains (RRSM) was also calculated, with an increase of 25% over the precipitation in the same period, according to a study of (Gheith & sultan, 2002). The probability of the occurrence of flash flood in the region (P (%)) was calculated by relying on the equation (Critchley & Siegert, 1991) as follows:

$$P\ (\%) = \frac{m - 0.375}{N + 0.25}\ X\ 100$$

$$P(\%) = \frac{m - 0.375}{N} + 0.25)\ X\ 100$$

P = probability in % of the observation of the rank m

M = the rank of the observation

N = the total number of observations used

By applying this equation to the data of the maximum amount of rain available, it becomes clear that the probability of March 12, 2020 flood "the strongest torrent that occurred in the region during the study period" to be returned again reaches 1.8%. As the amount of rainstorm water is inversely correlated with the probability of occurrence of flash flooding, the large floods are less likely to occur than small-scale ones. The time of return of floods Tp (yr) was also calculated through following the equation.

$T = \frac{100}{P1}\ (years)$ TP = 100/P

From the previous equation, the return time of floods was calculated, which is inversely proportional to the probability of the occurrence. The higher the probability of the flood is the less time period for its return and vice versa (Table 14 and Figure 33). Based on the foregoing, the probability of the return of the flood of March 12, 2020 is about 55.6 years. Therefore, it is expected that a flood that is similar in strength to the flood of 2020 could be returned by the year 2076.

Table 15: The calculated data of rainstorm returned probability

Date	year	Rain $_{max}$ (mm)	RRSMG	Rank	P (%)	T_p (yr)
27/1	2016	1	1.25	21	59.4	1.7
27/1	2016	1.4	1.75	17	47.8	2.1
13/3	2016	0.8	1	22	62.2	1.6
26/3	2016	0.2	0.25	31	88.1	1.1
27/10	2016	0.8	1	23	65.1	1.5
27/10	2016	3.4	4.25	8	21.9	4.6
23/12	2016	0.2	0.25	32	91	1.1
16/2	2017	1.3	1.63	18	50.7	2
18/3	2017	0.3	0.38	29	82.4	1.2
22/3	2017	0.8	1	24	68	1.5
25/1	2018	0.1	0.13	33	93.9	1.1
26/1	2018	0.5	0.63	28	79.5	1.3
12/2	2018	0.6	0.75	25	70.9	1.4
13/2	2018	1.2	1.5	20	56.5	1.8
25/4	2018	2.3	2.88	10	27.7	3.6
25/4	2018	0.6	0.75	26	73.7	1.4
23/11	2018	2.1	2.63	11	30.6	3.3
5/12	2018	1.8	2.25	13	36.3	2.8
5/12	2018	1.3	1.63	19	53.6	1.9
20/1	2019	0.1	0.13	34	96.8	1
6/2	2019	4.6	5.75	6	16.2	6.2
15/2	2019	0.1	0.13	35	99.6	1
5/3	2019	4	5	7	19.1	5.2
30/3	2019	1.8	2.25	14	39.2	2.6
22/10	2019	3	3.75	9	24.8	4
22/10	2019	1.6	2	15	42.1	2.4
24/2	2020	16.4	20.5	2	4.7	21.3

24/2	2020	4.8	6	5	13.3	7.5
12/3	2020	25.4	31.75	1	1.8	55.6
12/3	2020	9	11.25	3	7.6	13.2
4/2	2021	2	2.5	12	33.5	3
5/2	2021	5.2	6.5	4	10.4	9.6
12/11	2021	1.6	2	16	45	2.2
21/11	2021	0.3	0.38	30	85.3	1.2
31/12	2021	0.6	0.75	27	76.6	1.3

The depth of rain in some of the required repetitive periods (2-5-10-25-50-100 years) was calculated by applying the Long normal statistical distribution (Maximum Likelihood), which led to the prediction of the following amounts of rain as the maximum amount of rain that could fall in one day (Table 14, Figures 33, 34):

Table 16: Maximum rainwater could be received in one day

Return Period (year)	**Rain Depth (mm)**
2	1.21
5	3.79
10	6.88
25	13.0
50	19.6
100	28.4

It is noted from the data of the previous table that the maximum amount of rain expected to fall in one day increase with the increase in the time period. It can reach about 1.21 mm during two years return period, while it is expected to reach 28.4 mm in return period of 100 years.

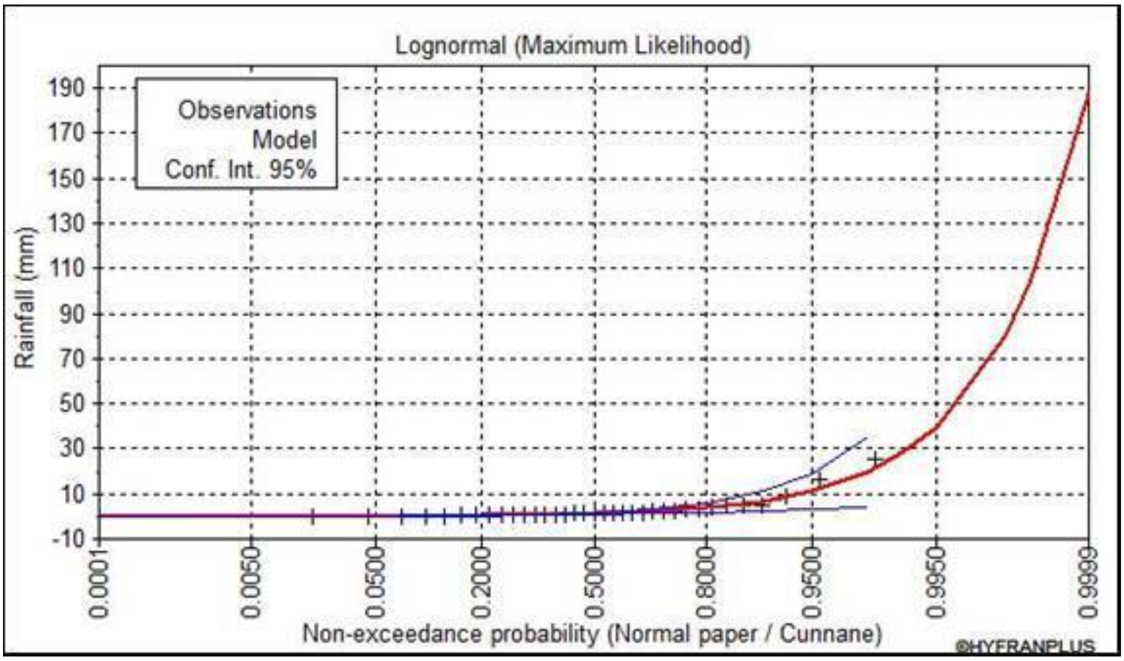

Figure 33: The probability of rain fall intensity

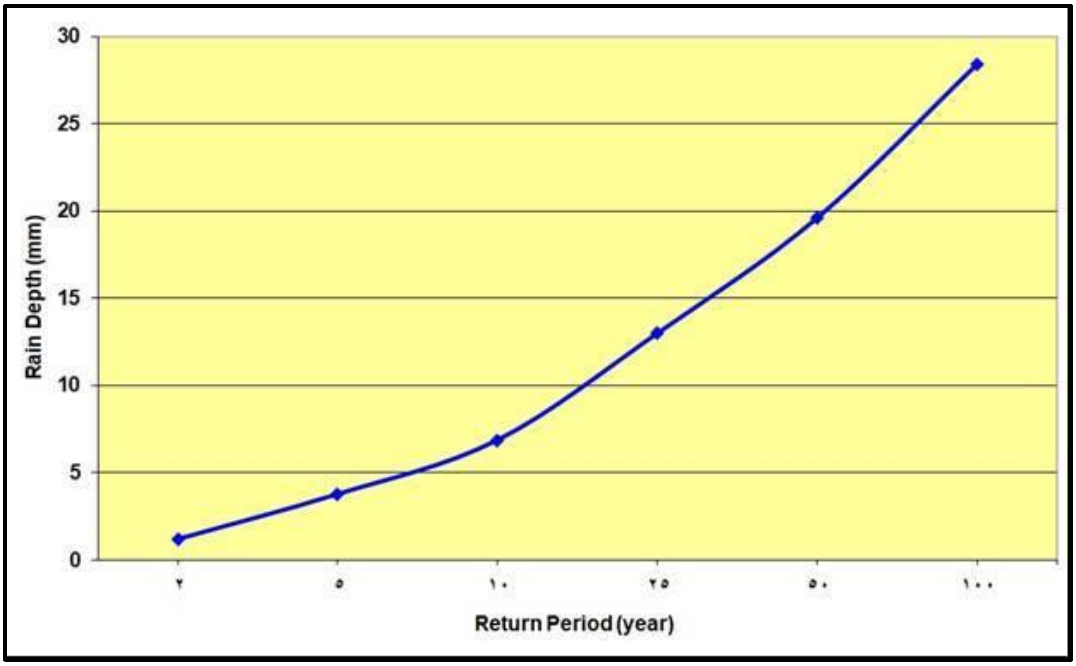

Figure 34: The returned periods of the maximum rainfall intensity.

Based on the above detailed study of the actual rainfall data collected from the closest meteorological stations to the project site (Air Arid station and Suez station), the following points could be concluded:

- In October 2016 when the study area received heavy rainfall that resulted in strong flooding, the recorded rainfall at Bir Arida station (to the NW by about 120 km from the site), and Suez stations (to the N by about 200 km from the site) was 3.4 and 0.8 mm respectively.
- In the year 2020 when the above two stations recorded 9 and 25.4 mm rainfall depths, respectively, the area of study did not subject to dangerous flooding.

- Global worming phenomena has been taken in consideration when designing the rainstorms and their returned periods through; 1) increase the amount of the recorded precipitation by about 25%, and 2) the calculation based on the maximum rainfall depths recorded in one day in the two stations (March, 2020) rather than the value recorded during the occurrence of floods (October 2016).
- The rain storm that recorded by 9 mm at Bir Arida and 25.4 mm at Suez station could be returned in a period of about 55 year.
- The rainstorm recorded during the occurrence of flooding in the study area at Bir Arida (3.4 mm) could be returned in 5 years.
- After the catastrophic flood event of the year 2016 on the study area, the mitigation applied along the dangerous drainage basins in the area like, three successive dams with artificial lakes along the main stream of Wadi Hawashyia 20 km to the north of the site, group of successive dams with lining the road and placing many culverts underneath to prevent the flow of water above the road along Wadi Abu Had, just to the north of the site, a dam with artificial lake at the mouth of Wadi Al Darb, east of the site, and Constructing concrete fences with a height of about 1 to 2 meters to protect the existing facilities in the tributaries that feeding the main stream from surface runoff. This is represented in the fences built around the power station, the high voltage towers and the communication towers located in Wadi Abu Had.
- All the above mitigations to great extent save the downstream cities (Ras Ghareb) and infrastructures (asphaltic roads, power stations, and power and communication towers) from the danger of floods and strong surface flow in the drainage lines distributed in the middle and upstream parts of the drainage basins.

9. Morphometric Analysis

9.1 The location and morphometric characteristics of the site

The study area is located on the coast of the Gulf of Suez, where the drainage basins of the region end to the Gulf at the city of Ras Ghareb and its south. Three drainage basins crossing the project site which are Wadi Al Darb, Wadi Kahrim and Wadi Abu Khashba (Figure 34). The area under consideration is bounded from the north by the watershed of wadi Abu Had Basin, from the south by Wadi Ghareb basin, from the southwest by Wadi Qena basin, from the west by the Wadi Tarfa basin, and from the west by the Wadi Tarfa basin. The area extends between latitudes 28° 3' 20.6" & 28° 22' 29.6" north, and extends between longitudes 32° 44' 9.7" & 33° 8' 1.3" east, (Figure 35).

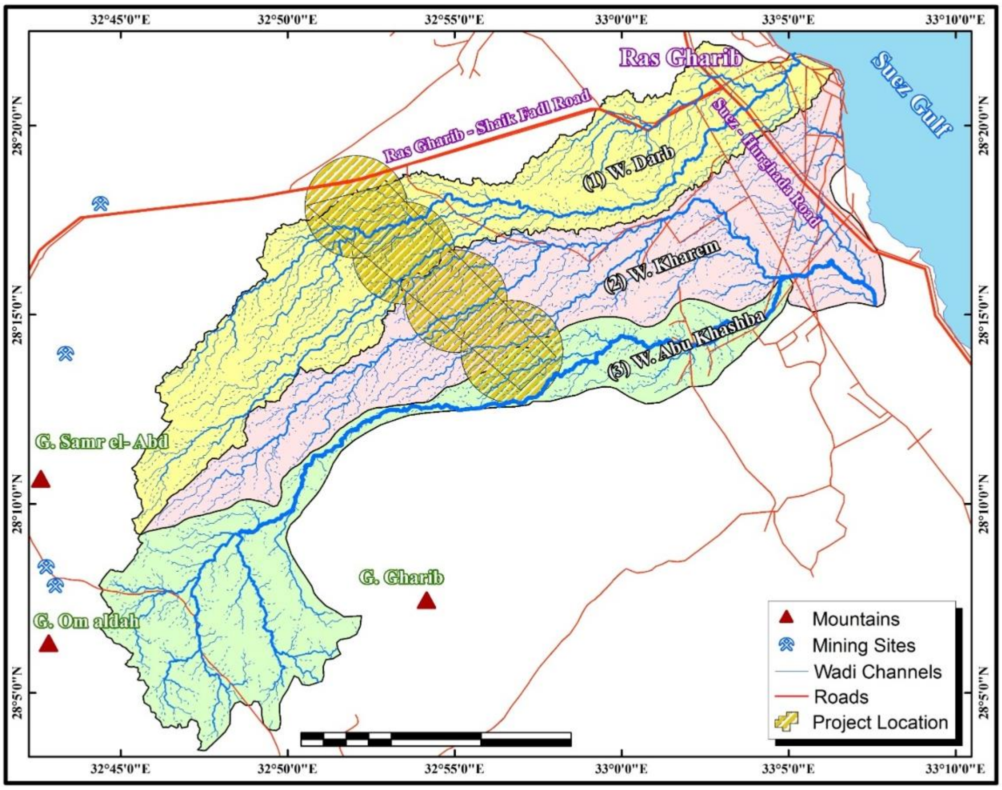

Figure 35: The site location

The project site is located in the middle part of the three basins where the outlet streams are to the east. The three drainage basins crossing the site will be studied and analyzed in the following.

9.2 The morphometric characteristics of drainage basins

Morphometric refers to the process of numerical analysis of earth surface features from topographic maps, Land Sat images and DEM that are supplemented by aerial, space and field measurements. The morphometric analyses of the three studied basins were done using ARC-GIS software and the values were compared to the limits of the basins along the Red Sea. The morphometric studies of the drainage basins are important to determine their hydrological characteristics and consequently the severity of the floods.

The morphometric parameters of the basin include the:

- Basin dimension
- Basin shape
- The topographic features of the basin.

a) Basin Dimension

They are represented by the area, length, width and perimeter.

Basin area (A) km^2

The area of the drainage basin measures the region that includes all the tributaries located within the basin territory and which is surrounded by the water-dividing line. The area of the basin is affected by the growth of the watercourse network and its distribution pattern.

There is an inverse relationship between the area of the drainage basin and the volume of sediments that the wadi transports to the downstream part, the greater the area, the less the volume of sediments the wadi carries to the downstream part. The potential power of the drainage basin to retain sediments increases with the increase in its area. The larger the drainage basin area, is the greater the capacity of the basin to retain and store sediments temporarily or permanently within the drainage basin itself (Muhammad Abd al-Latif, 2008, p. 57).

The area of the basin has an influential role in the possibility of floods, as there is a direct relationship between the areas of the basins and the discharge volume. The larger the area of the basin, the greater the volume of rain it receives and the higher possibility of flooding (Jouda etal, 1991). Therefore, there is a greater probability of flooding in large-sized basins than small ones (Cooke et al., 1985).

The area of the Red Sea basins ranges from 1796.5 km^2 (high flood risk) to 2.8 km^2 (low flood risk). Based on the software, the areas of the studied three basins are indicated in Table 15.

It becomes clear that the total area of the studied basins is about 515.8 km2, with a general average of about 171.93 km2. The area of the basins is ranged from 150.9 km2 (Wadi Abu Khashba at the south) the smallest one, to 185.3 km2 (Wadi Kharim). **Based on the role of basin area in expecting floods, Wadies Kharim has highest possibilities of expecting floods rather than the other two wadies.**

Table 17: The morphometric parameters of the studied 9 basins crossing the project site.

	W. Darb	W. Kharim	W. Abu Khashba	Average
A (km^2)	179.6	185.3	150.9	171.93
LB (Km)	38.4	44.1	55.2	45.90
W (Km)	4.3	4.8	3.6	4.23
Pr (Km)	113.9	109.4	107.8	110.37
Re	0.394	0.348	0.251	0.33
Rc	0.175	0.196	0.164	0.18
Ish	0.122	0.095	0.05	0.09
SH	2.397	2.267	2.475	2.38
Rlw	8.93	9.188	15.333	11.15
Rf	779	792	1126	899
Rh	20.29	17.96	20.40	19.55
Rr	0.684	0.724	1.045	0.82
Rn	2.427	2.373	3.068	2.62
Hi	0.231	0.234	0.134	0.20
Sl	1.162	1.029	1.169	1.12
Rb	4.18	4.11	3.57	3.95
D (km^{-1})	3.115	2.997	2.724	2.95

	W. Darb	W. Kharim	W. Abu Khashba	Average
F (km^{-2})	3.614	3.648	4.023	3.76
Rm	0.321	0.334	0.367	0.34
Lo	1.558	1.499	1.362	1.473
Rt	5.698	6.179	5.631	5.84

A; area of the basin (km^2)**,** BL basin length (km), W basin width (km), Pr perimeter of the basin (km), Re elongation ratio, Rc circularity ratio, Ish shape index, SH compactness ratio, K Lemniscates ratio, Rlw Length / Width Ratio, Rf relief (m), Rh relief ratio, Rr Relative relief, Rn ruggedness number, Gn Geometric Number, Hi Hypsometric Integral, Sg slope index, kc order of trunk channel, Snu sum of stream numbers, Slu sum of stream lengths (km), Rb bifurcation ratio, D drainage density by Horton method (km^{-1}), F stream frequency (km^{-2}), Rm Stream Maintenance Ratio, Lo length of overland flow (km), Rt texture ratio (Km^{-1}).

Basin Length (LB) km

The length of the basin is one of the basic dimensions on which to calculate certain morphometric parameters that depend on the length of the basin, especially the shape coefficients, and to determine some of the shape and topographic characteristics of the drainage basins (Gregory & Walling, 1973).

The length of the basin is influenced by a number of factors and processes which are as follows the growth direction and development of watercourses, which in turn are subject to the direction of the faults and fractures, the head ward erosion towards the water divide line or downstream with the growth of flood alluvial fans.

The length of the basin was measured using the ARC GIS software based on the method adopted from Schumm, 1956. The length of the basin is the distance from the mouth of the mainstream to the furthest point on the perimeter parallel to the main stream.

The total length of the studied three drainage basins is about 137.7 km, with an average of 45.9 km, where Wadi Al darb the less length among them of about 38.4 km followed by W. Kharim (44.1 km) and Abu Khashba 55.2 km. (Table 15).

The shorter is the length of the basin, the strong the water flow through it. Accordingly, Wadies Al darb basin could have strong surface water flow during the rainfall storms higher than the other two basins.

Basin width (W) km

The width of the basin contributes to the identification of its shape.

In general, it is possible to say that the basins of small length and width are the most dangerous ones. This is because their basins areas are small, short in length and width. Therefore, they can be totally covered by the rainstorm in a short period with limited water loss by leakage and evaporation. Thus, the surface runoff takes a short time to reach the outlet of the Wadi.

The total width of the studied basins is about 12.7 km, with an average of 4.23 km. Like basin length, the shorter the width, the higher water flow, so W. Kharim basin is expected to be less dangerous basin than the other two.

Perimeter of the basin (Pr) km

The perimeter is the water divide line which separates one basin from the adjacent basins.

The importance of measuring the perimeter of the basin is that it is used to calculate other morphometric parameters such as shape coefficients, basin elongation and basin circularity (Khader, 1997 and Mahsoub, 2002).

The basin Perimeter is affected by several factors, such as the development of first order tributaries, the emergence of seasonal small tributaries which arise after the rainstorms, and by the decline of slopes that their peaks represent water dividing lines of basins. Based on the software, the total perimeters of the basins reached 331.1 km with an average of about 110.37 km. Wadi Abu Khashba has the shortest perimeter of about 107.8 km followed by Wadi Kharim and Wadi Al Darb of 109.3 and 113.9 km, respectively (Table 15).

Based on the foregoing, the shorter the basin perimeter, the less its area and the rest of its dimensions and the greater its risk levels concerning flood possibility and vice versa. Therefore, Wadi Al Darb is considered as the less dangerous basin rather than the other two wadies.

b) **Basin shape**

The shape of the basin and its proximity to the circular or rectangular shape contributes to the time required for the arrival of the flood to the outlet of the basin. Then, assess the extent of the basin's impact on the facing objects. The shape of the basin also affects the recharge potential of the aquifer (Rashidi, 1994).

The shape of the discharge basin affects the flow of water as elongated basins have water discharge with more uniform time distribution and less in quantity than circular basins. On the other hand, the circular basins are characterized by their abundance of water, where water accumulates in most of the tributaries in one central area within a short time period and reaches the basin’s outlet in short time resulted in flooding.

Some morphometric parameters have been developed using the Arc GIS software that determine the degree of affinity of the drainage basin shape as follows:

Elongation Ratio (Re)

Elongation is one of the most accurate morphometric factors in measuring the forms of drainage basins, as it compares the shape of the drainage basin and the shape of the rectangle. The values of this ratio range between (0 : 1). The higher is the value, i.e close to 1, indicates that the shape of the basin is more approaching a rectangle shape and vice versa, i.e., the shape of the basin is close to the rectangular shape (Gardiner, 1975).

The elongation ratio indicates the level of flow in the basin. The longer is the basin length i.e., the higher the elongation and the irregularity, the less the flow of water exists and the less likely flooding to occurs.

The average of the elongation ratio of the studied basins is about 0.33 km, which indicates the tendency of these basins to elongation.

The elongation ratio of the Red Sea basins ranges from 0.32 (high risk) to 0.83 (low risk). The Elongation ratios in the three studied basins are listed in table 15. **This Ratio indicates that the studied drainage basins are medium to high flood possibility.**

Circulatory Ratio (Rc)

The circulatory ratio shows the degree of similarity of the basin boundary with the circle. It studies the relationship between the area of the basin and the area of a circle with a perimeter equal to the perimeter of the basin. The small value of this ratio close to zero" reflects the following:

- The irregular shape of the basin (close to elongation)
- The increase of the meander of the water divide lines
- The low risk of the basin in case of floods
- The high value of this ratio" close to unity" means that the basins are approaching the circular shape (Al-Wedani, 2007).

Basins with small areas are often more circular because they have not yet reached the advanced geomorphological stage compared to the large basins which are often inclined to elongation. The circular shape leads to accumulation of the water from most tributaries in the main course at the same time resulting in a sudden high discharge leading to devastating floods (Morisawa, 1958). The circularity ratio can be calculated according to the following equation (Gregory & Wallind, 1979); $Rc = \frac{4\pi A}{P2}$

Where; Rc = circularity ratio, π = 3.14, A = area (km2), and P = basin perimeter

The circularity of the Red Sea basins ranges from 0.13 (low risk) to 0.52 (high risk). The average circulatory ratio of the studied three basins is 0.18. The studied three basins are characterized low flood possibility could be expected in these three basins are their circularity values are close to zero (Table 15).

Shape Index (Ish):

The shape index expresses the degree of consistency between the dimensions of the basin where the shape of the basin is compared to triangle or square shape. The Ish was calculated by the following equation (Horton, 1932), using the ARC – GIS software.

Ish = A/L² $Ish = A/L^2$

Where; Ish = shape index, A = basin area (km2) , and L = basin length (km)

The low value of this factor indicates that the basin approaches the shape of the triangle and with low flood risk, while the high value of this factor indicates that the basin is close to the square shape and with high flood risk. The shape index is the numerical index (Horton, 1932) commonly used to represent different basin shapes. The international range of this factor is between 0.1-0.8. The shape indices of the studied basins are indicated in table 16. The average of the shape index factor of the three basins is 0.09.

The shape index that the Red Sea basins range from are 0.08 (low risk) to 0.54 (high risk). The smaller the value of this factor, the more elongated the basin is. The basins with high shape index of 0.8 or above have high peak flows of flood in a short period. However, the elongated drainage basin with low shape index has lower peak flow of flood in a long period. According to the calculated shape index factor of the studied basins (Table 15) compared with the whole Red Sea basins values, it can be stated that, the studied three basins are approaching the triangle shape (elongated) and thus they are of low flood risk possibility.

Length / Width Ratio (R/W)

It is considered one of the simple morphometric factors that measure the direction of the basin to the circular or rectangular shape. The increase in the value of this ratio indicates the proximity of the basin shape to the rectangle and can be calculated as follows:

R/W = L/W

Where; R/W = length/width ratio, L = basin length, and W, basin width.

The average of this ratio is 11.15 for the studied drainage basins. The high value indicates an increase in the length of the basins relative to their width, and thus basins tend to be elongated. The values of the length/width ratio of the studied drainage basins range from 8.93 for Wadi Al Darb to 15.33 Wadi Abu Khashba. This means that the three studied basins are more approaching rectangular shape and they are of low flood risk possibility.

c) **The morphological features of drainage basins**

The characteristics of the surface affect the hydrology of the basin regarding surface runoff. Surfaces with gentle slopes provide an opportunity to increase evaporation and leakage losses, due to the fact that rainwater takes longer time to runoff, while steep sloping surfaces reduce losses and help water to flow faster (Khedr, 1997). The characteristics of the surface of drainage basins will be based on several morphometric parameters as follows:

1) Maximum Relief, 2) Relief ratio, 3) Relative Relief, 4) Ruggedness value, 5) Geometric number, 6) Hypsometric integral, and 7) Slope gradient.

Maximum Relief (Rf)

It means the difference between the lowest point at the outlet of the basin and the highest point at the water divide.

There is a direct relation between the maximum relief and the slope gradient on one hand and the intensity of surface flow and the number of loaded materials, and then the severity of the drainage basin on the other hand. The higher the difference, the steeper the slope becomes, and thus the higher the flow of water is. The maximum relief of the Red Sea basins varies from 30 (low flood risk) to 2088 m (high flood risk). Based on the software, the maximum relief of the three studied basins is shown in table 15. The average value of the maximum relief is 899. Based on the basins values compared with the average values of the Red Sea drainage basins, the studied basins could be categorized as low to medium flood risk possibilities.

Relief Ratio (Rh)

The Relief ratio measures the relationship between the maximum relief and the length of the basin, and thus reflects a direct image of the slope of the basin surface. The basin surface is more significant than the maximum relief where it does not take into account the horizontal distance between the lowest and highest levels. The relief ratio was calculated by the equation provided by Strahler (1957).

Relief Ratio (Rh) = Maximum Relief (m) / Basin Length (km)

The type of rock, the amount of rain and the morphological stage of the basin are important factors that lead to a low Relief Ratio (Moussa, 2000). The higher the relief ratio of the basin, the higher is the risk of the flooding. The relief ratio of the Red Sea basins varies from 7.4 (low flood risk), to 109.5 m/km (high flood risk). The average of Rh values of the studied three basins is 19.55, where Wadi Kharim has the lowest value of about 17.96 which increased to 20.40 and 20.29 for the basins Wadi Abu Khashba and wadi Al Darb, respectively (table 15). **C**ompared with the Red Sea basins values, the three studied basins could be classified as low flood risk possibility, in case of heavy rain fall events.

Relative Relief (Rr)

The Relative Relief measures the relationship between the maximum relief (the difference between the highest and lowest level in the basin) and the basin perimeter. It can be calculated as follows; (Gregory & Walling, 1979)

Relative Relief = [Maximum Relief (m)/ Basin perimeter (km)] *100

The Relative Relief coefficient is inversely related to the area of the basin, and the degree of rock resistance to erosion in the case of constant climatic conditions (Jode et al., 199). The relative relief of the Red Sea basins varies from 0.2 (low risk) to 3.4 (high risk). Based on the software, the average relief ratio of the studied three basins is 0.82. Wadi Al Darb has the lowest value of about 0.68 increased to 0.72 and 1.05 for Wadi Kharim and Wadi Abu Khashba, respectively. These values may reflect the low resistance of rocks to erosion in Wadies Al Darb and Kharim to moderate resistance in Wadi Abu Khashba. These Relative Relief values of the studied basins indicate low to medium flood risk expected at the outlet parts of the studied basins.

Ruggedness number (Rn)

This coefficient examines the relationship between the topography of the basin and the length of its drainage network. It deals with the mutual relationship between more than two variables. It measures the relationship between the basin's relief with the lengths of the stream and the basin area. The Ruggedness value expresses the relationship between the basin relief and the density of drainage. Therefore, it is highly dependent on the type of rock and the abundance of rain (Awadallah, 2005). The ruggedness value was calculated by using ARC-GIS based on the formula of Strahler (1964).

Ruggedness = Basin topography (m) × Drainage density (km/km^2) / 1000

The ruggedness value of the Red Sea basins varies from 1.3 (low risk) to 30.9 (high risk). Based on the software, the average value of the ruggedness ratio is 2.62 of the studied three basins. The values of the three basins are 2.4, 2.4, and 3.1 for Wadi Al Darb, Wadi Kharim and wadi Abu Khashba, respectively. These values reflect the low flood risk possibilities in the studied basins.

Hypsometric Integral (Hi)

The hypsometric integral represents the age stage of the basin based on the relationship between the area and the topography (Khader, 1997). Hypsometrical integration of basins was calculated by the following equation (Mustafa, 1982) using the ARC- GIS software:

Hypsometric integral = Basin area (km^2) / Maximum basin topography (m)

The values of the hypsometrical integral of the Red Sea basins vary from 0.02 m, (low risk) to 1.6 m, (high risk). Based on the software, the hypsometric integral of the studied three basins are 0.231, 0.234 and 0.134 for Wadi Al Darb , Wadi Kharim and Wadi Abu Khashba, respectively. This indicates that all the three basins in the studied area are of low flood risk possibilities.

Slope index (SI)

The slope index measures the relationship between horizontal distance (basin length) and vertical distance (the difference between the lowest and the highest elevations expected in the basin). This index indicates the extent of basin erosion (Khader, 1997). This relationship is expressed by the following equation:

Slope index = [(Maximum basin topography/Maximum basin length) *1000] *57.3

Basins that have low slope index are characterized by slow gradient, slow surface water flow and less danger basin and vice versa. The slope gradient values of the Red Sea basins vary from 0.9, (low risk) to 13.4, (high risk). Based on the software, the hypsometric integral of the studied three basins are 1.16, 1.03 and 1.17 for wadies Al Darb, Kharim and Abu Khashba, respectively. The slope gradient of the studied basins is low, indicating the slow surface water flow and the low flood risk possibilities expected at the outlet parts of the three basins.

9.3 Morphometric Analyses of the Drainage Networks

The term Drainage Network is commonly referred to the general appearance of a group of drainage in a region (Figure 36). This network is a main course fed by a group of tributaries, each of which takes place in a wadi that is proportional to its size. These tributaries all converge in the form of a net descending towards the main course.

The drainage network is the result of a complex relation between the surface characteristics, such as rock type, degree of hardness, sensitivity, permeability, and the structural properties such as cracks, joints, faults and folds in addition to climatic conditions. The morphometric parameters of the drainage network of the studied three basins are mentioned in Table 16.

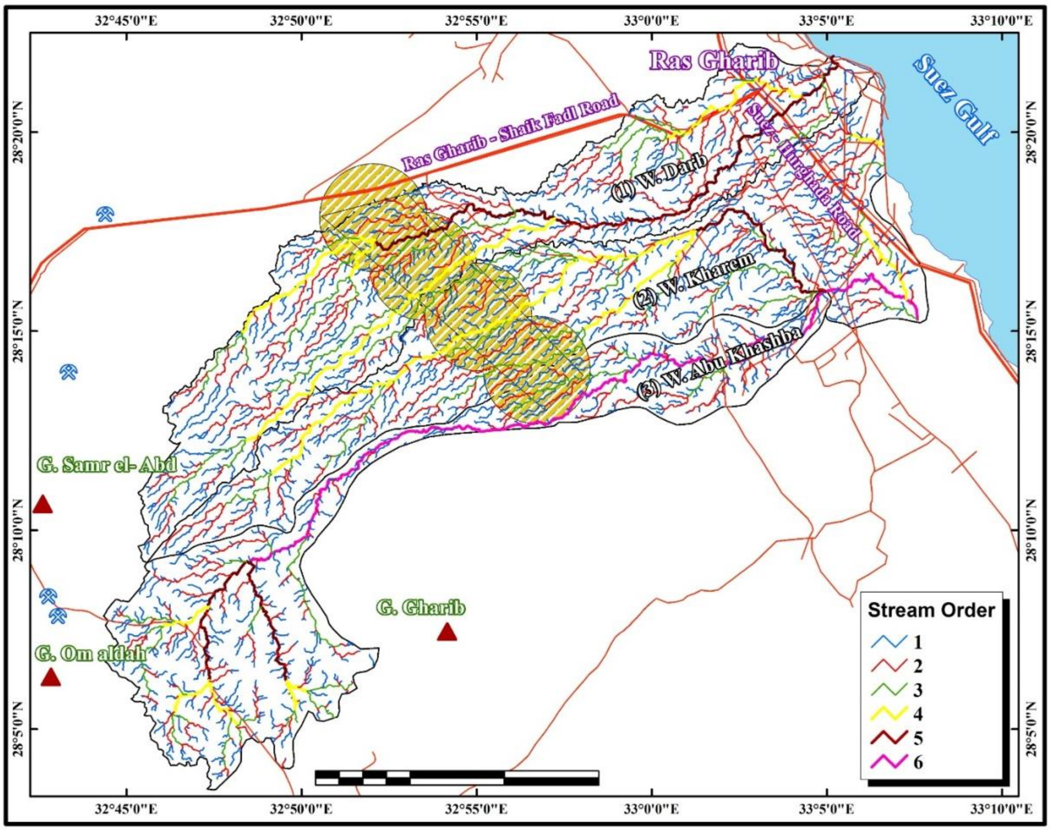

Figure 36: The drainage network in the area

Table 18: The drainage network parameters

Wadies	Order 1		Order 2		Order 3		Order 4		Order 5		Order 6		Total	
	No	(km)	No	(km)	No	(km)	No	(km)	No	(km)	No	(km)	No	(km)
S. Al Darb	514	256.9	109	160.1	21	68.5	3	42.8	1	31.3	-	-	684	559.6
Kharim	539	285.2	107	145.8	25	71.3	4	42.8	1	10.1	-	-	676	555.2

Abu Khashba	469	204.6	105	90.7	24	46.2	6	12.2	2	14.5	1	42.8	607	411
Total	1522	746.7	321	396.6	70	186	13	97.8	4	55.9	1	24.8	1931	1525.8

Stream Order (Kc)

The Stream Order is the first step of the morphometric study of discharge networks, through which the size and density of the network can be identified. In addition, the orders and numbers of streams are related to the hydrological system of basins.

The order is defined as the location of a stream through an arrangement process. It is based on the division of the drainage network into a set of separate channels, each consisting of one or more links according to the order of arrangement.

Based on the international common ordering method (Strahler, 1958) incorporated within the software, the basins order of the three wadies ranges 5 in wadies Al Darb and Wadi Kharim and 6 in wadi Abu Khashba.

Stream Number (Sno)

The number of streams is one of the important indicators of the size of the drainage network, and clearly shows the developmental stage reached by the basin. The greater the number of the streams is, the higher the maturity of the basin. There is also a direct relationship between the area of the basin and the number of streams. The larger the area, the greater is the number of streams and vice versa.

The number of streams must be taken into consideration in estimating the risk of the floods. The increase in the number of streams increases the efficiency of the drainage network to transfer the surface water and accordingly, the flood probability increases.

The stream number of the Red Sea basins ranges from 183 (low risk) to 6630 (high risk). Based on the ARC GIS software, the stream numbers of the studied three basins are 648, 676 and 607 in the basins of wadies S. Al Darb, Kharim and Abu Khashba, respectively (Table 16). The stream numbers of the studied basins compared with the stream numbers of the Red Sea basins indicated that, the three basins have low flood risk possibilities.

Stream Lengths (SL) Km

The length of the stream constitutes the distance travelled by the flow in its tributaries until it reaches the main valley and then to the outlet of the basin. The length of the stream is a reflection of the erosion process of water movement, the surface characteristics of the slope and the kind of rocks and structural elements prevailed in the area. The lower the gradient, the longer the water course is and the more the lateral sculpting is, thus leading to the formation of the shallow, meanders and wider drainage lines. In the case of a steep slope, the vertical sculpting processes predominate, making the drainage lines shorter, deeper and straighter.

The length of the stream affects the flood hazards. In the long stream, the water takes time to reach the outlet, in addition to what is lost by evaporation and leakage during this long journey. In short streams, the losses are reduced, and the water reaches the outlet of the basin within a short period of time.

The length of stream of the Red Sea basins ranges from 108.2 km (low risk) to 9813.7 km (high risk). Based on the ARC GIS software, the length of streams of the studied three basins in km are 559.6, 555.2 and 411 in wadies Al Darb, Kharim and Abu Khashba, respectively (Table 16). The length of the stream of the studied basins compared with the length of stream of the Red Sea basins indicated that the three basins are of low flood risk possibilities.

Bifurcation Ratio (Rb)

The bifurcation ratio refers to the ratio between the number of streams of an order and the number of streams to the following order. The bifurcation ratio was calculated by entering the following equation: in the ARC- GIS software

Bifurcation Ratio = No. streams at a given order/ No. of the next order

The bifurcation ratio is related to the basin shape; the rectangular basins have high bifurcation ratio and therefore the water falling on the basin reaches the main valley in a longer period of time than that of the circular basins. The flow in the circular basins is more intense than the rectangular basins due to the shorter flow length of the discharge period.

Based on the above, the bifurcation ratio is inversely proportional to the risk of floods. The lower the bifurcation ratio, the higher is the risk of floods, and vice versa. The value of the bifurcation ratio of the Red Sea basins ranges from 1.6 (high risk) to 10.9 (low risk). Based on the ARC GIS software, the bifurcation ratios of the studied three basins are 4.18, 4.11and 3.57 for wadies Al Darb, Kharim and Abu Khashba, respectively (Table 15). The values of the bifurcation ratios compared with that of the Red Sea basins reveal that the three basins crossing the site are characterized by low to medium flood risk possibilities.

Drainage Density (Dd) Km^{-1}

Drainage density is an important indicator of the extent to which the basin is cut by drainage lines. It also reflects the effect of rock type, soil, and topography (Rashidi, 1994). The high density of the drainage indicates the weakness of the bed rocks and their rapid response to the erosion processes, in addition to low permeability. The low density indicates the hardness of the rock and its high permeability, and accordingly the low flood risk.

The drainage density was calculated by using the following equation (Horton, 1945) using the ARC GIS software;

Drainage Density = Total lengths of streams (km) / Basin area (Km^2).

Strahler, Morisawa has rated the discharge density in several categories as shown in the following table:

Table 19: The ranks of the drainage density (Strahler, 1957 & Morisawa, 1985)

Rank	Morisawa, 1985	Strahler, 1957
Low	< 8 (permeable rocks, wet, dense vegetation	< 5 km/km^2
Medium	8-20 permeable rocks, high rain, dense vegetation	5-13.7 km/km^2
High	20-200 impermeable rocks, low rain and vegetation	13.7 : 155 km/km^2
V. High	> 200 (200 impermeable rocks, no rain and vegetation, weak rocks)	> 155.3 km/km^2

The drainage density of the Red Sea basins ranges from 5.4 (low risk) to 77 (high risk). Based on the ARC GIS software, the drainage density of the studied three basins are 3.1, 2.99 and 2.7 for wadies Al Darb, Kharim and Abu Khashba, respectively. All the studied basins are considered to be of low flood risk possibility, concerning the values of drainage density.

Stream Frequency (F) Km^{-2}

The frequency of stream reflects the relationship between the total number of streams in a basin and its area. It is an important measure that provides a beneficial picture of the extent of surface incision in the drainage basin, as well as the efficiency of the drainage network at the speed of water flow. The frequency of the stream was calculated by the following equation (Horton, 1945, p.285).

Stream Frequency = No. of Streams / Basin Area (km2)

The clogged clay surfaces increase the stream frequency, while the highly permeable sandy and gravel surfaces reduce the stream frequency (Salloum, 2004). The stream frequency of the Red Sea basins ranges from 9.5 (low risk) to 123 (high risk). Based on the ARC GIS software, the stream frequency of the three studied basins are 3.6, 3.65 and 4.02 for the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. The values of stream frequency of the three basins indicate that they are all having low flood risk possibility.

Stream Maintenance ratio (Rm)

The stream maintenance ratio is used to denote the average unit area required for feeding the longitudinal unit from the drainage network. The higher its value is, the greater the size of the basin area on the expense of the streams, and thus its drainage density decreases and accordingly the lower the flood risk is. The stream maintenance ratio of the basin is also affected by the density of the drainage due to climatic conditions prevailing in the area, the type of the rocks, their porosity and permeability, as well as the density of the vegetation cover (Jode et al., 1991). The survival rate of the Wadies was calculated by the ARC – GIS software using the following equation developed by Schumm (1956).

Stream Maintenance ratio = Basin Area km2 / Total Stream Length

The values of stream maintenance ratio of the Red Sea basins vary from 0.01 (high risk) to 0.18 (low risk). Based on the ARC GIS software, the stream maintenance ratio of the studied three are 0.32, 0.33 and 0.37 for the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. The values of stream maintenance ratio of the studied basins indicate that they are all having low flood risk possibility.

Surface flow (Lo) Km

Surface flow refers to the excess water that begins to move on the slopes after evaporation and leakage to feed the groundwater reservoir. This movement is unfocused in different directions, covering a large part of the surface (Saleh, 1999).

Surface flow covers the area between the water divide line and the beginning of the stream where the surface water accumulates and move in a concentrated flow. The water depth, velocity, and length of movement up to the first streams vary according to the geomorphological and hydrological characteristics of each basin (Saleh, 1999).

The average length of surface flow was calculated by entering the following equation (Horton, 1945) using the ARC- GIS Software:

Mean surface flow = 1/2 Drainage Density km/km2

The surface flow of the Red Sea basins ranges from 2.7 (low flood risk) to 38.5 (high flood risk). Based on the ARC GIS software, the surface flow of the three basins are 1.56, 1.5 and 1.47 for the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. These values indicate that all the studied basins are characterized by low flood risk possibility.

Texture Ratio (Rt) Km^{-1}

The texture ratio of the topography reflects the degree of proximity of the drainage lines in the basin, irrespective of their lengths. The importance of this factor lies in the fact that it is used to determine the extent to which the basin is being dissected by drainage lines (Gouda et al., 1991, p. 330).

The texture ratio is affected by the climate. In wet areas, the basin is being cut by an abundance of streams, whereas in arid and semi-arid areas, there is a little number of streams of the basin. It is also affected by the type of the rock. The weak rocks are easily eroded by water and reflect a soft texture, while the hard rocks are hardly eroded and therefore reflect rough texture. The lack of vegetation helps to form the rough texture. Texture ratio is calculated by the following equation, (Horton, 1945, p.288)

Texture Ratio = No. Streams / Basin Perimeter

The classification of the studied basins according to the Smith classification is as follows:

Table 20: Texture Ratio classification (Smith, 1950)

Texture ration classification, Smith, 1950	
Rough Texture	<4 stream/km
Medium Texture	4 - 10 stream/km
Soft texture	> 10 stream/km

The texture ratio of the Red Sea basins ranges from 6.7 (high risk) to 100.6 (low risk). Based on the ARC GIS software, the texture ratio of the three basins that were studied are 5.69, 6.18 and 5.6. Compared with the Red Sea basin's texture ratio values, all the studied basins have medium texture, and therefore they classified as medium flood risk possibility.

9.4 Factors Affecting the Occurrence of Flooding

The flood flow is controlled by several factors, the most important of which are (Table 19):

- Hydrological factors of drainage basins.
- Hydrological budget of drainage basins

Table 21: The hydrologic parameters of the studied basins. (The parameters automatically calculated by the ARC-GIS software)

Wadi	Al Darb	Kharim	Abu Khashba	Average
LT	229.4	228.6	323.2	260.4

CT	382.3	381	538.6	434.0
DR	160.3	164.9	137.1	154.1
DV	324.9	322.8	250	299.2
DT	2.42	2.39	2.58	2.5
FV	6.03	6.9	7.67	20.6
Pre	4561840	4706620	3832860	4367106.7
EL	159365.1	162384.6	142751.4	154833.7
Lti	171667.7	176498.3	203212	183792.7
Se	68671.86	69972.99	61512.88	66719.2
L	399704.7	408855.9	407476.3	405345.6
Ru	4162135	4297764	3425384	3961761.0

LT Lag – Time (min), CT concentration Time (min), DR Drainage rate, DV Drainage Volume (m^3), DT Discharger Time (h), FV Flow velocity (m/sec), Pre precipitation (mm), EL Evaporation Losses (m^3), LTI Lag time infiltration (min), Se Seepage (m^3), TL total losses (m^3), Ru Run off

h) Hydrological Factors of Drainage Basins

Hydrological factors are a product of morphometric properties and climatic conditions. Based on the Land Sat images, DEM and the average values of the climatic conditions, ARC-GIS software has been used to calculate the hydrological factors. The effect of hydrological factors on the studied three basins will be studied through some hydrological parameters, namely: Lag-Time, b) Concentration time, c) Discharge volume, d) Flow Volume, e) Discharge time, and f) Velocity of water.

Lag-Time (LT) Min

Is the time interval between the onset of rainfall and the onset of surface run-off. This time is characterized by high rates of subsurface leakage and evaporation. The longer the lag time, the higher are the evaporation and leakage rates and consequently the lower the flood possibility is. The importance of studying the lag time is to identify the time period required for the onset of the flow. It is also used to identify the net flow through the leakage account during this time. The lag time is affected by the basin's lithology. As the rocks are very permeable and porous and thick with cracks and joints, the lag time increases and vice versa. The slope of the surface is also affected. The higher the slope, the slower the lag time is due to the flow velocity, which in turn reduces the loss of leakage and evaporation. Thus, the lesser the lag-time is, the more dangerous the basin is. The lag time of the basins was calculated through the equation (US Conservation Services, 1972).

LT= KI CT

Where; TL =Lag-Time, KI= constant (0.6), CT (Concentration Time (min)

The lag time factor in the three studied basins is 229.2, 228.6 and 323.2 min for the drainage basins of the wadies Al Darb, Kharem, and Abu Khashba respectively. According to this factor the studied three basins are less vulnerable to expecting flooding at their downstream outlets.

Basin concentration time (CT) Min

Concentration time refers to the period of time that the rainfall needs from the farthest point at the water divide to reach the outlet of the basin in the form of running water (Goroshkov, 1979). The time-concentration equation depends on the effect of basin length and the vertical difference on the surface water velocity. Calculation of the concentration time based on the following equation:

CT = 0.28 (L/V)

Where; CT = concentration time (min), L = the mainstream length (m), V= flow velocity (L m/T min)

The concentration time is useful in identifying the time required for the flow to reach the outlet of the Wadi and determining the Wadies that are suitable for setting up flood warning stations. Sometimes the concentration time may decrease in some Wadies to a degree that cannot be warned. The CT values of the three studied basins area 382.3, 381 and 538.6 mins for the drainage basins of wadies Al Darb, Kharem, and Abu Khashba respectively (Table 19). The concentration time for the three studied basins is more than 6 hours, so it is not necessary to set a flood warning stations in these basins.

Discharge Rate (DR) m^3/sec

The discharge rate is the volume of water that passes through an area of one square kilometer in cubic meters per second. This factor considers that all the parts (any drop of rain fall on any square centimeter has been taken into consideration) of the basin are added to the volume of discharge. The discharge rate can be calculated from the formula of the "Centre for Development and Technological Planning".

DR = 1.5*A^$^{0.9}$ "This equation calculates the discharge rate ignoring the leakage and evaporation percentages." Where; DR is the discharge rate, A is the area of the basin, 0.9 is a constant to refer to the basin characters.

The discharge rate of the Red Sea Basins ranges from 3.8 m^3/sec (low risk) to 1273.4 m^3/sec (high risk). The discharge rate of the studied basins is 160.3, 164.9 and 137.1 for the drainage basins of wadies Al Darb, Kharem, and Abu Khashba respectively. Compared to the Red Sea basins discharge rates, the three basins that were studied are expected to be of low flood risk possibilities at their downstream outlets.

Discharge Volume (DV) m3

The volume of discharge is the sum of what can be discharged by the drainage network, and the volume of discharge is measured in a thousand cubic meters. The greater the flow, the higher is the flood risk of the basin. The discharge volume can be calculated from the equation of the "Centre for Development and Technological Planning".

DV = 1.5 * (LT)^0.85

Where; DV is the discharge volume in m3, LT is the sum of all tributaries length, and 0.85 is a constant to refer to the basin characters.

The discharge volume of the drainage basins in the Red Sea varies from 80.4 thousand m3 (low risk) to 3708.1 thousand m3 (high risk). According to ARC-GIS software, the discharge volumes of the three basins are 324.9, 322.8 and 299.2 thousand m3 from the drainage basins of wadies Al Darb, Kharem, and Abu Khashba respectively. The calculated values of the discharge volume of the basins compared to the average values of the Red Sea basins indicated that, the studied basins are of low flood risk possibility.

Discharge Time (DT) h

The discharge time means the time required for the basin to drain all its water from the upstream to the outlet area. The discharge time of the basin was calculated by the following equation, (Salwa, 1989).

$$\mathbf{DT = (0.305\ L)^{1.15} / 7700\ (0.305\ H)^{0.38}}$$

Where; DT = discharge time, L = the main stream length, H = the elevation difference

The average discharge time of the Red Sea basins ranges from 0.05 h (high risk) to 4.9 h (high risk). The discharge time in the three basins is 2.42, 2.39 and 2.58 h for the drainage basins of wadies Al Darb, Kharem, and Abu Khashba respectively. It can be concluded that, the drainage basins crossing the site area of low to medium flood risk concerning the discharge time factor.

Flow Velocity (FV) km/h

The velocity of any moving object can be calculated by the following mathematical equation:

Velocity = distance / time

This equation is based on the calculation of water flow velocity:

Flow Velocity (FV) = Basin length (L) / Concentration Time (CT)

The flow velocity of surface water in the Red Sea basins ranges from 5.2 km/h (Low risk) to 39.9 km/h (high risk). The flow velocity in the three studied basins are 6.03, 6.9, 7.67 km/h in the drainage basins of wadies Al Darb, Kharem, and Abu Khashba respectively. Based on the surface flow velocity, it can be stated that, the drainage basins of the studied Wadies could be considered as low flood risk possibilities.

i) The Hydrologic Budget of the Basins

The hydrological budget is based on the calculation of the amount of water falling on the basin, the evaporation and the leakage losses to determine the net flow and thus to identify the possibility of runoff (Saber, 2007). The hydrologic budget was studied through the following elements:

- The volume of water falling on drainage basins.
- The volume of losses.
- The volumes of net flow.

The volume of rain falling on drainage basins (Pre) m^3

The volume of water falling on each basin depends on the area of the basin and the largest amount of rain fall in one day. The volume of water falling on the basin can be calculated. The largest quantity of rain falls in one-day from the closest meteorological station was 25.4 mm in 12 March 2020 where the average evaporation in the same year was 8.8 mm. The water volumes were calculated by the following equation:

The amount of water falling (Pre) = the area of the basin × the largest amount of rain falls in one day

The volumes of rainfall on the three basins that were studied in case of the highest precipitation value (25.4 mm) are 4561840 m3, 4706620 and 3832860 m3 for the drainage basins of wadiesAl Darb, Kharem, and Abu Khashba respectively. The drainage basins of Wadi Al Darb and Kharim and receive almost equal volume of rain while Wadi Abu Khashba receives less volume.

Loss Volume m^3

The water lost by evaporation and leakage affects the flow. The flow is the remaining rain after evaporation and leakage.

There are many types of water losses:

- Evaporation during runoff.
- Leakage during Lag-time.
- Fixed leakage during discharge time.

Evaporation lose during runoff (EL) m^3

Due to the arid climatic conditions prevailed in the area, the evaporation rates increase due to the high temperature, especially during the summer. In addition to the temperature, the period of precipitation also affects the evaporation; where the shorter the period of precipitation is, the less is the chance of evaporation. Also, the time of precipitation affects the evaporation; the evaporation increases in daytime fall, while it decreases at night (Mustafa, 2004). In addition, the slope gradient affects evaporation; evaporation increases on gentle slope gradient surfaces, while it decreases on steep surfaces. The evaporation data from the closest meteorological station has been used to calculate the evaporation during runoff through the following set of equations

Total evaporation daily = Mean evaporation x Basin area

The total evaporation in an hour is then calculated by the following equation:

Total evaporation per hour = total daily evaporation / 24

The values resulting from the calculation of the discharge time of basins are then used to calculate evaporation during discharge time, as shown in the following equation:

Evaporation during discharge time (EL) = Total evaporation/hour × Basin discharge time.

The evaporation loos of the three studied basins are 159365.1, 162384.6 and 142751.4 in the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. The drainage basins of Wadi Al Darb and Kharim loss water volume greater than the drainage basin of Wadi Abu Khashba.

Leakage during Lag-Time: (LTI) m^3

Leakage is the infiltration of water through the soil surface. The soil has a higher infiltration limit (infiltration capacity) as it cannot pass more than this limit. When the amount of rain falling is much greater than the soil infiltration capacity, runoff begins to form by collecting the rainwater above the soil surface. The degree of water leakage through the soil depends on the degree of porosity of the rock, its permeability and the degree of slope of the surface, as well as the depth and type of the surface layer. The following table (Table 20) shows the volume of leakage through the soil layers (Wilon & Lane, 1980).

Table 22: The volume of leakage in soil sediments

Type of sediments	Grain size	inch/h	Notes
Gravel, coarse sand	2 mm	5	

Clean sand, Gravel	2	2:5	Agricultural land
Sand, gravel, silt, clay	Varies	3:1	Few silt & Clay
Sand, gravel mixed with silt and clay	Varies	0.25	Much silt & clay
Consolidated materials, high % of silt and clay	varies	0.1-0.001	
Average		1.93	0.08mm/min

Leakage is calculated during the lag-time by the following equation:

Leakage during lag-time = Basin area × lag time × 0.08 mm/min

Where; 0.08 mm/min is the average amount of leakage for all types of surface sediments (Wilson & Lane, 1980).

Leakage during the lag-time is known as the leakage that occurs at the onset of rainfall and continues until the water appears on the surface of the earth and begins to flow. The (LTi) for the studied three basins is 171667.7, 176498.3 and 203212 for the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. The drainage basins of Wadi Al Darb and Wadi Kharim loss volume of water through infiltration less than that in Wadi Abu Khashba.

Fixed leakage during Discharge Time (Se) m^3

Fixed leakage values reflect the amount of leakage within the bed rock that lies beneath the surface soil sediments that cover the sides and bottoms of the basin (Awadallah, 2005).

The constant leakage is calculated during the discharge time of the basin through the following equation:

Fixed leakage values (Se) = basin area × discharge time × w

Where (w) = constant expressing the original rock type

The fixed leakage values of the three basins are 68671.86, 69972.99 and 61512.88 in the drainage basins of wadies Al Darb, Kharem, and Abu Khashba respectively. The fixed leakage during the discharge time in the drainage basin of Wadi Al Darb and Wadi Kharim are more that fixed in Wadi Abu Khashba.

Total loss (L) m^3

The total loss means the amount of water lost, either by evaporation or by leakage, on the basis of which the amount of net flow is determined. It is clear whether there is a surface runoff or not. The loss is calculated by collecting evaporation and leakage values previously calculated as follows:

Total Loss = Evaporation during runoff + leakage during lag-time + Fixed leakage values

The total loss of Red Sea basins vary from $0.02*10^6$ m3 to $2.1*10^6$ m3. The total losses in the three studied basins are 399704.7, 408855.9 and 407476.3 m3**.** These values are fairly high due to the climatic conditions, as well as the surface characteristics and geological composition of the area.

Net flow volumes in drainage basins (Ru) m^3

The net flow means the remaining water after subtracting evaporation and total leakage losses out of the total rainfall. The increase in net flow indicates a higher probability of runoff (Saber, 2007). Thus, net flow is calculated by subtracting total losses from total precipitation.

Net flow (Ru)= total precipitation - total losses

Based on the ARC-GIS software, the values of net flow in the three studied basins are 4162135, 4297764 and 3425384 m^3 in the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. These net flow amounts in the drainage basins could form flash flood at the outlet of them in case of rain fall intensity up to 25.4 mm in 24 hs duration time. It is a medium amount of water compared to the large drainage basins on the coast of the Red Sea and the Gulf of Suez, but it may pose a threat to the facilities that can be built in the main streams of the drainage lines especially in the middle and downstream parts of the area when the amount of rain falls similar to the largest amount that fell according to global warming. Therefore, the necessary measures must be taken to protect these facilities from the strong surface runoff. While the maximum rainfall received in the studied area was 3.4 mm, so the wadies crossing the project site individually are of low dangerous flood possibilities expected under the climatic conditions currently prevailed.

9.5 Summary of the studied basins according to some of the measured parameters

In order to determine the risk and the rate of hazard of the surface flow in the studied three basins, thee morphological characteristics of the drainage basins were studied. The morphometric characteristics of the drainage basins along the Red Sea were also referred. The degree of risk the drainage basin has been determined according to a set of morphometric variables. The parameters have been chosen according their importance in basin characteristics and great significance with regard to flooding as follows:

1. Shape properties: The circulatory ratio was selected as an important indicator to measure the risk of runoff in the region.

2. Geomorphological characteristics: The rates of (relief ratio, ruggedness value, and hypsometric integral) were selected as indicators to measure the risk of flow in the basins.

3. The morphometric characteristics of the drainage network: The parameters of the (drainage density, stream frequency, texture ratio) have been selected to indicate the effect of bed rock characteristics on the surface flow.

4. Hydrological factors: The coefficients of (lag-time - concentration time - water velocity) were selected as indicators to measure the risk of flow in the three basins.

The following points could be concluded based on the limits of each parameter for the three basins in accordance with their values in all Red Sea and Gulf of Suez basins:

- In terms of circulation, the studied three basins are characterized low flood possibility could be expected in these three basins where their circularity values are close to 0. Accordingly, they will have non-destructive floods in times of heavy rain fall.
- In terms of the relief factor, all basins are in the low-risk category, indicating no severity of the slope of the water discharge basins in the area. Where the high values of the relief factor indicate the high possibility of the flow of flood;
- In terms of Ruggedness, the values of the ruggedness ratio of the three basins are 2.4, 2.4, and 3.1 for Wadi Al Darb, Wadi Kharim and Wadi Abu Khashba, respectively. These values reflect the low flood risk possibilities in the studied basins.
- In terms of hypsometrical integral; the hypsometric integral of the studied three basins are 0.231, 0.234 and 0.134 for Wadi Al Darb, Wadi Kharim and Wadi Abu Khashba,

respectively. This indicates that all the three basins in the studied area are of low flood risk possibilities.

- In terms of drainage density, the values of the drainage density of the studied three basins are 3.1, 2.99 and 2.7 for wadies Al Darb, Kharim and Abu Khashba, respectively. All the studied basins are considered to be of low flood risk possibility, concerning the values of drainage density.
- In terms of stream frequency, , the stream frequency of the three basins studied are 3.6, 3.65 and 4.02 for the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. The values of stream frequency of the three basins indicate that they are all having low flood risk possibility.
- In terms of topographic texture, the texture ratios of the three basins that were studied are 5.69, 6.18 and 5.6. Compared with the Red Sea basin's texture ratio values, all the studied basins have medium texture, and therefore they classified as medium flood risk possibility.
- In terms of the lag-time, the lag time factor in the three studied basins is 229.2, 228.6 and 323.2 min for the drainage basins of the wadies Al Darb, Kharim and Abu Khashba, respectively. According to this factor the studied three basins are less vulnerable to expecting flooding at their downstream outlets.
- In terms of concentration time, the CT values of the three studied basins area 382.3, 381 and 538.6 mins for the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively (Table 19). The concentration time for the three studied basins is more than 6 hours, so it is not necessary to set a flood warning stations in these basins
- In terms of water velocity coefficient, the flow velocity in the three studied basins are 6.03, 6.9, 7.67 km/h in the drainage basins of wadies Al Darb, Kharim and Abu Khashba, respectively. Based on the surface flow velocity, it can be stated that, the drainage basins of the studied wadies could be considered as low flood risk possibilities.

10. Flash Flood Risk Assessment Model

10.1 Flash flood risk of the studied three basins compared to the morphometric data of all Red Sea Basins

The numerical data produced from the morphometric analysis of the three drainage basins that were studied has been processed statistically within the framework of the general data available to the Red Sea basins. The most important morphometric parameters have been chosen to categorize the studied drainage basins according to the severity of flooding. 5 parameters out of the 23 parameters which have background limits in the Red Sea area were chosen for simple statistical processing to throw in-depth insight on the severity level of the three studied basins (Table 21). The chosen five parameters are (**area, circularity, slope index, drainage density, and net flow**). These parameters are the most important factors in the morphometric analyses of the drainage basins. The actual reasons for choosing the previous five coefficients in the severity calculations are:

1) The basin dimension parameters interacted to determine the **basin area**.
2) Circularity parameter reflects the other basin shape parameters.
3) Slope index is the final product of the interchange of the topographic features.
4) Drainage Density is the most important parameter among the morphometric parameters of the basin.
5) The factors controlling the flood occurrence which are climatic conditions, hydrological factors, and hydrologic budget are finely resulted in the **net flow**.

The calculation steps

The maximum (Max) and minimum (Min) values of the 23 Red Sea basin parameters categorized in four levels; L1 to L4 were used (Annex 1, Table 22).

For the selected 5 parameters; difference between the higher and the lower limits divided by 4 to classify the range into 4 category limits (C1 to C4) for each parameter (Table 22).

The range of the 4 risk category levels [Low (1), Medium (2), High (3) and Very High (4)] were calculated based on the 4 category limits (Table 22).

Each parameter of the selected 5 represents a 20% of the severity of the expected flood.

The values of the selected 5 parameters for the three basins were compared to the 4 risk category limits (Table 23) to determine the risk category level of each parameter individually in each basin (Table 23).

The severity percentages of the 5 selected parameters for the three basins were calculated based on the risk category level of each parameter (Table 24).

The category level of the severity of each basin was determined (Table 25).

The expecting probability (likelihood) of flash flood with an intensity levels low, medium, high and very high was determined based on the historical record of flash flooding along the Red Sea area as shown in figure (37). This figure shows that the project site located in an area that witnessed medium to very high dangerous flooding at the outlets of some drainage basins.

Then the likelihood of the flash flood could be categorized into four levels [(1) low, (2) medium, (3) high and (4) very high].

The risk matrix of the flash flood was calculated based on the categories of the severity and likelihood as in (Table. 26).

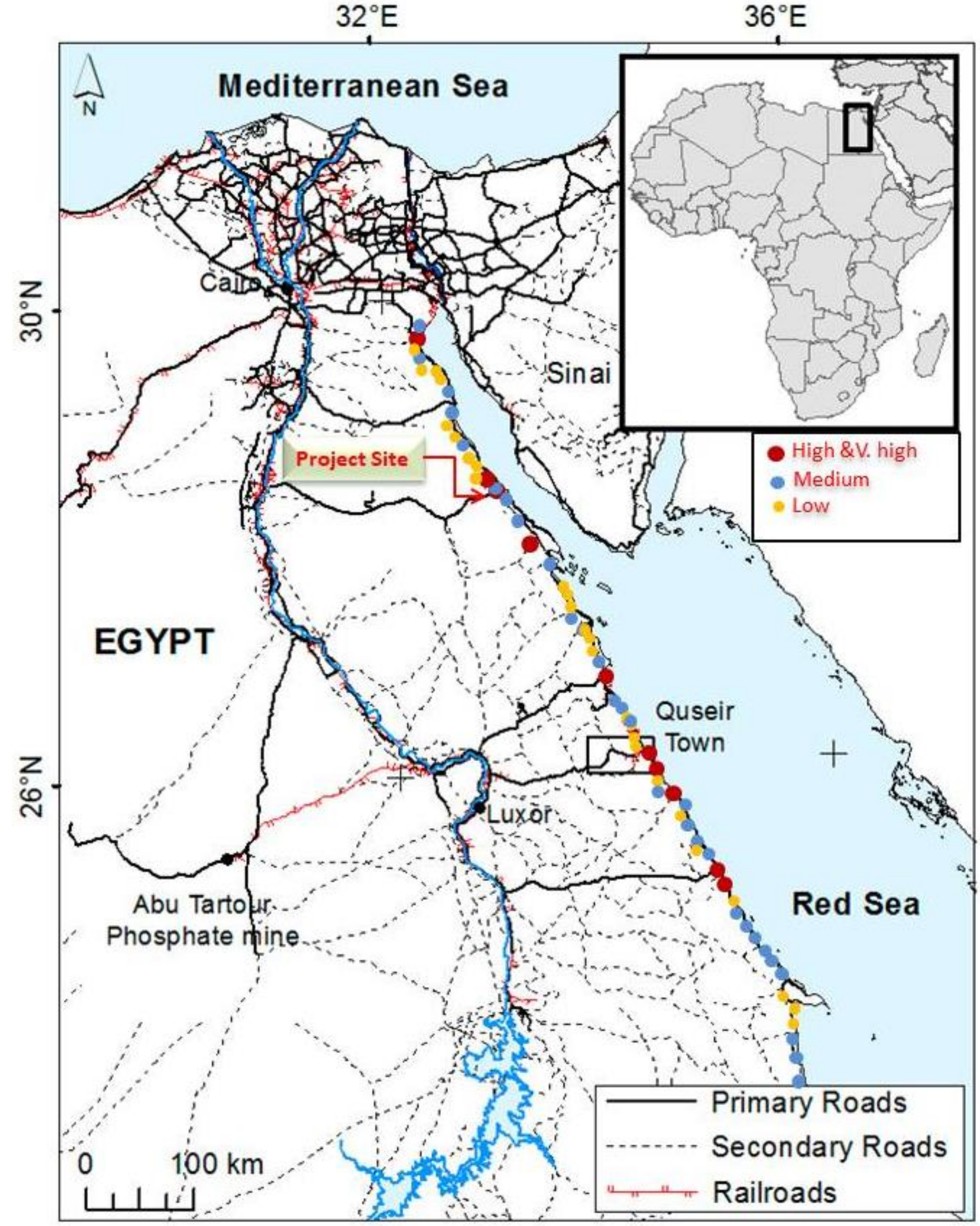

Figure 37: The likelihood flooding of the Red Sea area based on the historical record of the flash flooding.

Table 23: The flood parameters of the Red Sea basins categorized in four levels (L1 to L4)

	Parameters range			**The four categories limits**			
Parameters	Max	Min	(Max-Min)/ 4	L1	L2	L3	L4
Area (km^2)	1796.5	2.8	448.4	451.2	899.7	1348.1	1796.5
Circularity Ratio (Rc)	0.52	0.13	0.1	0.2275	0.325	0.4225	0.52
Elongation Ratio(Re)	0.8	0.3	0.1	0.4	0.6	0.7	0.8
Form Factor	0.5	0.1	0.1	0.2	0.3	0.4	0.5
Relief Ratio	109.5	7.4	25.5	32.9	58.5	84.0	109.5
Max. Relief	2088.0	30.0	514.5	544.5	1059.0	1573.5	2088.0
Relative Relief	3.4	0.2	0.8	1.0	1.8	2.6	3.4
Ruggedness	30.9	1.3	7.4	8.7	16.1	23.5	30.9
Hypsometric Int.	1.6	0.02	0.4	0.4	0.8	1.2	1.6
Slope index	13.4	0.9	3.1	4.0	7.2	10.3	13.4
Stream No.	6630.0	183.0	1611.8	1794.8	3406.5	5018.3	6630.0
Stream length (Km)	9813.7	108.2	2426.4	2534.6	4961.0	7387.3	9813.7
Bifurcation ratio	10.9	1.6	2.3	3.9	6.3	8.6	10.9
Drainage density (Km^{-1})	77.0	5.4	17.9	23.3	41.2	59.1	77.0
Frequency (Km^{-2})	123.0	9.5	28.4	37.9	66.3	94.6	123.0
Surface flow	38.5	2.7	9.0	11.7	20.6	29.6	38.5
Texture ratio (Km^{-1})	100.6	6.7	23.5	30.2	53.7	77.1	100.6
Stream Maintains	0.2	0.01	0.04	0.053	0.095	0.138	0.2
Flow volume	3708.1	80.4	906.9	987.3	1894.3	2801.2	3708.1
Discharge volume	1273.4	3.8	317.4	321.2	638.6	956	1273.4
Flow velocity	39.9	5.2	8.7	13.9	22.6	31.2	39.9

Total loss	2.1	0.02	0.5	0.5	1.1	1.6	2.1
Net flow	3.7	0.1	0.9	1.0	1.9	2.8	3.7

Table 24: The limits and risk levels of the selected 5 parameters according to the whole Red Sea basins

	The four categories limits				**Risk Category levels**			
Parameters	C1	C2	C3	C4	Low (1)	Medium (2)	High (3)	V. High (4)
Area (km2)	451.2	899.7	1348.1	1796.5	2.8 - 451.2	451.2 - 899.7	899.7 - 1348.1	1348.1 - 1796.5
Circularity	0.2275	0.325	0.4225	0.52	0.13 - 0.2275	0.2275 - 0.325	0.325 - 0.4225	0.4225 - 0.52
Slope index	4.0	7.2	10.3	13.4	0.9 - 4	4 - 7.2	7.2 - 10.3	10.3 - 13.4
Drainage density	23.3	41.2	59.1	77.0	5.4 - 23.3	23.3 - 41.2	41.2 - 59.1	59.1 - 77
Net flow	8.15	16.2	24.25	32.3	0.1 – 8.15	8.15 – 16.2	16.2 – 24.25	24.25 – 32.3

Table 25: The limits and risk levels of the studied three basins

	Basins			**Risk Category levels**		
Parameters	S. Abu Had	Al Darb	Kharem	W1	W2	W3
Area (km2)	179.6	185.3	150.9	1	1	1
Circularity	0.175	0.196	0.164	1	1	1
Slope index	1.162	1.029	1.169	1	1	1
Drainage density	3.115	2.997	2.724	1	1	1
Net flow $*10^6\ m^3$	4.16	4.29	3.43	1	1	1

Table 26: The severity % of the selected 5 parameters on the nine basins

Parameter	**Category**	**Low (1)**	**Medium (2)**	**High (3)**	**Very high (4)**
Area					

	% limits	1 – 5%	6 – 10%	11 – 15%	16 – 20%
	Red Sea range	2.8 – 451.2	451.2 – 899.7	899.7 – 13481.1	1348.1 – 17.96.5
% of Severity	W1	2			
	W2	2.1			
	W3	1.7			
Circularity					
	% limits	1 – 5%	6 – 10%	11 – 15%	16 – 20%
	Red Sea range	0.3 - 0.4	0.4 - 0.6	0.6 - 0.7	0.7 - 0.8
% of Severity	W1	2.19			
	W2	2.45			
	W3	2.05			
Slope index					
	% limits	1 – 5%	6 – 10%	11 – 15%	16 – 20%
	Red Sea range	0.9 - 4	4 - 7.2	7.2 - 10.3	10.3 - 13.4
% of Severity	W1	1.45			
	W2	1.29			
	W3	1.46			
Drainage Density					
	% limits	1 – 5%	6 – 10%	11 – 15%	16 – 20%
	Red Sea range	5.4 - 23.3	23.3 - 41.2	41.2 - 59.1	59.1 - 77
% of Severity	W1	0.67			
	W2	0.64			
	W3	0.58			
Net flow					
	% limits	1 – 5%	6 – 10%	11 – 15%	16 – 20%
	Red Sea range	0.1 – 8.15	1 - 1.9	1.9 - 2.8	2.8 - 3.7
% of	W1	2.6			

Severity	W2	2.6			
	W3	2.1			

Table 27: The category level of the severity for the three studied basins

Basins	W1	w2	w3
Area	2.00	2.10	1.70
Circularity	2.19	2.45	2.05
Slope gradient	1.45	1.29	1.46
Drainage Density	0.67	0.64	0.58
Net flow	2.60	2.60	2.10
Total %	8.91	9.08	7.89
Category level	1.00	1.00	1.00

Table 28: Matrix of the risk of the flash floods that could be expected in three studied basins

Severity Likelihood	1	2	3	4
1	1	2	3	4
2	2	4	6	8
3	3	6	9	12
4	4	8	12	16

Low	Medium	High/v. High

Note:

- **Wadies 1, 2, and 3 risk factors:**
  1 (severity) * 2 - 4 (likelihood)
  Risk factor = either 2, 3 or 4
  All of them are low flood risk severity

In conclusion

Based on the morphometrical analyses of about 38 parameters of the three studied basins compared to all other basins in the Red Sea and Gulf of Suez (taking in consideration the maximum rainfall received in the area in one day), the three basins have low flood risk severity.

10.2 Flash flood risk specific to the study area (the three basins)

In the previous analysis, the three studied basins were compared with all basins of the Red Sea and the Gulf of Suez. Therefore, the results of that analysis concluded that there are no dangerous floods could be expected in these three basins. Due to the extreme variation in the characteristics of the Red Sea basins, the small areas of the three studied basins compared to most of the Red Sea ones, the special climatic conditions of the study area, and recording many dangerous floods in and around Ras Ghareb at the outlet of many basins included the three under investigation, the flood potential of these three basins has been evaluated separately according to their characteristics in comparison with neighboring basins under the same conditions such as Wadi Hawashyia, Wadi Abo Had, and Wadi Dara.

The integrated assessment matrix method was relied upon to study the dangers of floods in the region due to its comprehensiveness and dependence on a large number of variables as well as the high accuracy of its results (Horton 1932, Gregorgy & Walling 1973, Strahler 1964, 1985). In calculating the risk, it depends on all the variables that were studied in detail to determine the degree of danger of floods in the basins of the region, as the number of these reached 38 coefficients. From studying the morphometric factors of the drainage basins and networks, in addition to the hydrological factors and the hydrological budget for the basins and classifying them into categories according to the severity of the flood, the following becomes clear:

- The third category represents the severe risk category in a number of factors accounted about 21 factors.
- In some other factors "about 17 factors", the first category represents the risk category instead of the third category, due to the geomorphological, structural and hydrological conditions affecting the basins.
- Thus, one basin may fall into the first category in some factors, and in the second or third category in other factors, and therefore there is no general rule in the distribution of basins among the categories in all factors.
- The average degree of risk for each basin in the region was calculated in the group of different factors, and then the degree of risk was calculated for all factors as a whole, as shown in Table 27.

Table 29: The degree of flood hazards of three studied basins

		Al Darb	Kharim	Abu Khashba			Al Darb	Kharim	Abu Khashba
1) Basin dimension	A (km2)	2	3	1	4) Drainage network	Kc	1	1	3
	LB (Km)	3	2	1		Snu	2	3	1
	W (Km)	2	1	3		Slu (km)	1	2	3

	Pr (Km)	1	2	3
Average		**2**	**2**	**2**
Category		**2**	**2**	**2**
2) Basin shape	Re	3	2	1
	Rc	2	3	1
	Ish	3	2	1
	SH	2	3	1
	K	1	2	3
	Rlw	3	2	1
Average		**2.3**	**2.3**	**1.3**
Category		**2**	**2**	**1**
3) Topography	Rf	1	2	3
	Rh	2	1	3
	Rr	1	2	3
	Rn	2	1	3
	Gn	3	2	1
	Hi	2	1	3
	Sl	2	1	3
Average		**1.9**	**1.4**	**2.7**
Category		**2**	**1**	**3**

	Rb	1	2	3
	D (km-1)	3	2	1
	F (km-2)	1	2	3
	Rm	3	2	1
	Lo	3	2	1
	Rt	2	3	1
Average		**1.9**	**2.1**	**1.9**
Category		**2**	**2**	**2**
5) Hydrology	TL	2	3	1
	Tc	2	3	1
	Dr	2	3	1
	Dv	3	2	1
	Td	2	3	1
	Lt	1	3	2
Average		**2.0**	**2.8**	**1.2**
Category		**2**	**3**	**1**
6) Water Budget	Pre	**2**	**3**	**1**
	EL	2	1	3
	Lti	3	2	1
	Se	2	1	3
	L	3	1	2
	Ru	2	3	1
Average		2.3	1.8	1.8
Category		2	2	2

From the above calculated flood risk categories of the three basins the following points could be deduced:

- **Basin dimensions**

The number of basin dimensions factors is 4. According to the basin dimension, the three studied basins are in the second flood risk category i.e. moderate severity surface runoff.

- **Basin shape**

The factors of basin shape are 6. Wadi Al Darb basin and Wadi Kharim basin are in the second flood risk category while Wadi Abu Khashba basin is in the first category. This means that Wadi Al Darb and Wadi Kharim expect moderate severity surface runoff while Wadi Kharim has low minor severity surface runoff.

- **Basin topography**

The number of the shape factors reached 7 transactions. Wadi Abu Khashba Basin came in the dangerous runoff category, while the Al Darb and Kharim basins came in the medium and low runoff categories, respectively.

- **Morphometry of drainage networks**

The number of these factors is 9, in which the studied three basins are in the medium severity of the surface runoff.

- **Hydrology of the three basins**

The number of these factors is 6, in which Wadi Kharim basin came in the category of dangerous surface runoff, while the Al Darb basin came in the medium severity of surface runoff, and Wadi Abu Khashba basin came in the category of low severity runoff.

- **Water budget**

There are 6 factors determine the water budget of the basins (Table 27). According to the water budget factors, all the studied three basins could be subjected to medium severity of surface runoff.

This category represents the average risk scores in the three basins of the study area for about 38 factors studied (Table 27). In general in the event of heavy rain fall, the basins of Wadi Kharim and Al Darb could be expected surface flow of medium risk along the drainage lines crossing the project site, while, the basin of Wadi Abu Khashba falls into the category of low-risk runoff.

The importance of Ras Ghareb city and its surrounding areas is due to the presence of many important roads such as the Zaafarana-Hurghada road and Minya-Ras Ghareb road, oil and gas transmission lines, in addition to the electricity and communications networks and other important infrastructure. This is in addition to many oil fields and wind stations established and under construction. Due to the exposure of this region to many flash floods with hazardous impacts on many of these facilities, especially those located at the exits of some drainage basins in the region, such as Wadi Hawashiya, Wadi Abo Had, and Wadi Al-Darb (Figure 38). There are many studies concerned with evaluating the risk of floods in most of the Basins. The most important of these studies will be dealt with so that we can verify the results of the data analysis of the three basins under investigation.

Figure 38: The most important drainage basins close to the project site.

Note that the drainage basin of wadi Hawashiya is a way to the north, and wadi Abo Had basin is just to the north outside the area of the project. The project site located in the middle part of the drainage basins of Wadi Al Darb, Wadi Kharim and Wadi Abu Khashba.

Abdel Moneim (2004), overviewed the geomorphological and hydrogeological characteristics of about 27 drainage basins in the Eastern Desert. He analyzed the morphometrical data of the basins that was published by EShamy 1992 and concluded that, Wadi Hawashiya and Wadi Abu Had, Wadi Ghareb and Wadi Dara are characterized by high flood probability (Figure 37). He collected the three studied basins in one basin called, the drainage basin of Wadi Ghareb.

Youssef and Hegab (2005), based on the GIS and statistics, they developed data base management system of the flood hazard of Ras Ghareb area. They stated that the drainage basins of Wadi Abo Had and wadi Al Darb are the most frequent wadies in which flash floods occur and threatens Ras Ghareb area.

After the Elnazer etal., (2017), in the aftermath of the flash flood that hit the city of Ras Ghareb in October 2016 that resulted in tens of deaths and damage to infrastructures and properties. They established the city faced a high hazard flash flood from the drainage basin of Wadi Abu Had. Therefore, they proposed a flash flood channel of about 38 km long to transfer the surface runoff drained out at the outlet of Wadi Abu Had to the north out of Ras Ghareb city so that the city could be protected from future hazardous flash floods.

Sadek and Li (2019) assessed the impact of 2016 flash flood on the City of Ras Ghareb. They concluded that, the main source of the flood is the drainage basin of Wadi Abu Had, where the most vulnerable area is the city at the outlet of the wadi at the downstream area.

Ibrahim etal., (2021), studied the hydrogeological conditions and characteristics of the groundwater occurrences in Ras Shukeir area to the south of Ras Ghareb. He assessed the flash flood hazardous in the drainage basin of the area. They concluded that Wadi Abu Had is classified as high flood risk possibility where Wadi Al Darb, Kharim and Abu Khashba area of moderate flood risk probability.

Based on the data extracted from the flood risk assessment models of the three studied basins that has been developed in this study compared with the data of all Red Sea basins on one hand and to the very close basins on the other, the following could be concluded:

- The vulnerable areas for flooding are that located at the mouth of the drainage basins.
- Wadi Hawashiya and Wadi Abu Had are two of the most dangerous wadies in which dangerous torrential rains occur in the Ras Ghareb region in the event of high rainfall intensity. These two drainage basins have nothing to do with the project site, as the main stream of Abu Had is located outside the site boundaries from the north, while Wadi Hawashiya is about 20 km away from the site in the north direction.
- To mitigate and control the effects of floods, many applications have been established that would overcome the torrents and prevent the arrival of large quantities of rain water at the exits of the basins, which causes destructive torrents to occur. These actions will be recognized.
- Wadi Al Darb "one of the three wadies crossing the site" came in the second category concerning flash flood hazard i.e. medium flood risk assessment possibility.
- Despite the small area of Wadi Al-Darb basin, it may cause dangerous floods in the city of Ras Ghareb in the event of heavy rains, and therefore a dam and an artificial storage lake were built at its exit in the east outside the site.
- The basins of Wadi Kharim and Wadi Abu Khashba are considered to be among the basins in which torrential floods were not expected.
- Since the downstream parts of the basins are exposed to the dangers resulting from torrential rains, the middle and upper regions of these basins are responsible for collecting rainwater and directing it to the main streams. Rainwater has been collected in the upper and middle parts of the basins in many drainage lines. These drainages are varying in length, width, depth, shape, slope, and the volume of sediments transported and deposited along their paths. Due to the absence of any constructions or population centers mostly in these areas, the impact of the floods on them is unknown. But if these areas are included in the scope of development, the surface runoff in their tributaries must be evaluated and the extent of its danger to the facilities to be built.
- According to the location of the project site, it is quite to say no dangerous flooding could be expected in the whole area of the project.
- Strong surface runoff could be expected in the drainage lines crossing the project site.
- The intensity of surface runoff can be deduced by:

• The lack of danger in the main trunks of these tributaries
• The general slope of the earth's surface in these areas
• The wideness and shallowness of the drainage lines indicates weakness surface runoff, and vice versa
• The small size of the sediment in these drainage lines indicates the weakness of the surface runoff and vice versa.

- Therefore, the field visit to the site and its surrounding areas is of importance, as it was to clarify the final image and verify the models that were built based on the data of satellite images, meteorology, topographical and morphometric analyses, etc.

11. Field Visit

11.1 Field Visit Focus

The site visit was undertaken in 12/05/2023. The focus of this visit was on the project site specified by the client, with an emphasis on visiting all the important locations referred to and verifying all the required details. All observations and evidence on the ground were documented and recorded through many field photos that illustrate them as much as possible. GPS map Camera mobile application was utilized to determine the geographical location of field images. It is worth noting however, that the Consultant faced instability in the network and complete absence at some of the visited places, which led to the emergence of errors in some locations, as evident in some of the pictures. In order to overcome this problem, a GPS device was used to determine the location of the places that were filmed.

The locations of interest are illustrated in Figure 39. These were the areas that were closely observed during the site visit.

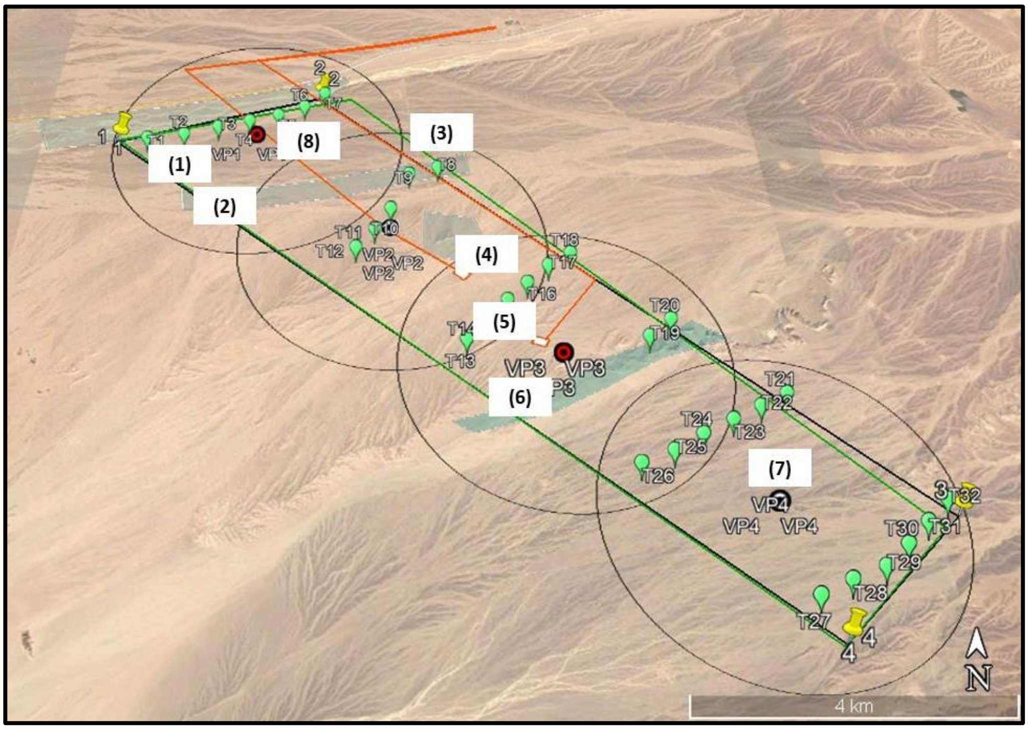

Figure 39: The proposed design for the site

The site visit focused on two areas (for comparison purposes):

1. **Within Site Boundary**- With regard to the project site, the field visit focused on examining the drainage lines that pass through the site to inspect any traces of severe surface runoff, especially in the aftermath of the rainy season, and the dimensions of these valleys. The proposed locations of the turbines in relation to the drainage lines and the possibility of being affected by any severe surface runoffs that may occur in the future were also investigated. Filming the effect of surface runoff on the paved roads through the site. Figure

39 shows the locations that were visited at the project site, which we will deal with in detail and direct field images below.

2. **Areas outside the site boundaries (adjacent to the site)**

The visit also dealt with places outside the boundaries of the site and picking up the mitigation measures that were implemented to protect the facilities located in the main streams that are actually exposed to the impact of torrents.

These are elaborated further below.

11.2 Locations within site boundaries

The important points that were considered during the site visit as shown in figure 39 are:

- Locations 1, 2, 3; are parts of the drainage lines passing through the northwestern of the site which are parts of wadies Al Darb drainage lines (Figures 40 – 43).

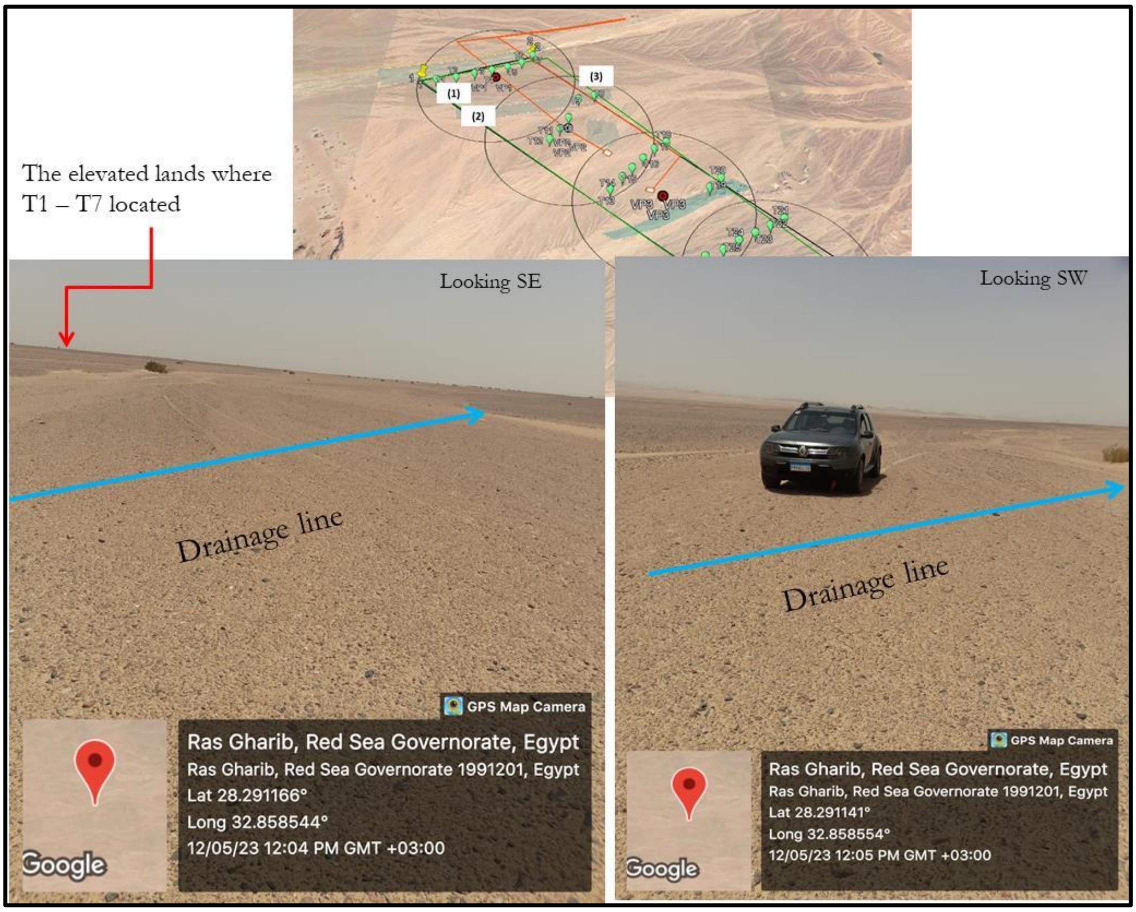

Figure 40: Part of Wadi Al Darb tributaries at the NW part of the site.

Note the large width and shallowness of the drainage lines. There is no indication about sever surface flow. The turbines T1 to T7 located in the elevated areas completely away from the drainage lines.

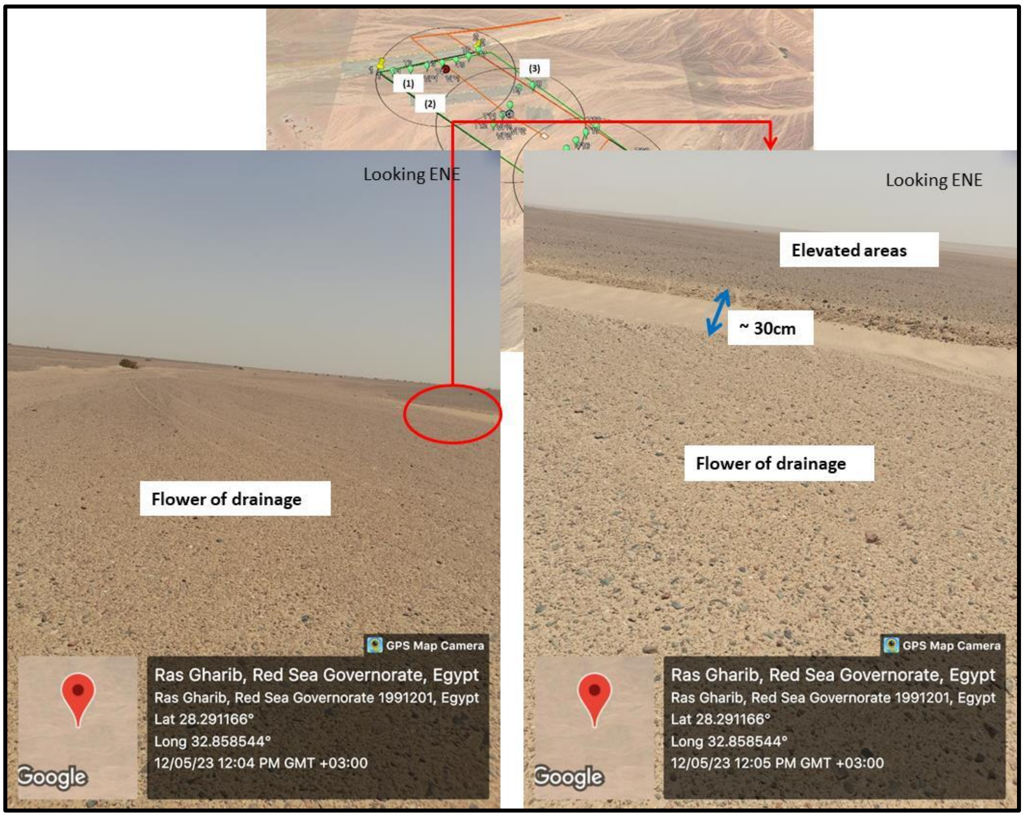

Figure 41: The elevation difference between the floor of the drainage lines and the next elevated areas where the turbines located.

Note the difference is about 0.3 to 0.5 m at the west.

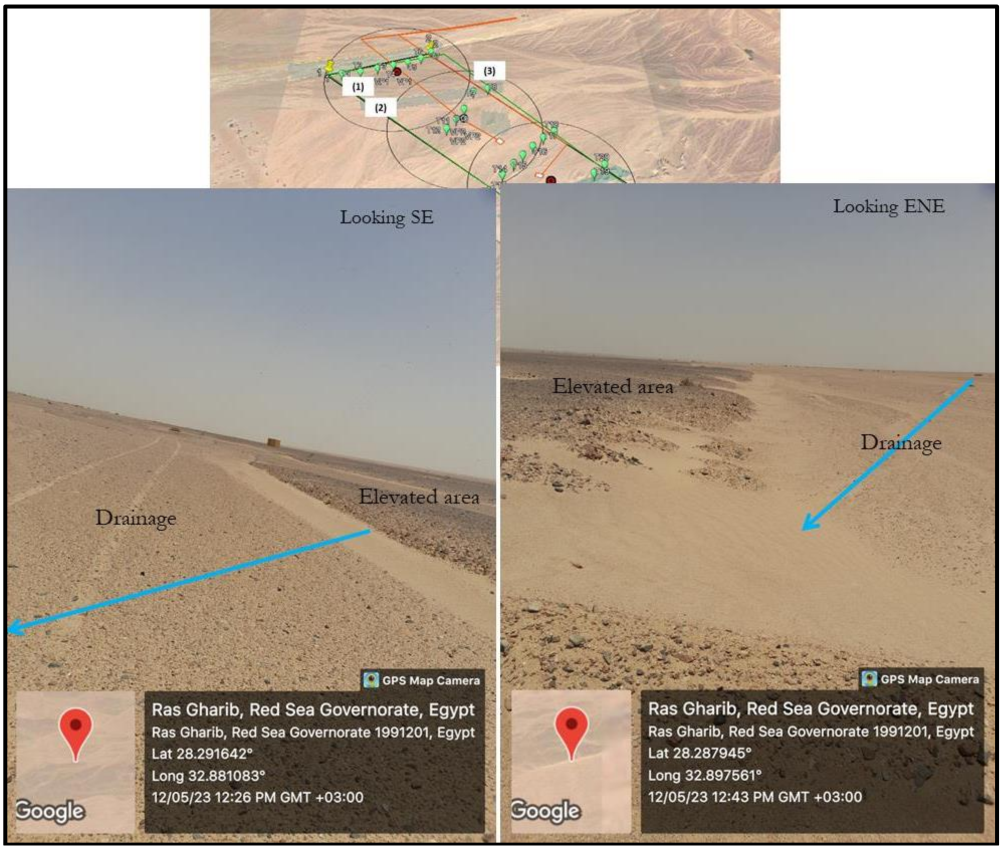

Figure 42: The elevation difference between the floor of the drainage lines and the next elevated areas where the turbines located.

Note the difference is about 0.3 to 0.5 m at the middle of the site.

Figure 43: The elevation difference between the floor of the drainage lines and the next elevated areas where the turbines T8 and T9 are located. Note the difference is about 0.5 to 1 m at the east of the site.

Note the difference is about 0.5 to 1 m at the east of the site.

- Location 4 where the T10, T11 and VP2 is located in the elevated areas facing to a wide plane area of extremely wide drainage (Figure 44).

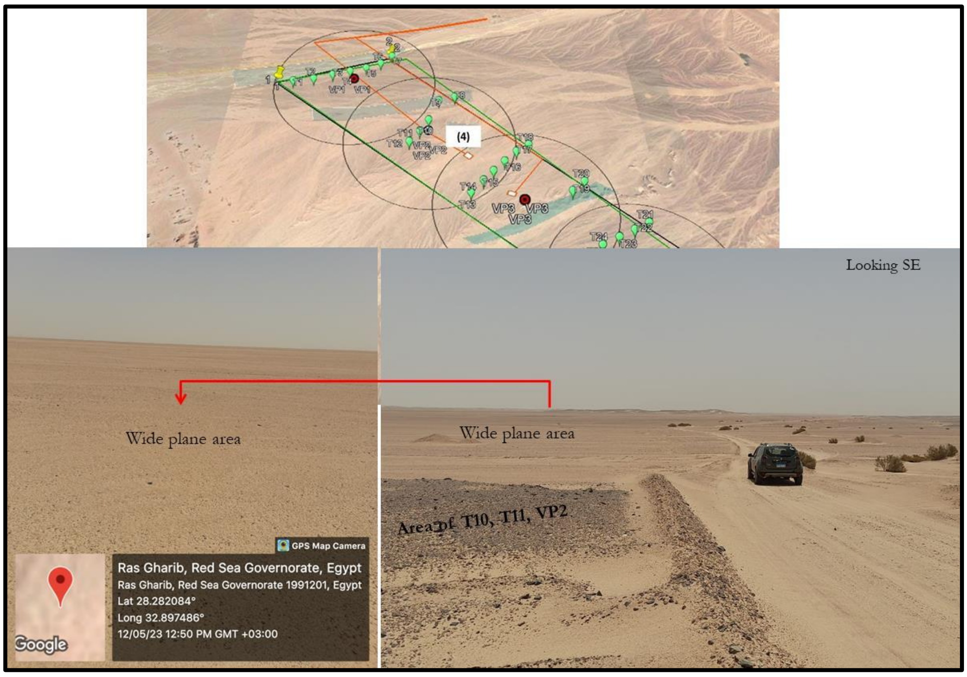

Figure 44: The location of T10, T11 and VP2 in an elevated area of about 1.5-meter-high from a wide plane area to the SE.

The wide area is a part of the drainage lines feeding Wadi Al Darb. Note a complete absence of any effect of the surface runoff either on the drainage floor or on the vehicle paved track.

- Location 5; the elevated area where turbines T13 to T18 are located (Figure 45). There is any sign of flooding in this location could be cause any impact on the nearby constructed facilities.

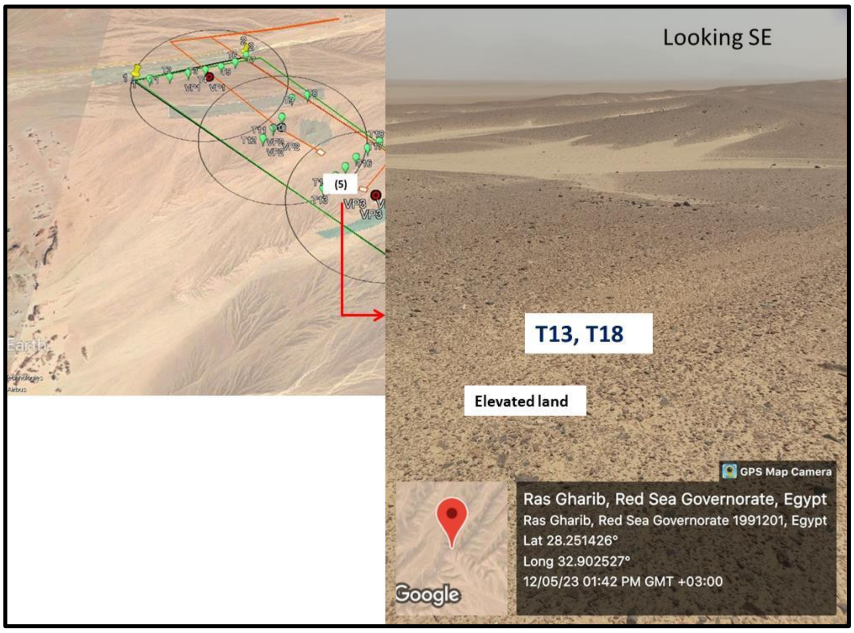

Figure 45: The area where the turbines T13 to T18 are located. Note the very weak drainage lines without any sign of sever surface runoff.

- Location 6; the drainage lines feeding Wadi Kharim (Figure 46). Note that at the wadi is very wide and shallow in its part crossing the site. At the east the turbines T19 and T20 are located in the elevated area away from the main stream of the drainage.

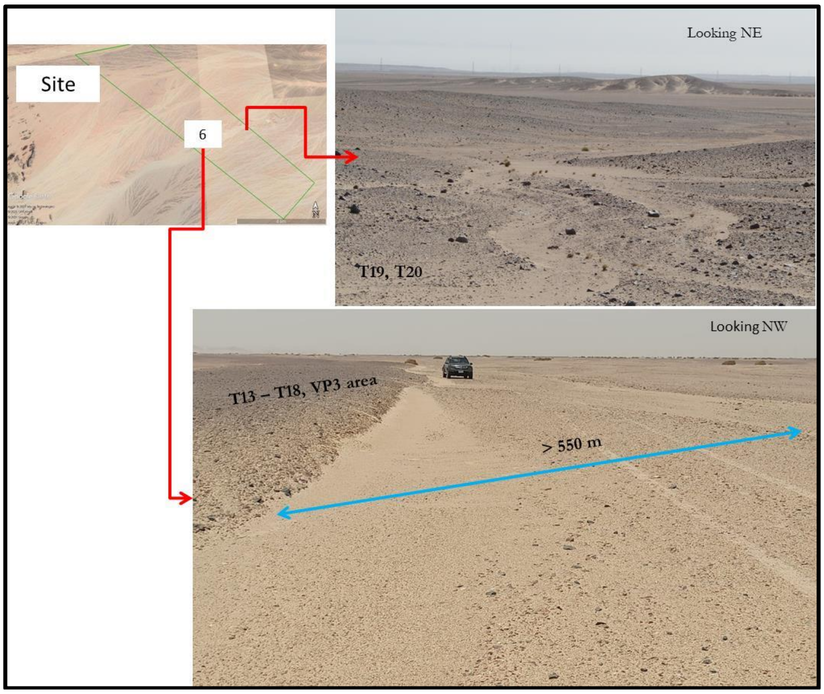

Figure 46: The drainage lines of Wadi Kharim basin. The drainage is extremely wide and shallow.

The area where the turbines located is at elevation of about 0.5 to 1.5 m above the drainage floor. T19 and T20 are located in an elevated areas within the drainage pass. There is no indication about the presences of strong surface flow along this drainage.

- Location 7; the elevated area where the turbines T21 to T32 are located (Figure 47). The southern part of the site is characterized by elevated land with numerous shallow and wide tributaries.

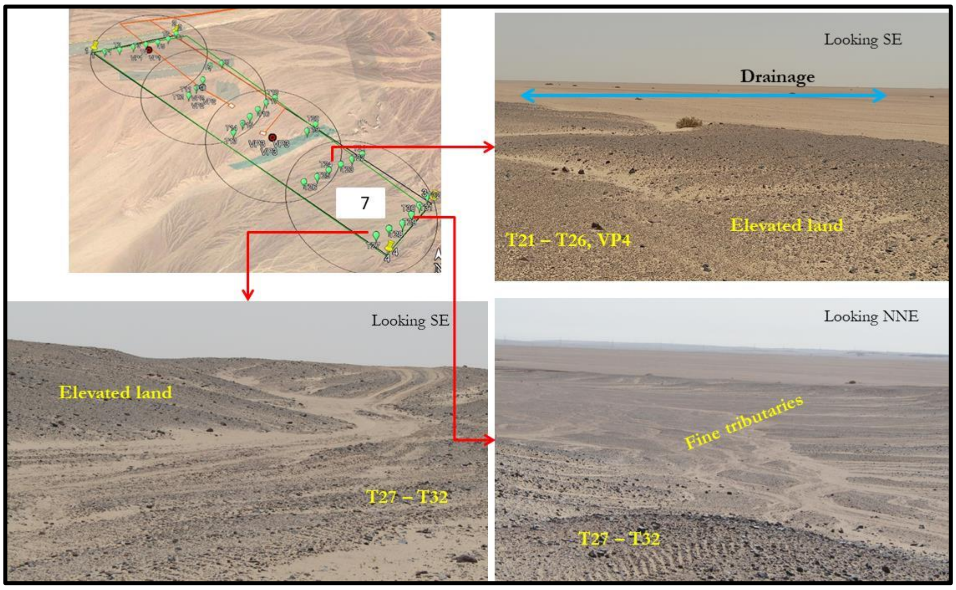

Figure 47: The southern part of the site where the Turbines T21to T32 and VP4 are located.

Note the fine tributaries discharging surface rainwater to the main stream of the basin. The tributaries are very shallow and sinuous reflected the weakness of the water flow.

- Location 8; at the northeastern part of the site where turbines T5, T6 and T7 located (Figure 48). The area is almost table land away from the drainage lines of Wadi Al Darb basin. Abo Had basin which is the most dangerous basins in the region at all is completely out of the site area to the north.

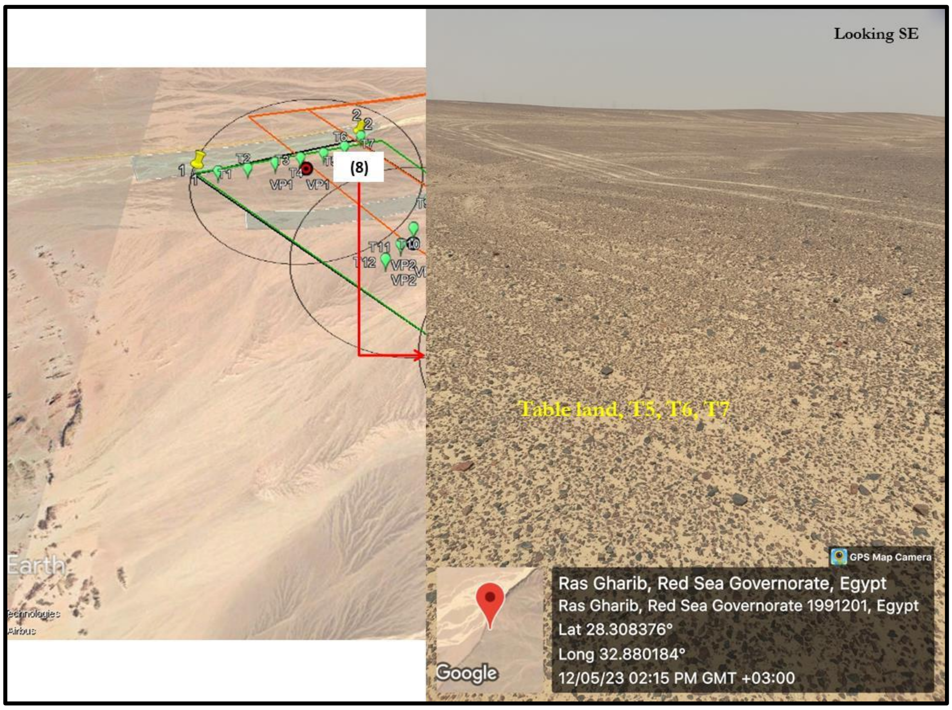

Figure 48: The northeastern part of the site where turbines T5, T6, and T7 are located.

Note the wide plane area out of any drainage lines completely devoid of any drainage lines. The location of turbines T1 to T7 is quite save from any sever surface flow could occurred in Wadi Abo Had.

11.3 Locations out of Site boundaries (at a distance from the site)

During the site visit, the Consultant visited locations that are out of the site boundaries. The same assessment was carried out noting drainage lines in addition to the type of structures used to mitigate the flood impacts. These structures portray an understanding of the severity of flooding in the area.

1- **Along Wadi Abo Had.**

Wadi Abu Had has been considered as one of the most dangerous basins in the area over the city of Ras Ghareb, due to the violent flash floods that expected during heavy rainstorms. During these storms, severe surface runoff occurs along the main stream in the upper and middle part of the basin (Figure 49). This flow may cause road cut and erosion of weak facilities in the stream. Consequently, many measures were implemented that would reserve large amounts of rain water to prevent it from reaching the downstream cities, and others to protect the existing facilities in the stream from erosion. The following figures show some of these measures and their location relative to the project site.

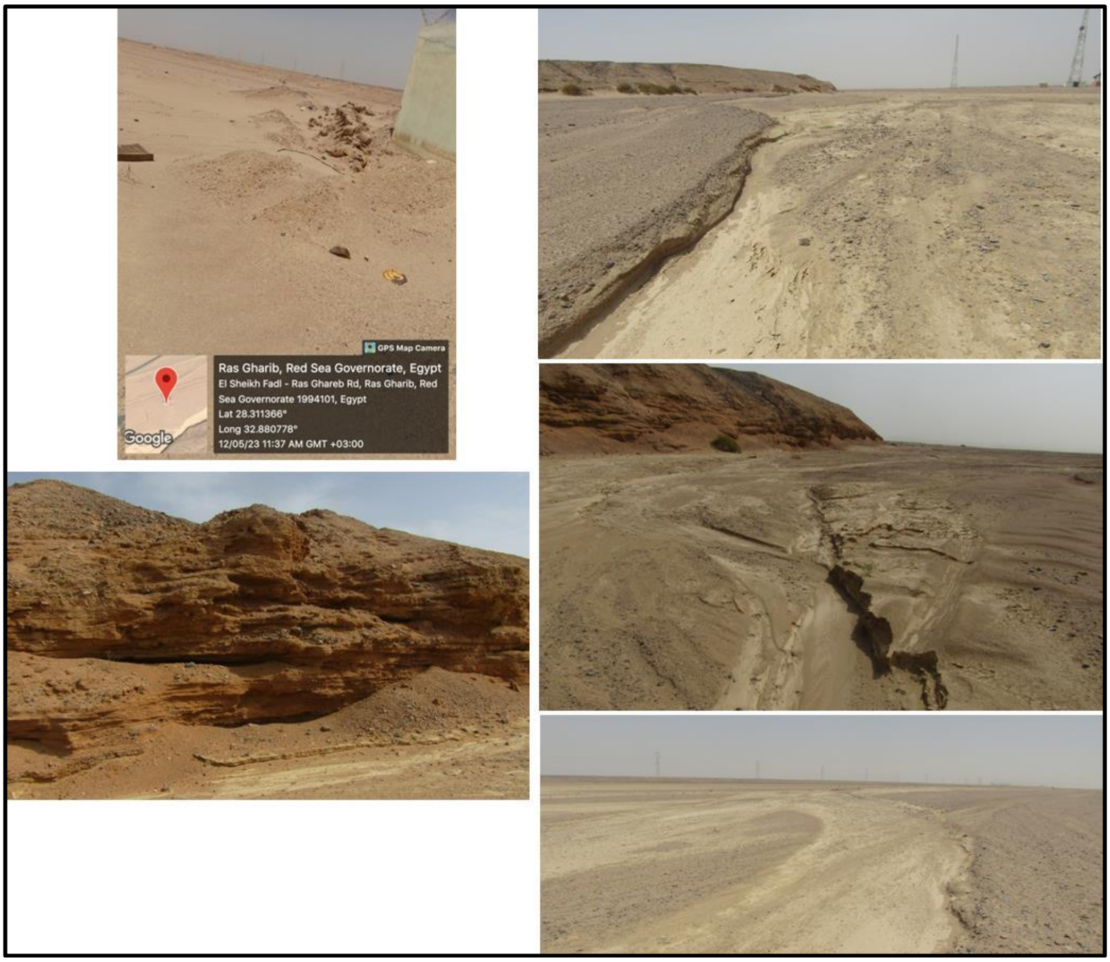

Figure 49: Part of the main stream of Wadi Abo Had facing the project site.

It was noted that the main stream of the wadi floor is topographically lower than the site surface by about 3m. The effect of surface runoff in the stream is quite clear, even if it appears weak due to the depth of the resulting excavations in the floor, as well as the small size of the particles transported by water.

Simple fence built using the local materials to protect the communication towers located along Wadi Abo Had close to the project site (Figure 50).

Concerning the power towers, the towers located in the main stream of wadi Abo, a fence made of stone and cement, about one and a half meters high from the ground, in addition to lining the floor below the tower with the same materials. This fence is closed in the upstream directions and opened from the downstream part (Figure 51). While the towers located in same area like the project site, no special measures have been applied to protect the tower from the flowing water (Figure 51)

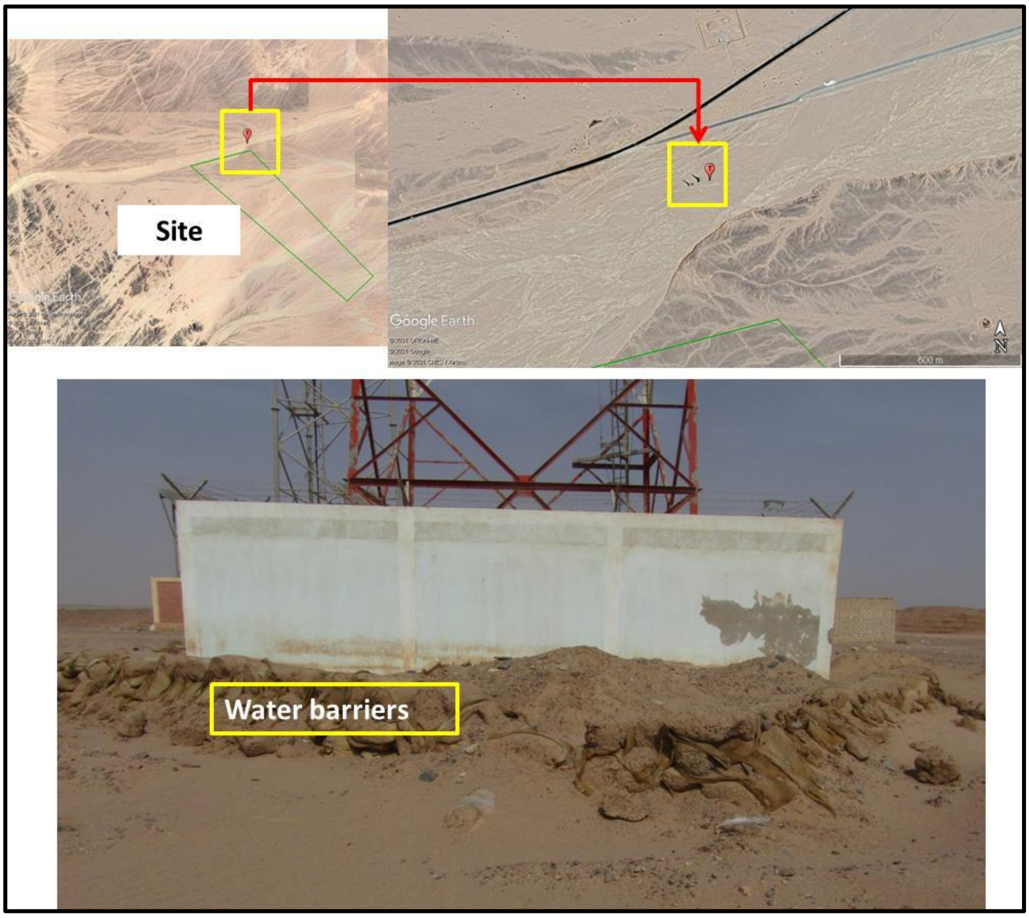

Figure 50: Containers (Shawwals) filled with sand and gravels stacked on top of each other, forming a wall about 1.5 meters high to protect the towers.

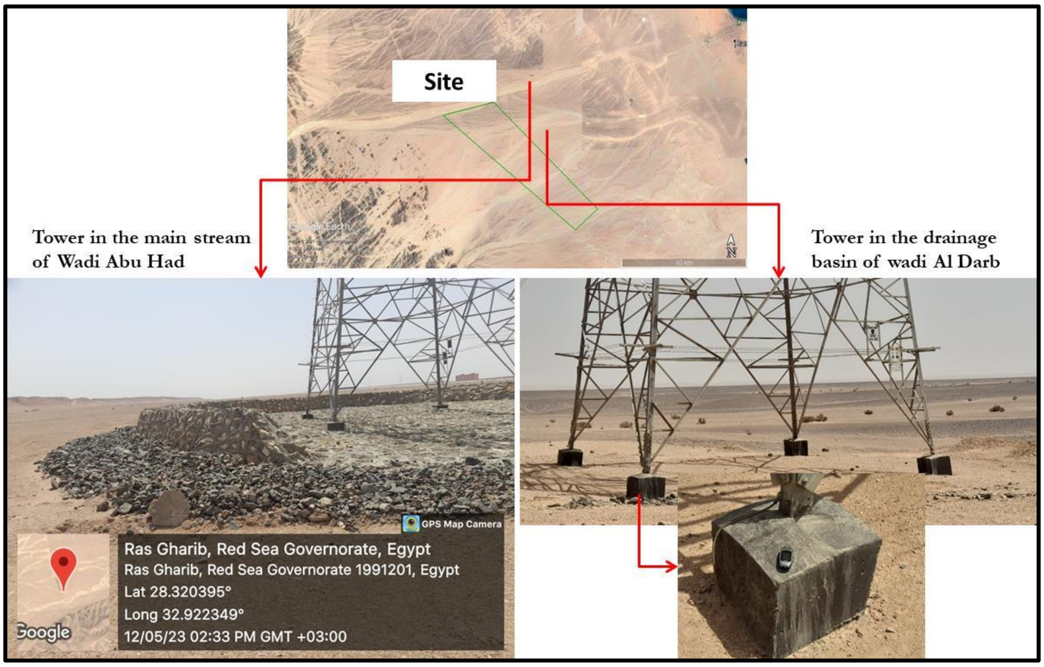

Figure 51: Mitigation measures to protect the tower of the power line running NNE- SSW to the east of the site.

Note tower located in the mainstream where the surface flow is expected, the base of the tower protected by concrete fence, where that built on the upper land has no special applications to protect them from surface flow.

Along the main stream of Wadi Abu Had, many dams to impede and store water to prevent its arrival in large quantities to the outlet of the wadi, in addition to many redirected culverts extending down the Ghareb – Sheikh Fadl Road were established since 1916. At the 8 km distance from Ghareb City, a dam includes 16 culverts with a capacity of the 3 × 3 meters (Figures 52 & 53).

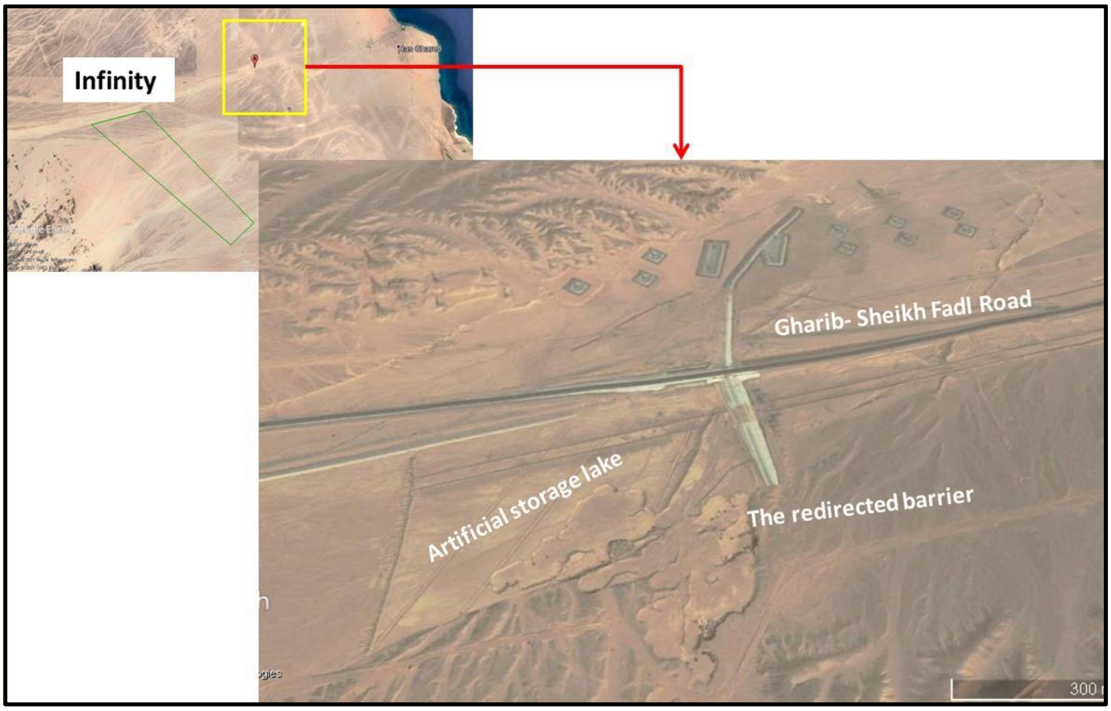

Figure 52: The water impedance and storage dame established along the Ghareb-Sheikh Fadl road at the Km 8.

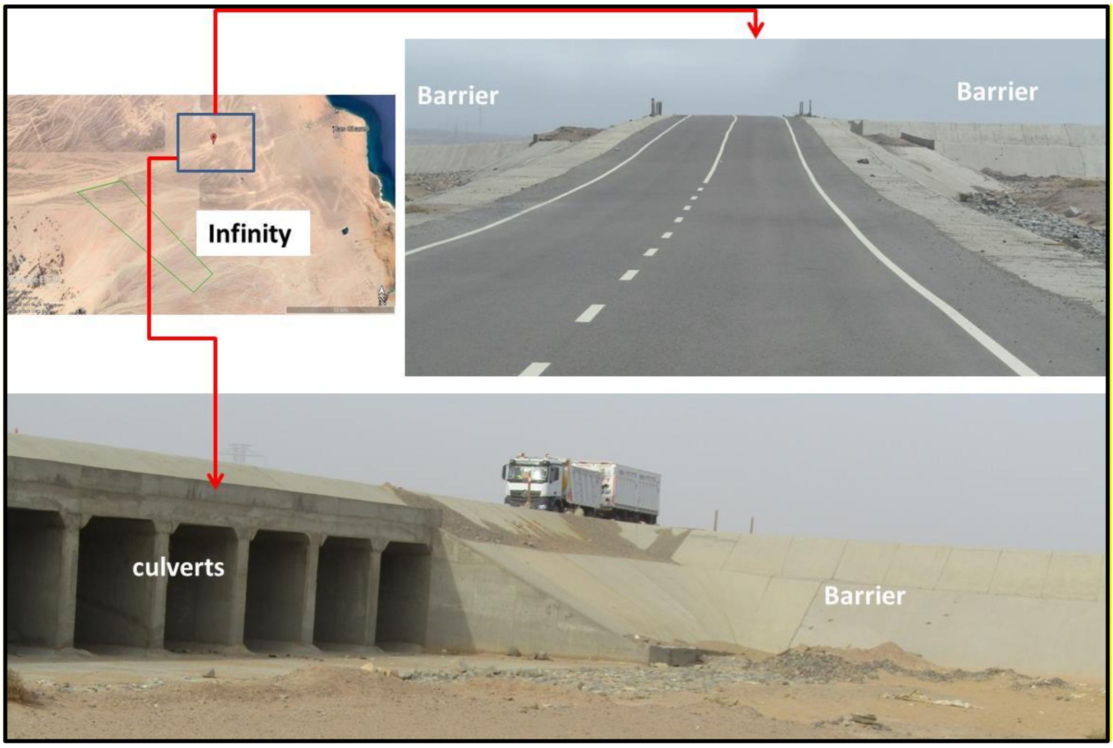

Figure 53: Field photographs show the water barrier at the km 8 and the associated culverts.

Other applications were built to protect the important constructions in the area.

- Concrete fence to protect the power station in the area close to Wadi Abo Had (Figures 54, 55).

Figure 54: Stone and concrete fence protecting the power station.

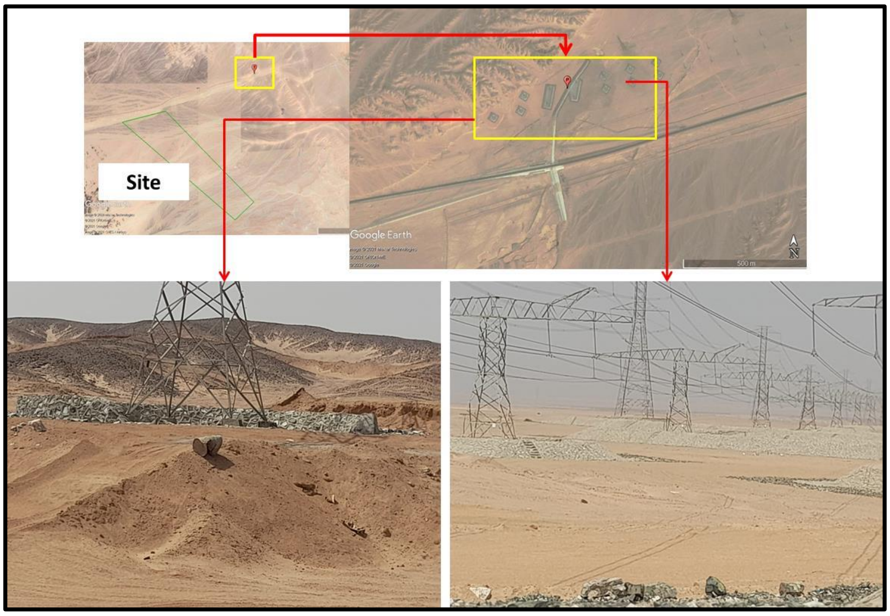

Figure 55: Stone and concrete fence at the base of the high voltages towers to protect them from surface run off.

Note that, however the tower is just facing a drainage line, no extra protections required just like the others in any location along the mainstream part.

2- **At the downstream part of Wadi Al Darb**
A barrier dame was constructed at the outlet of Wadi Al Darb with an artificial lake can store nine million seven hundred cubic meters of water in rainy events to protect Ras Ghareb city (Figure 56). The dame located at the east away from the project site. Despite the rush of

large quantities of water at the downstream of this wadi, no heavy runoff was observed in its drainage lines along the project site, or at least simple erosion in the paved roads.

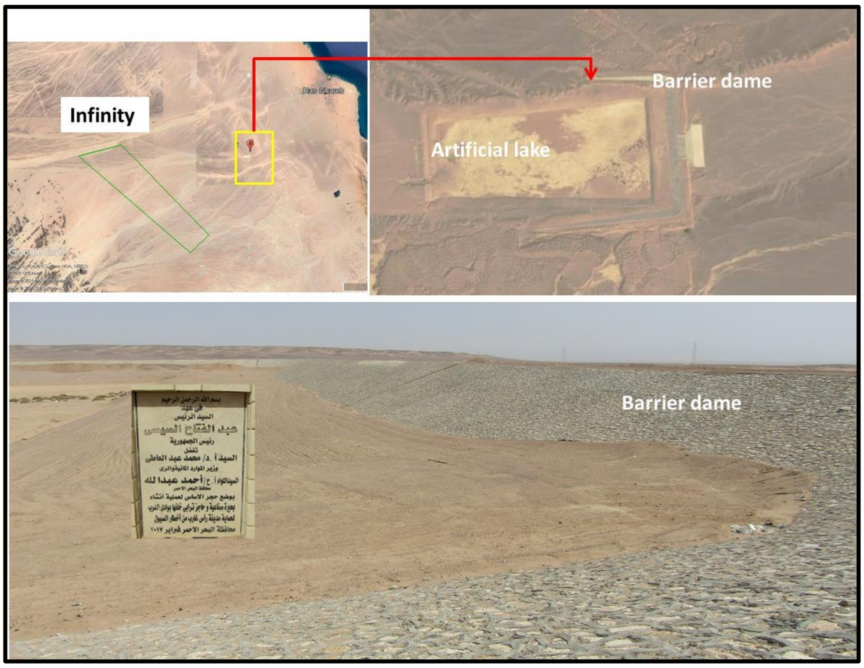

Figure 56: The barrier dame and its artificial lake established at the out lit of wadi Aldarb

3- **Along the main stream of Wadi Hawashyia basin**

El Hawashyia basin is to the North by about 30 km from the project site. Masoud etal., (2012) stated that, rainfall event of a total of 18.3 mm with duration 3h at the station of Hurghada, which has an exceedance probability of 5–10%, produces a discharge volume of 10.2 x 106 m3 at the outlet of Wadi Hawashyia resulted in sever flood. Therefore, three successive dams were built after the flash flood disaster in 2016, and they are as follows:

The first dam: is located at the far west just below the foot slope the Red Sea Mountains (Figure 57). An artificial lake was constructed in front of the dame. The average dimension of the dam and its lake are as follows:

- The Dam
  - Length: 250 m
  - Width: 70 m
  - Height: 5 m
  - Coordinates: Lat: 28°27'55.10"N Long: 32°45'14.74"E
- The artificial lake:
  - Length: 450 m
  - Width: 250 m
  - Depth: 3 m

The second dam: was built to the east of the first one by about 6 km with the following dimensions (Figure 58):

- The Dam
  - Length: 350 m
  - Width: 70 m
  - Height: 5 m
- Coordinates: Lat: 28°27'52.50"N

- The artificial lake:
  - Length: 450 m
  - Width: 350 m
  - Depth: 3 m

Long: 32°48'57.61"E

The third dam: was established down the second dam by about 7 km to the east. The dam is located at the northwest corner of the AMEA site with the following dimensions (Figure 59).

- The Dam
  - Length: 450 m
  - Width: 70 m
  - Height: 5 m
  - Coordinates: Lat: 28°29'22.23"N
- The artificial lake:
  - Length: 400 m
  - Width: 350 m
  - Depth: 3 m

Long: 32°52'33.97"E

Figure 57: The 1st dam at the west of Wadi Hawashiya. (Coordinates: Lat: 28°27'55.10"N, Long: 32°45'14.74"E)

Figure 58: The 2nd dam at the west of Wadi El Hawashiya, (Coordinates: Lat: 28°27'52.50"N, Long: 32°48'57.61"E)

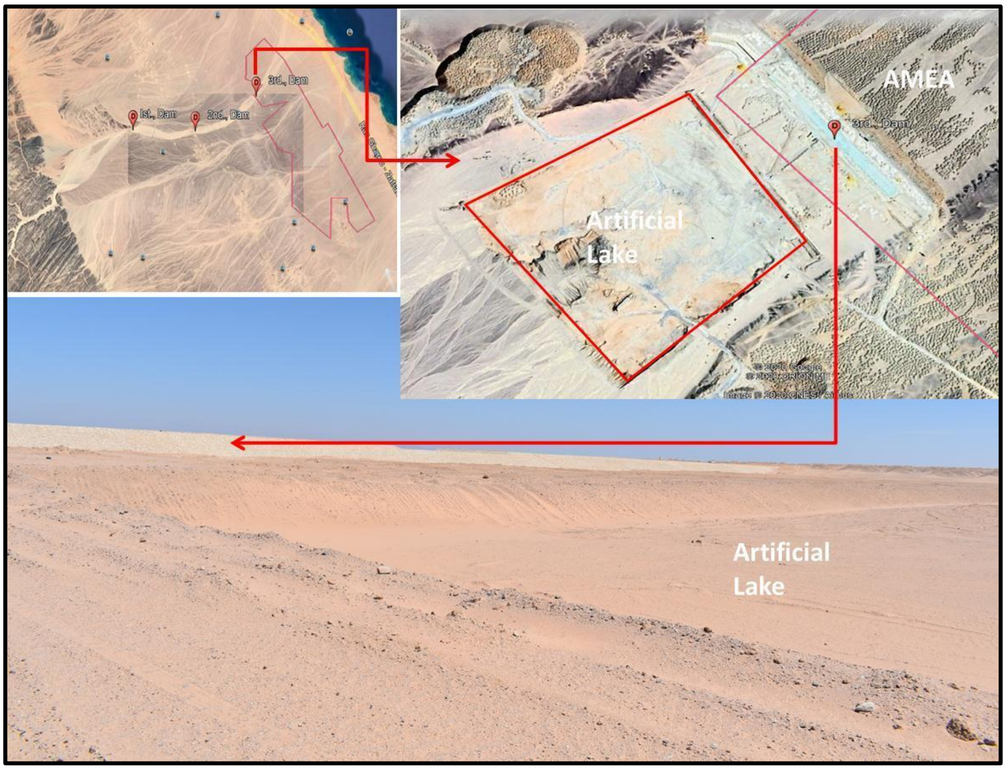

Figure 59: The 3rd dam at the west of Wadi Hawashiya (Lat: 28°29'22.23"N, Long: 32°52'33.97"E)

12. Summary and Conclusions

The section below shows the summary and main conclusions arrived at as a result of the analysis carried out:

- **Main objectives:** 1) detailed assessment of floods risk expected within the project site during rainstorms, 2) integrated models to assess the risk of floods based on the natural characteristics of the region, the prevailing climatic conditions in the current climatic cycle, taking into account the active climatic changes and the resulting effects, especially the unexpected increase in rainfall intensity, 3) determine the extent of the surface runoff passing directly in the drainage lines that cross the site and locate the highly dangerous places within the site, and 4) develop all suggestions that would overcome and mitigate the negative effects of floods and how to protect facilities and people live in the event heavy rainfall.
- **Methodology:** 1) Review all published articles, reports ... etc on the area of interest with regards to climate, rain, and the flash flooding hazards. 2) Getting the rainfall data during the period (2016 – 2021) of Suez and Bir Arida stations 'the closest to the site". 3) Design flood risk assessment models based on Satellite Visual Analysis especially climatic satellites, rainfall data and maximum rain fall intensity data recorded in one day in the area, and morphometric analysis of the drainage basins using ARC-GIS software. 4) Determination of the severity and likelihood of the expected floods. 5) Conducting a site visit to observe in the area that show traces/remains of natural phenomena and indications on the intensity of rain, the floods occurrences, the extent of the capacity of these floods and their impact on the surrounding environment. Also, to validate all the processed models and proposed mitigation measures on ground.
- **General overview of the site: t**he project site is located at about 25km to the west of Ras Ghareb city along the Ghareb – El Sheikh Fadl road. Numerous drainage lines of three drainage basins cross the site in the east west direction. The site represents the middle part of these three drainage basins which are Wadi Al Darb, Wadi Kharim and Wadi Abu Khashba. The area of the site is characterized by moderate elevation compared to the whole area of the three drainage basins. The site is mainly covered by thick layer of clastic deposits with high porosity and permeability which resulted in infiltration of large volume of rainwater underneath the surface and reducing the intensity of surface runoff is significant. With the global warming and climate change, Ras Ghareb region began to experience dangerous floods in the rainy seasons during the last 15 years. Rainwater collects Wadi Abu Had and Wadi Al Darb directly affects the city of Ras Ghareb. Wadi Abu Had runs outside the boundaries of the project site to the north and does not cause any danger on the infrastructure to be built on the site. The site represents a part of the watershed area of Wadi Al Darb basin, in which rainwater collects through the small tributaries abundantly spread in the area in the form of a weak surface flow until it meets at the exit of the main wadi located to the east out of the site, causing a violent torrent.
- The project site is part of Wadi Al-Darb basin which is one of the basins that faces serious floods in the city of Ras Ghareb. Although the site is located in the watershed area, far from the main exit of the wadi, and did not show clear evidence of dangerous floods, the infrastructures that could be establishment in the site may be affected by the severe surface runoff. Therefore, it is necessary to determine the intensity of this surface runoff, which may occur in the drainage lines pass through the project site, so that mitigation measures can be put in place to reduce the risk of this runoff.
- With climatic change and global warming phenomenawhich may lead to an increase in the amount of rainwater falling in the area, flood risk assessment models must be conducted to determine the largest volume of surface runoff expected in the project site based on recent

data with higher odds in the future. So that mitigation measures to reduce the expected impact of the strong surface flow on the infrastructures and foundations of the project should be proposed.

- **Precipitation models based on the climatic satellite images**; according to the prevailing climatic changes, the accumulation of clouds causing rain increases with time. 2- The heavy accumulations of clouds that cause rain are concentrated in the central and eastern parts of the study area. This may be due to the effect of winds on these dense clouds and moving them to the east. The occurrence of torrential floods at the exits of the wadies is largely related to the amounts of accumulated clouds and the rain that falls on the elevated areas in the far west and southwest of the region (Red Sea mountain range). Rainfall on the middle part of the three studied basins, in which the project site is located, even if it is heavy, does not cause torrential rains, which may threaten the facilities on the site. This is because the project site is far from the exits of the three wadies passing through it. With the positive trend in increasing the amounts of clouds accumulating in the middle and eastern parts of the region as a result of climate changes, the volume of surface runoff may increase, which requires an application of some necessary measures to protect any facility that may be located in these drainage lines. The highest expected average precipitation was in April 2019, May 2018 and December 2021, however no serious impacts of these torrents were recorded on the residential areas located at the outlet of the wadies or on the infrastructures. This could be due to the established many protection measures in all dangerous basins especially Wadi Hawashyia and Wadi Abu Had north of the site and also at the exit of Wadi Al-Darb East of the site, and the heavy amounts of rain fell on areas with gentle slopes in the middle and eastern parts of the drainage basins. In May, 2018 the region witnessed torrential rains that led to the suspension of all roads leading to the Gulf of Suez, and the traffic stopped for more than a day as a result of the strong rainstorm, which was accompanied by severe surface runoff, without any damage to lives and infrastructures. Although the amount of rain expected to fall on the study area in the year 2016 is considered the least among the months of the year, the concentration of clouds in October was on the high elevated areas in the west and southwest, resulted in a strong rush of water in the main streams of the wadies as a result of the steep slope, which led to violent torrential rains hit the city of Ras Ghareb.
- **Design of rainstorm model based on the recorded rainfall data of the 6 years (2016 – 2021) of Suez and Bir Arida**. In October 2016 when the study area received heavy rainfall that resulted in strong flooding, the recorded rainfall at Bir Arida station (to the NW by about 120 km from the site), and Suez stations (to the N by about 200 km from the site) was 3.4 and 0.8 mm respectively. In the year 2020 when the above two stations recorded 9 and 25.4 mm rainfall depths, respectively, the area of study did not subjected to nay dangerous flooding. Global worming phenomena has been taken in consideration when designing the rainstorms and their returned periods through; 1) increase the amount of the recorded precipitation by about 25%, and 2) the calculation based on the maximum rainfall depths recorded in one day in the two stations (March, 2020) rather than the value recorded during the occurrence of floods (October 2016). The rainstorms of 1.21, 3.69, 6.88, 13, 19.6, and 28.4 mm precipitation have been expected with the returned periods of 2, 5, 10, 25, 50 and 100 year, respectively. The rain storm that recorded by 9 mm at Bir Arida and 25.4 mm at Suez station could be returned in a period of about 55 year. The rainstorm recorded during the occurrence of flooding in the study area at Bir Arida (3.4 mm) could be returned in 5 years. After the catastrophic flood event of the year 2016 on the study area, set of mitigation measures were applied along the dangerous drainage basins in the area like, three successive dams along the main stream of Wadi Hawashyia, , group of successive dams with lining the road and placing many culverts underneath to prevent the flow of water above the road along Wadi Abu Had, a dam with artificial lake at the mouth of Wadi Al Darb, and Constructing concrete fences with a height of about 1 to 1.5 meters to protect the existing

facilities in the tributaries that feeding the main stream from surface runoff along wadi Abo Had. All the above mitigations to great extent save the downstream cities (Ras Ghareb) and infrastructures (asphaltic roads, power stations, and power and communication towers) from the danger of floods and strong surface flow in the drainage lines distributed in the middle and upstream parts of the drainage basins.

- **Flood risk assessment model based on the morphometric analyses of the three drainage basins crossing the site.** Based on the morphometric analyses of about 38 parameters of three basins using SRTM images processed by ARC-GIS. Tacking in consideration the historical floods recorded in the area. The expected severity and likelihood of dangerous flooding in three studied basins was calculated in the frame work of the whole Red Sea and Gulf of Suez basins. Then the three studied basins are of low flood risk severity. But, when calculating the flood severity of the three basins according to their morphometric parameters, the basins of Wadi Kharim and Al Darb could be expected surface flow of medium risk along the drainage lines crossing the project site, while, the basin of Wadi Abu Khashba falls into the category of low-risk runoff. The results of the model are reasonable as they are in line with most of the previous studies conducted on the drainage basins of the region.
- **Validation Site visit in site locations.** The focus of this visit was investigate all the important locations and verifying all the required details. All observations and evidence on the ground were documented and recorded through many field photos that illustrate them as much as possible. GPS map Camera mobile application was utilized to determine the geographical location of field images. However, the problem of the instability of the communication network and its complete absence in some of the visited places led to the emergence of errors a GPS device was used to determine the location of the places that were filmed. The site is characterized by; the drainage lines (rainfall assembly drainages) of wadi Al Darb, Wadi Kharim and wadi Abu Khashba are shallow and wide. The locations for placing turbines are in the elevated areas away from any drainage lines. These area are very save no matter how intense the runoff. There are no indications on the ground showing the presence of severe surface flow, even in main streams of drainage lines. There are no indications of the impact of this year rainy season on the site like severe erosion in the access paved roads along the site.
- **Validation Site visit out site locations.** The visit also dealt with places outside the boundaries of the site and picking up the mitigation measures that were implemented to protect the facilities located in the main streams that are actually exposed to the impact of torrents. There are many applications that have been established at the exits of dangerous wadies to protect the infrastructures and cities located at the downstream of these basins, such as Wadi Hawashiya, Wadi Abu Had and Wadi Al Darb. They are dams to hold the flood water and prevent it from reaching the outlet of the wadi in large quantities. As for the facilities located in the main streams, such as Wadi Abu Had, which are directly exposed to surface runoff. These facilities represented as roads, high voltage and communications towers. These structures were protected by building fences to direct the surface flow away from the structure, either by cement walls or by piling rubble. As for the roads, they were lined with concrete, with culverts placed at the bottom to absorb torrential waters and prevent them from spilling over and destroy the road.

13. Recommendations

In depth studies have been conducted to assess the possibility of dangerous flooding in the project site in addition the intensity of surface runoff during severe rainstorms. The study relied on the design of many simulated models based on multi-source data such as climate satellite images, rainfall data collected from the nearest meteorological stations, and the digital elevation models for the region and processing them by ARC-GIS software. Site visit was conducted to investigate the results of the studies and verify the models that have been designed.

Therefore, the following can be recommended:

4. **Protection of site, turbines, and pylons:** Onsite turbines and VPs are considered safe and are far from the expected areas of surface runoff (the drainage lines) during severe rainstorms. According to the locations of the turbines, which are mostly placed in elevated locations, they are considered naturally protected. However, this assessment should be refined during the detailed design to identify the specific turbines which may need additional or supplementary protection. This approach should also be conducted for the transmission line pylons to identify those which may require additional means of protection.
5. **Site access paved or asphaltic roads:** As for the protection of site access roads, the drainage lines in which surface runoff may occur are very wide and shallow reflecting the weak to medium runoff intensity, not concentrated in narrow and specific paths. Therefore, impacts on the paved and asphalt access roads within the site is not significant as there is no evidence of violent drifts in the paths of the roads crossing drainage lines. Therefore, in some places, simple cement culverts with a diameter of one meter at most can be placed below the road crossing these valleys in specific places to accommodate the surface flow and prevent its flow up the road.
6. **Electricity cables:** Cables need to be buried underground at a depth of one meter, while taking measures for protection against subsurface infiltrated water by ensuring that adequate insulation is installed on all subterranean cables.

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15. Annexes

15.1 Annex 1: Suez Metrological Station Data

وزارة الطيران المدني
الهيئة العامة للأرصاد الجوية
الإدارة العامة للمناخ
إدارة الدراسات والتقارير المناخية

Ministry of civil aviation
Egyptian Meteorological Authority

Department of studies and climate reports

تاريخ الطلب : ٢٠٢٢/٨/٣١ رقم الطلب :- ٨٤٩ الصفحات : ١

قراءات شهرية لعدد أيام المطر & كميه المطر(مم)
& أكبر كمية مطر سقطت فى يوم (مم) وتاريخها
للفتره من عام (٢٠١٦حتى ٢٠٢١) لمحطة ارصاد السويس البحرية

↓ العنصر / الشهر ←		يناير	فبراير	مارس	إبريل	اكتوبر	نوفمبر	ديسمبر	العام↓
عدد ايام المطر	(مم / شهر)	٢	=	١	=	١	=	=	٢٠١٦
مجموع كمية المطر	(مم / شهر)	١.٨	٠.٠	٠.٢	٠.٠	٠.٨	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم	(مم/ يوم)	١.٠	٠.٠	٠.٢	٠.٠	٠.٨	٠.٠	٠.٠	
تاريخ حدوثها		٢٧	=	٢٦	=	٢٧	=	=	
عدد ايام المطر	(مم / شهر)	=	=	١	=	=	=	=	٢٠١٧
مجموع كمية المطر	(مم / شهر)	٠.٠	٠.٠	٠.٨	٠.٠	٠.٠	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم	(مم/ يوم)	٠.٠	٠.٠	٠.٨	٠.٠	٠.٠	٠.٠	٠.٠	
تاريخ حدوثها		=	=	٢٢	=	=	=	=	
عدد ايام المطر	(مم / شهر)	١	١	=	٢	=	٢	١	٢٠١٨
مجموع كمية المطر	(مم / شهر)	٠.٥	٠.٦	٠.٠	٣.٠	٠.٠	٣.١	١.٨	
اكبر كمية مطر سقطت فى يوم	(مم/ يوم)	٠.٥	٠.٦	٠.٠	٢.٣	٠.٠	٢.١	١.٨	
تاريخ حدوثها		٢٦	١٢	=	٢٥	=	٢٣	٥	
عدد ايام المطر	(مم / شهر)	=	٢	١	=	١	=	=	٢٠١٩
مجموع كمية المطر	(مم / شهر)	٠.٠	٥.١	٤.٠	٠.٠	٣.٠	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم	(مم/ يوم)	٠.٠	٤.٦	٤.٠	٠.٠	٣.٠	٠.٠	٠.٠	
تاريخ حدوثها		=	٦	٥	=	٢٢	=	=	
عدد ايام المطر	(مم / شهر)	=	١	٢	=	=	=	=	٢٠٢٠
مجموع كمية المطر	(مم / شهر)	٠.٠	١٦.٤	٣٦.٥	٠.٠	٠.٠	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم	(مم/ يوم)	٠.٠	١٦.٤	٢٥.٤	٠.٠	٠.٠	٠.٠	٠.٠	
تاريخ حدوثها		=	٢٤	١٢	=	=	=	=	
عدد ايام المطر	(مم / شهر)	=	٢	=	=	=	١	٢	٢٠٢١
مجموع كمية المطر	(مم / شهر)	٠.٠	٧.٦	٠.٠	٠.٠	٠.٠	٠.٣	٠.٧	
اكبر كمية مطر سقطت فى يوم	(مم/ يوم)	٠.٠	٥.٢	٠.٠	٠.٠	٠.٠	٠.٣	٠.٦	
تاريخ حدوثها		=	٥	=	=	=	٢١	٣١	

ملاحظات : -
هذه البيانات من واقع سجلات و استمارات محطة أرصاد (السويس)
أعدت هذه البيانات للاستاذ الدكتور /عصام عبد الرحمن محمد – وكيل كلية علوم الارض للدراسات العليا والبحوث – جامعة بني سويف
بناء على طلبه بتاريخ ٢٠٢٢/٨/٣١ وذلك للإستعانه بها في الابحاث العلمية وتدريب الطلاب .
لايجوز تداول هذة البيانات الا للغرض المخصص لها

أعدت بمعرفة رئيس البيانات مديرإدارة البيانات مدير عام المناخ

١٥/٩/٢٠٢٢

Fig. 59: Suez Metrological Station Data

15.2 Annex 2: Bir Arida Metrological Station Data

Ministry of civil aviation
Egyptian Meteorological Authority

Department of studies and climate reports

وزارة الطيران المدني
الهيئة العامة للأرصاد الجوية
الإدارة العامة للمناخ
إدارة الدراسات والتقارير المناخية

تاريخ الطلب : ٢٠٢٢/٨/٣١ رقم الطلب :- ٨٤٩ الصفحات :١

قراءات شهرية لعدد أيام المطر & كميه المطر(مم) & أكبر كمية مطر سقطت فى يوم (مم) وتاريخها للفتره من عام (٢٠١٦حتى ٢٠٢١) لمحطة ارصاد بيرعريضة

العنصر ↓ / الشهر ←	يناير	فبراير	مارس	إبريل	اكتوبر	نوفمبر	ديسمبر	العام↓
عدد ايام المطر (مم / شهر)	٢	=	١	=	١	=	١	٢٠١٦
مجموع كمية المطر (مم / شهر)	٢.٠	٠.٠	٠.٨	٠.٠	٣.٤	٠.٠	٠.٢	
اكبر كمية مطر سقطت فى يوم (مم/ يوم)	١.٤	٠.٠	٠.٨	٠.٠	٣.٤	٠.٠	٠.٢	
تاريخ حدوثها	٢٧	=	١٣	=	٢٧	=	٢٣	
عدد ايام المطر (مم / شهر)	=	١	١	=	=	=	=	٢٠١٧
مجموع كمية المطر (مم / شهر)	٠.٠	١.٣	٠.٣	٠.٠	٠.٠	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم (مم/ يوم)	٠.٠	١.٣	٠.٣	٠.٠	٠.٠	٠.٠	٠.٠	
تاريخ حدوثها	=	١٦	١٨	=	=	=	=	
عدد ايام المطر (مم / شهر)	١	٢	=	١	=	=	١	٢٠١٨
مجموع كمية المطر (مم / شهر)	٠.١	٢.٠	٠.٠	٠.٦	٠.٠	٠.٠	١.٣	
اكبر كمية مطر سقطت فى يوم (مم/ يوم)	٠.١	١.٢	٠.٠	٠.٦	٠.٠	٠.٠	١.٣	
تاريخ حدوثها	٢٥	١٣	=	٢٥	=	=	٥	
عدد ايام المطر (مم / شهر)	١	١	١	=	١	=	=	٢٠١٩
مجموع كمية المطر (مم / شهر)	٠.١	٠.١	١.٨	٠.٠	١.٦	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم (مم/ يوم)	٠.١	٠.١	١.٨	٠.٠	١.٦	٠.٠	٠.٠	
تاريخ حدوثها	٢٠	١٥	٣٠	=	٢٢	=	=	
عدد ايام المطر (مم / شهر)	=	١	١	=	=	=	=	٢٠٢٠
مجموع كمية المطر (مم / شهر)	٠.٠	٤.٨	٩.٠	٠.٠	٠.٠	٠.٠	٠.٠	
اكبر كمية مطر سقطت فى يوم (مم/ يوم)	٠.٠	٤.٨	٩.٠	٠.٠	٠.٠	٠.٠	٠.٠	
تاريخ حدوثها	=	٢٤	١٢	=	=	=	=	
عدد ايام المطر (مم / شهر)	=	١	=	=	=	١	=	٢٠٢١
مجموع كمية المطر (مم / شهر)	٠.٠	٢.٠	٠.٠	٠.٠	٠.٠	١.٦	٠.٠	
اكبر كمية مطر سقطت فى يوم (مم/ يوم)	٠.٠	٢.٠	٠.٠	٠.٠	٠.٠	١.٦	٠.٠	
تاريخ حدوثها	=	٤	=	=	=	١٢	=	

ملاحظات : -

هذه البيانات من واقع سجلات و استمارات محطة أرصاد (بيرعريضة)

أعدت هذه البيانات للاستاذ الدكتور /عصام عبد الرحمن محمد – وكيل كلية علوم الارض للدراسات العليا والبحوث – جامعة بني سويف

بناء على طلبه بتاريخ ٢٠٢٢/٨/٣١ وذلك للإستعانه بها في الابحاث العلمية وتدريب الطلاب .

لايجوز تداول هذة البيانات الا للغرض المخصص لها

أعدت بمعرفة رئيس البيانات مديرإدارة البيانات مديرعام المناخ

١٠/٩ ١٠/٩ ٢٠٢٢/٩/١٠

Fig. 60: Bir Arida Metrological Station Data