Flash Flood Mitigation for Sustainable Development in Arid Regions

التخفيف من آثار الفيضانات المفاجئة من أجل تحقيق التنمية المستدامة في المناطق القاحلة

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ABSTRACT

Om Lashtan village is part of the Egyptian North coast that has numerous natural resources. This paves the way for development growth in the region; however, development efforts are still modest and not commensurate with the richness and capabilities of the region. Besides rainfall is the source of fresh water in the city, it also forms the main reason for flash flood occurrence that causes serious disasters and huge losses. In November 2020, one of the extreme weather events caused great harms on the different activities and development projects in the city. The main aim of the paper is to propose methods to mitigate the risks of flash flood events in Om Lashtan village considering its rural communities and poor infrastructure. First, the Om Lashtan wadi was specified as the active hydrological wadi that threatens the village located near the outlet. Then, the water volumes and peak discharges were estimated from modeling the extreme flash flood event, which occurs during the storm in November 2020. Furthermore, some measures were investigated to mitigate flood risk and the possibility of selecting the suitable one to protect the village and harvesting storm water. Consequently, the outcome from this paper would help decision-makers in their future development plans in Om Lashtan City. In addition, the harvested storm water would promote various activities such as cultivation, grazing and creating the appropriate climate for the implementation of development plans in the area.

KEYWORDS

Flash Floods, Wadi systems, Flood mitigation, Extreme weather events, Egypt

الملخص

قرية أم لشطان هي جزء من الساحل الشمالي المصري الذي يحتوي على العديد من الموارد الطبيعية. وهذا يمهد الطريق لنمو التنمية في المنطقة. ومع ذلك، لا تزال جهود التنمية متواضعة ولا تتناسب مع ثراء وقدرات المنطقة. من أهم أسباب تباطؤ جهود التنمية قلة المياه العذبة اللازمة للتنمية. إلى جانب الأمطار التي تعتبر مصدر المياه العذبة في المدينة، فإنها تشكل أيضًا السبب الرئيسي لحدوث الفيضانات المفاجئة التي تسبب كوارث خطيرة وخسائر فادحة. في نوفمبر ٢٠٢٠، تسببت إحدى الظواهر الجوية المتطرفة أضرار جسيمة للأنشطة المختلفة ومشاريع التنمية في المدينة. الهدف الرئيسي من الورقة هو اقتراح طرق للتخفيف من مخاطر الفيضانات المفاجئة في قرية أم لشطان بالنظر إلى مجتمعاتها الريفية وضعف البنية التحتية بها. في البداية تم تحديد وادي أم لشطان على أنه الوادي الهيدرولوجي النشط الذي يهدد القرية الواقعة بالقرب من المخرج. ثم تم تقدير أحجام المياه وتصريفات الذروة من خلال نمذجة الفيضان المدمر الذي حدث أثناء عاصفة نوفمبر ٢٠٢٠. بالاضافة إلى أنه تم التحقيق في بعض التدابير للتخفيف من مخاطر الفيضانات وإمكانية اختيار الأعمال المناسبة لحماية القرية وحصاد مياه الأمطار. وبالتالي فإن نتائج هذه الورقة ستساعد صانعي القرار في خططهم التنموية المستقبلية في مدينة أم لشطان. بالإضافة إلى مياه الأمطار التي سيتم حصادها، والتي ستعمل على تعزيز الأنشطة المختلفة مثل الزراعة والرعي وتهيئة المناخ المناسب لتنفيذ خطط التنمية في المنطقة.

الكلمات المفتاحية

الفيضانات الفجائية، التخفيف من حدة الفيضانات، الظواهر الجوية المتطرفة، التنمية المستدامة، مصر

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INTRODUCTION

The Egyptian North coast is considered one of the regions that has promising forthcoming in terms of economic, natural resources, the availability of cultivable land and tourism industry. Therefore, large-scale development projects are continuously implemented by the government, including those associated with industry, tourism, and protection of the environment. Achieving the success of these projects is connected in way or other to the climate and extreme weather events such as flash floods and sand storms (Lotfy, 2018).

Background

Severe damage caused by flash floods from extreme rain storms to the infrastructures in rural communities such as road networks, electricity lines, natural gas, irrigation stations, housing, schools, and tourist villages. Accordingly, proper flood risk mitigation is essentially needed, especially with increasing probabilities of the occurrence of extreme weather events (Baldi et al., 2020).

Flood risk is a function of the probability of flooding and damage resulting from flooding. The goal of flood risk management is the minimization of flood risk through the implementation of measures that can most efficiently reduce risk. This can be done by reducing the probability of flooding, minimizing potential damage or a combination of both (Hooijer et al., 2004). Blackwell and Maltby, (2006) talked about five basic approaches that can be taken to flood risk management (Runoff reduction, Preventive flood risk reduction, Preparatory, Incident, and Post-flooding measures).

Many measures are being used to control or mitigate flood effects. Mostly of focused are mitigation measures in the upstream side of the catchment areas, which are physically distant from the monuments. There are two types of measures that can be used for flood mitigation in flood management: structural and non-structural measurements. The former includes different types of works and interventions aimed at either controlling flood or reducing flood peak. The later offers a variety of possibilities ranging from land use planning to constructions and structure management codes to contribute toward the mitigation of flood-related problems (Colombo et al., 2002).

In another perspective, water resulting from flash floods and extreme rain storms could be counted as a potential source of water under the condition of good management, particularly in arid regions (Baldi et al., 2017). Rainwater Harvesting (RWH), is the process in which acquiring and reservation of water, act as a main objective in areas that suffer from water shortage (Myers, 1975; Critchley et al., 1991; Oweis, 2004; Kahinda et al., 2008). RWH system selection depends on three main parameters: the catchment area (runoff area), storage facility (reservoir or pounds above the ground, in the soil profile, or in underground storage containers), and finally the purpose (Ali, 2017). Three categories of RWH systems are distinguished depending on catchment size (Mbilinyi et al., 2005; Oweis et al., 2012). The first category is in situ RWH, where the rainfall is captured, stored and used in the same area where it fell. The second category is called a micro-catchment system where the runoff and production area are adjacent to each other (Gowing et al., 2015). The third category consists of macrocatchment systems. The runoff area in these systems is large and located outside the cultivated area like dams (Ali, 2017).

Study area description

The study area, represented in the Om Lashtan Village at Marsa Matrouh governorate is located 25 km west of Marsa Matrouh City and 222 km east of Salloum City in the Egyptian North coast, see figure 1. The Village to be protected including (residential villages, tourist villages, Al-Obeid Club and Hotel for Armed Forces Officers, Carols Hotel, Blue Beach Village, Pearl of Al-Abyad Beach, etc.…) is located at the outlet of Wadi Om Lashtan and some main roads intersecting with main streams of the Wadi.

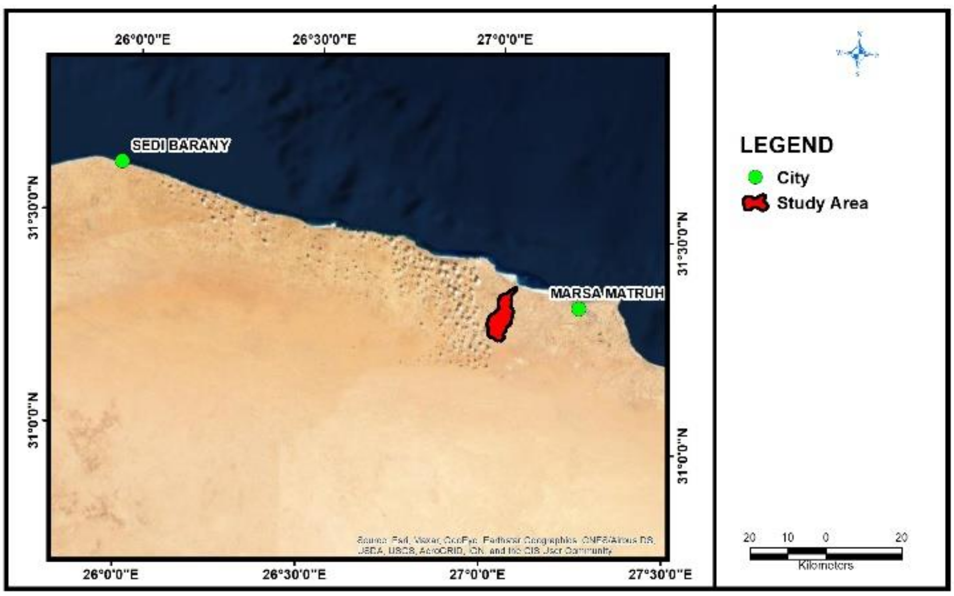

Figure 1. Location of the Study Area

Flash Flood Extreme Events in the Region

Generally, flash floods may occur anywhere in the world, but to cause a disaster, it is more popular in arid or semi-arid areas (Negm, 2020). Egypt is one of these arid and semi-arid countries that suffer from destructive flash floods, especially in the last decades (Abdel-fattah et al., 2015). Recently, a destructive flash flood caused by an extreme weather event in November 2020, attacked many areas in Egypt (Eastern Desert, North coast, Red Sea Mountains, Sinai Peninsula, etc.). This event caused great harms on the different activities and development projects in the study area of this paper, Om Lashtan Village. The Nov. 2020 flash flood considers as one of the costliest and deadliest natural hazards in the village. Figure 2 shows the extent of damages from this event in houses, roads, barriers, hotels, and other tourist facilities. In addition, agricultural activities in Om Lashtan Village have been damaged, as the fig trees were destroyed due to the high speed of the flood water, see figure 3.

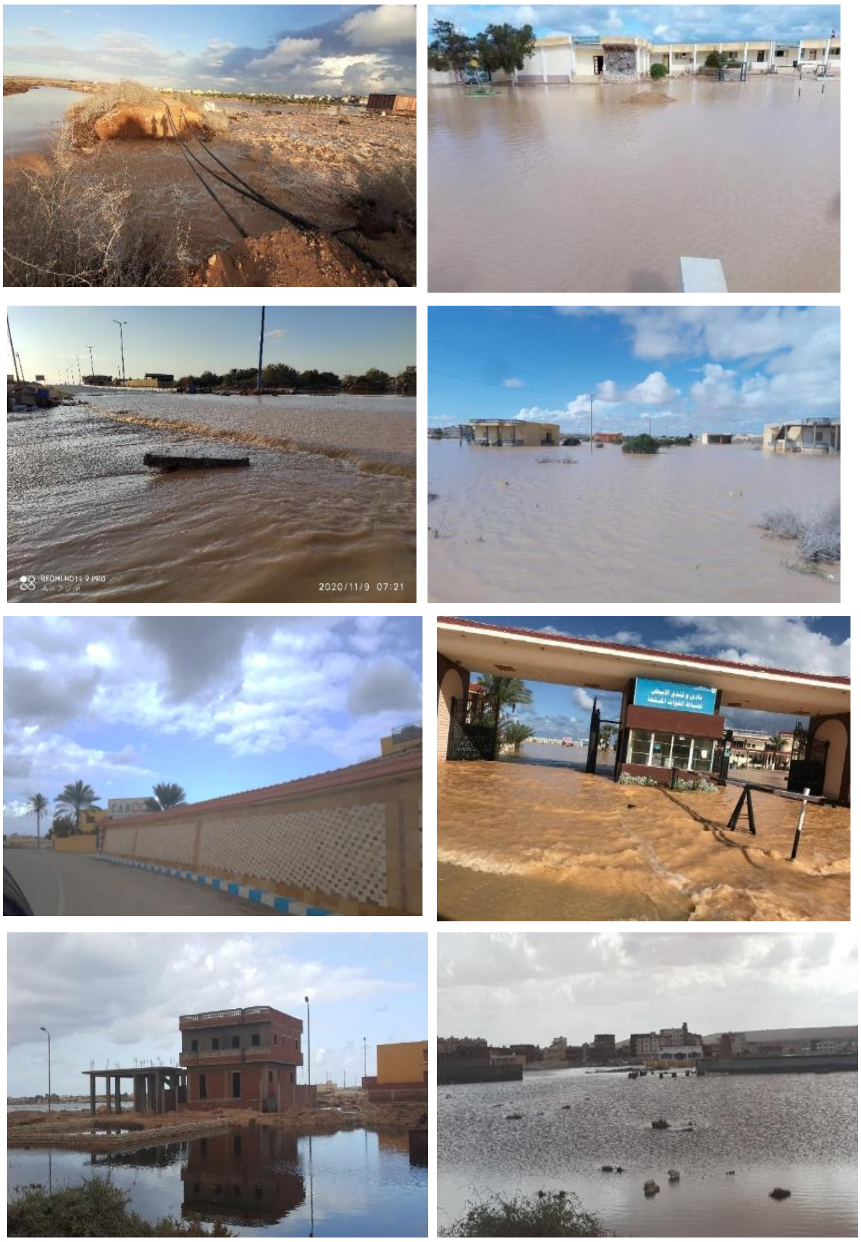

Figure 2. Damages on existing facilities in Om Lashtan Village

(a) before the flood (b) after the destructive flood

Figure 3. Photos of fig trees in the Wadi

In addition, the area suffers from water scarcity and shortage, thus these extreme events could be used as a non-traditional water resource for fulfilling the water requirement in small communities. Water harvesting for sustainable development could be a solution for the problem of Integrated Water Resources Management (IWRM) that becomes the most critical issues in most arid and semi-arid regions including the study area. Therefore, the main aim of the paper is to propose methods to mitigate the risks of flash flood events in Om Lashtan village considering its rural communities and poor infrastructure.

1. MATERIALS AND METHODS

The overview of this research methodology is selecting mitigation measures and techniques to consider IWRM for sustainable development in Om Lashtan Village. To achieve this, many analyses were carried out, including; physical analysis, field surveying, and social investigation.

1.1. Topography

Wadi Om Lashtan is one of the valleys of the northwest coast, which descend in the north to drain into the Mediterranean Sea. The study area extends from 26º 59' to 27º 03' E longitude and 31º 14' to 31º 22' N latitude. The tributaries of Wadi Om Lashtan begin in the southern Mediterranean (Wadi Abu Jawdat, Wadi Al-Ajarmah, and some subsidiary valleys...) that flow from the heights of the northwest coast to the Mediterranean coast.

The study area is characterized by the difference and diversity of its topographic features due to the presence of the Marmarica plateau, where the altitudes in the study area range between 0 and 180 meters above sea level. The elevations are great in the south, where the primary tributaries begin at 175 m of height approximately. Then, the elevations decrease gradually as we head to the mouth in the north until it reaches the level of the Mediterranean Sea in the coastal plain.

The Digital Elevation Model (DEM) with an accuracy of 30 m was obtained for the study area. The ArcGIS program was used to analyze the DEM and deduce the topography of the area as shown in figure 4.

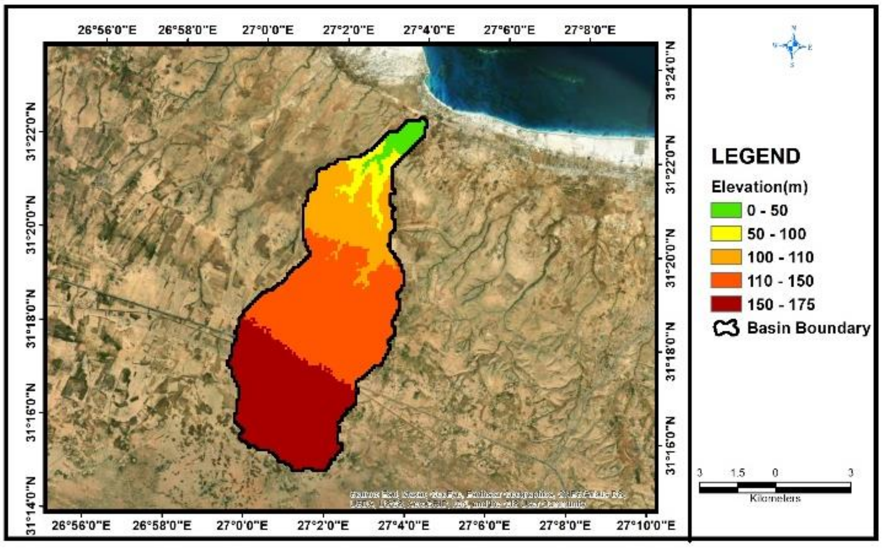

Figure 4. Digital Elevation Model for the Study Area

1.2. Geology

The geology of northwestern desert is discussed briefly by Shata (Shata, 1953). Different studies by other researchers give us a good idea about the geology of Egypt and western desert as special case. In general, the north western part of western desert is covered by a thin blanket deposit of Quaternary, Pliocene and Miocene rocks that unconformable overlap older strata. The outcrops of these strata occur as well as in the fault block escarpment facing the Mediterranean Sea between Salloum and Marsa Matrouh.

Three types of sedimentary rocks are recognized in the study area, See figure 5. The following is a detailed description of the rocky units extending along the valley.

The first formation: the Quaternary deposits (Q) that consist of wadi deposits (gravels, silt and sand) as a result of erosion and well represented at wadi floor and the delta of the wadi. These deposits covered an area about 10% of the drainage basin.

The second formation: the Pliocene deposits (El-Hagif formation, Tplh), this occurs at the center of the area and occupies about 50% of the total area of the catchment.

The third formation: the Miocene rocks (Marmarica formation, Tmm), which consists of fossiliferous shallow marine platform limestone with few marly intercalations. The plateau surface covered with numerous light-colored mud pans. The Marmarica limestone covers the area from Qattara depression to Salloum along the Libyan borders. This formation covered an area about 40% of the drainage basin.

From the geological maps, the northern western desert forms part of unstable shelf, this shelf was affected by large diastrophism along its history. So, it is clear that the study area was greatly affected by the ground movements, which led to the presence of a large number of faults. The surface-marked features such as faults are affected to the Marmarica limestone. Figure 5 shows the main direction of these faults, which is North-East / South-West. The degree of cracking in the basin is ranging between low and medium effects. These faults and drainage patterns play an important role in the hydrological calculation.

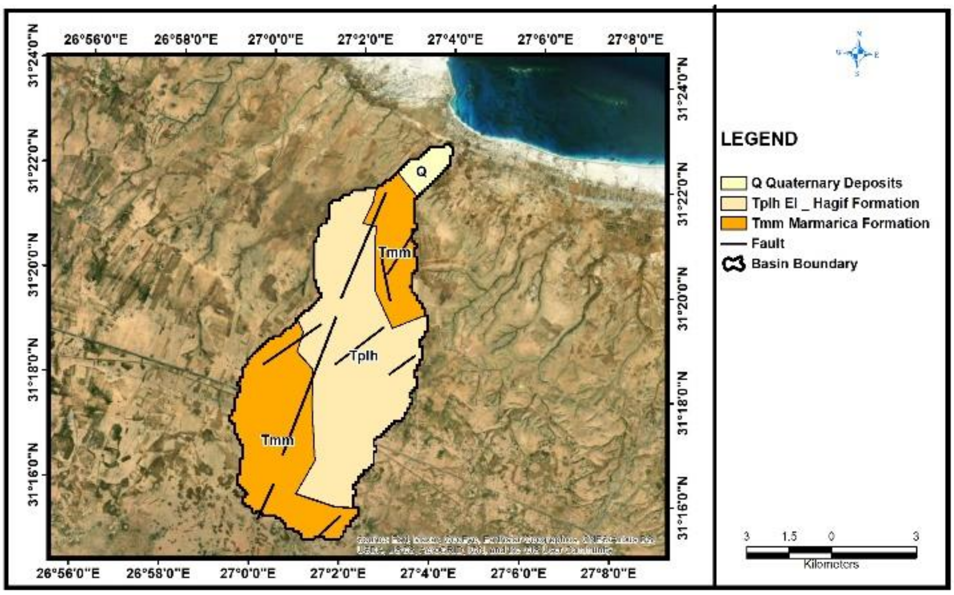

Figure 5. Geology of the Study Area

1.3. Field Investigation

Field investigation includes detection and inspection of the whole wadi from upstream to downstream and all the harmed areas in Om Lashtan Village downstream. The required information was collected to determine geological, morphological and hydrological characteristics. Also, information about existing roads and infrastructures surrounding the village was investigated to consider them in flood mitigation. The result of field investigations shows that the area has been highly affected by the severe flash flood, see figures 1 and 2.

In addition to the physical field investigation, social investigations were done (figure 6). The social assessment includes the damages from the Nov. 2020 flood, the water uses in the small communities, existing and future development in the area, their personal opinion on rainwater harvesting and propose location for protection or water harvesting measures.

Figure 6. During field and social investigation

1.4. Morphological Study

This study concerns with the delineation of all streams in Wadi Om Lashtan. In addition, using the natural characteristics of the basin to compute unit hydrograph terms such as time of concentration (T_c) and lag time (T_L). the software used in this study is Watershed Modeling System (WMS). WMS is a complete program for developing watershed computer simulations and is one of the softwares that successfully describes the relationship between rainfall and runoff (Al-Weshah & El-Khoury, 1999; Makke, 2002). It was developed by Brigham Young University and the U.S. Army Corps of Engineers and it is currently being developed by AQUAVEO.

1.5. Collecting The Rainfall Data

This part concerns with collecting the rainfall data from several sources, in addition to analyzing rainfall data from the rain stations located near to study area. Next, this analysis is used to determine the fit distribution to these data, so that it is possible to estimate rainfall depths from previous recorded data. Afterwards, the rainfall data of the basins were analyzed to predict runoff volume and discharge for different return periods. On the other hand, regarding the extreme flash flood event in November 2020, the rainfall was collected from different sources as the Egyptian Meteorological Authority. In addition, the rain data were collected from the Water Resources Research Institute (WRRI).

Figure 7 demonstrates the locations of different rainfall stations near drainage basins in the study area. These stations are Sallum, Marsa Matrouh and Siwa. In addition, the figure displays the rainfall stations that affecting on study area by using the recommended Theissen method (figure 7). It clearly seen that, Only, Marsa Matrouh rainfall station is covering the whole Om Lashtan basin. Thus, it was decided to use the available data from Marsa Matrouh station and then adjust their row data to carry on the statistical analysis.

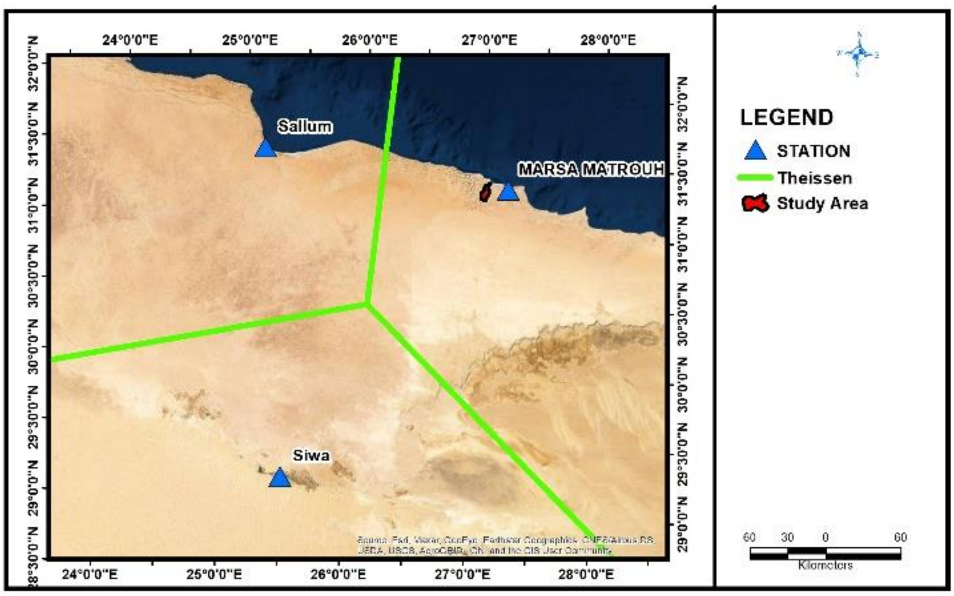

Figure 7. Rainfall stations affecting the Study Area

1.6. Hydrological Study

This study is concerned with hydrograph and peak discharge calculations of flash floods to estimate its volumes in Om Lashtan basin that affect the target village. This study depends on the previous; metrological, geological, topographic and morphological studies.

1.6.1. Losses estimation

Part of the rainfall is infiltrated into the soil according to the soil type and the remaining part runoff to the ground causing flash floods. Thus, the infiltration rate is one of the most important hydrological components during the storm analysis that need to be calculated. A method called Curve Number (CN) was used to estimate infiltration rates and depends on soil type and land use. Therefore, geological analysis was done to investigate types of rocks, Wadi deposits, cracks and percentage of area for each type in Wadi formation.

1.6.2. Rainfall runoff model

A rainfall runoff model was built with data from the previous carried study results using HEC-1 model through WMS software for calculating the hydrological characteristics of the basin, figure 8. According to the lack of measured runoff data in the area, the SCS unit hydrograph method was used to calculate unit hydrograph and hydrograph curve (Masoud, 2009). Unit hydrograph (UH) is a hydrograph of runoff resulting from a unit of rainfall excess.

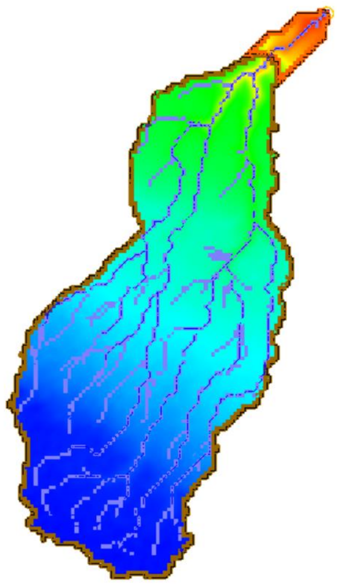

Figure 8. The developed Rainfall Runoff Model for the Study Area

1.7. Flash Flood Risk Management

Mitigation measures for flash floods have played an increasingly pivotal role in recent years, with the intensification of flash floods coupled with urban expansion into flood-risk areas (Abdel-fattah et al., 2021; Al-Rawas, 2013). Flood risk management does not only involves minimizing the actual risk, but also deals with the perceived risk as well. Thus, the goal of flood risk management in this study is the minimization of flood risk through the implementation of measures that can most efficiently reduce risk.

Two main alternatives were suggested for flash flood mitigation in the study area. First, using structure measures to control the flash flood in the upstream of the basin. So, no excess water flows to the village and other infrastructures downstream. Second, proposing other structure measures to control the flash flood in the downstream of the basin. Then, the harvested water would be more reachable for usage. Afterwards, the selection of the suitable locations and techniques for water harvesting will be based on physical, social, and environment.

On the other hand, the existing measures for water harvesting in the area were evaluated after investigating these structures in the field, in order to assess the current status after the extreme floods.

2. RESULTS AND DISCUSSION

2.1. Morphological Analysis

All streams in Wadi Om Lashtan were delineated using the DEM and the mathematical model in WMS. The delineation was done by executing the following four steps:

Step 1: Flow directions: Defines the direction of flow for each cell within the DEM and the flow moves from the highest elevation to the lowest elevation;

Step 2: Flow accumulation: Defines the number of upstream cells that drain to another cell;

Step 3: Stream definition: Indicates to the stream density of the stream network;

Step 4: Basin delineation and morphological parameters computation: Om Lashtan basin was delineated after defining the stream network and the basin boundaries. Then, the morphological Parameters were calculated (such as; area, length, slope and mean elevation), as shown in Table 1.

Table 1. The main morphological parameters

Basin	Om Lashtan
Area (km^2)	55.01
Length (km)	15.72
Slope (m/m)	0.0167
Mean Elevation (m)	135.14
Concentration time (hr)	3.868
Lag time (hr)	2.321

2.2. Metrological Study

The rainfall data from Marsa Matrouh station were used in the metrological study to perform statistical analysis. Statistical analysis was performed to determine the depth of the design storm for different return periods. Figure 9 shows the results from statistical analysis for different frequencies from 2 to 200 years for Marsa Matrouh station. In addition, the most fitting one is Method of Moments, Two-Parameter

Lognormal (LN2). So, the max rainfall depth from this distribution will be used in calculating the runoff using the design storm in the rainfall-runoff modeling later on.

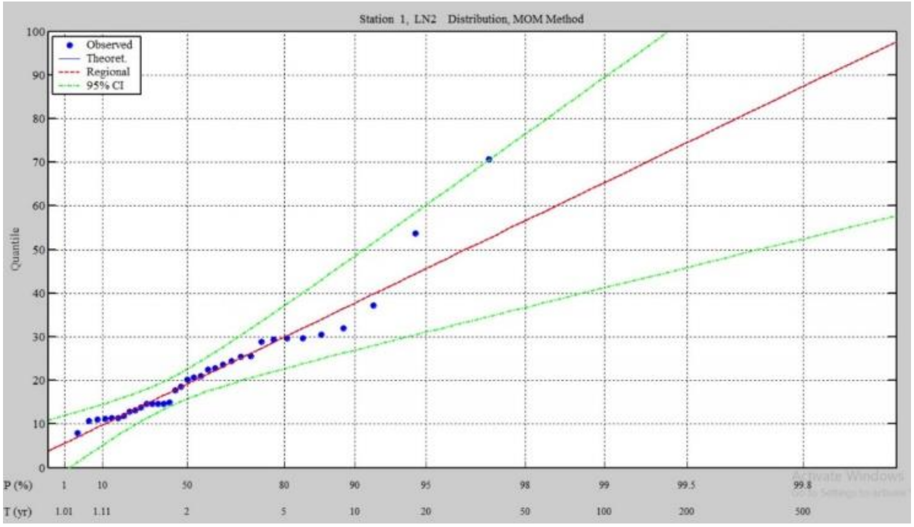

Figure 9. Statistical analysis results for rainfall data from Marsa Matrouh Station

2.3. Rainfall Runoff Model

The hydrological calculation was done for Om Lashtan basin using rainfall runoff model for different return periods. In addition, the extreme flash flood in November 2020 was simulated as a separate single storm. The outcomes from the mathematical model are illustrated in table 2. In addition, figure 10 presents the hydrographs from the whole basin for all return periods and the extreme event.

As a result, the total volume of the calculated runoffs from the whole basin ranges from 0.5 to 3.3 million m^3 for return period 2 to 200 years. Furthermore, the simulated extreme event accumulates nearly 3.1 million m^3 as a total runoff.

It is clear that the 2020 extreme event was close to the design storm of 200 years. This illustrates the huge damage occurs in the area during this storm.

Table 2. The flood properties for different return periods

Return Period (years)	Q_{peak} (m^3/s)	Volume (1000 m^3)	Time to reach peak (hr)
2	40.07	504.80	3.50
5	77.87	988.87	3.50
10	106.65	1,360.11	3.50
100	219.18	2,823.22	3.25
200	260.52	3,358.20	3.25
Storm Nov. 2020	241.10	3,090.71	3.25

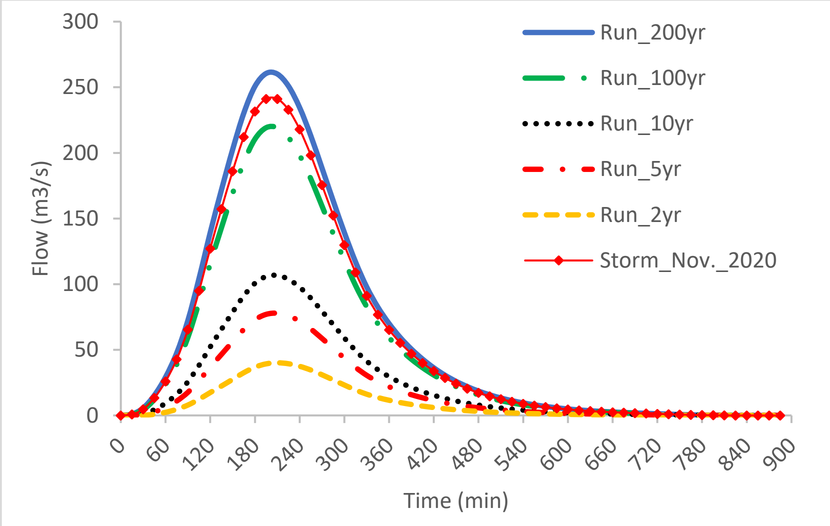

Figure 10. Flash Flood hydrograph for Om Lashtan basin

2.4. Flood Mitigation for Sustainable Development

According to the field investigation and hydrological study, flash flood mitigation is designed. The potential sites for water harvesting were examined considering different land slopes, topography, land use, permeability, and physical characteristics (potential water). Subsequently, physical and social factors were combined in the site's selection process.

2.4.1. Evaluation of the existing structures

The field investigations indicated an earth fill barrier exists on the left side of the flood water direction. This barrier has gradual height, ranging from 1.0 m to 3.0 m maximum. It is in a good condition, except for some areas that have partial collapsed because of the Nov. 2020 flood, see figure 11.

The field investigations indicated that there are six diversion barriers exist along the wadi stream, perpendicular to the flood water direction. The height of these barriers reaches 3.0 m. Because of the sedimentation from the successive storms, the existing barriers lost its function with the huge accumulated sediments in front of it, see figure 12.

Figure 11. Collapse in the earth fill barrier

Figure 12. Sedimentation in front of one of the diversion barriers

2.4.2. Proposing mitigation measures

The needs of the residents in the village are to be protected from the flash flood dangers, in addition to their desire to make the most of that water for their agricultural activities. Consequently, it is decided to choose the second alternative for flood mitigation, which is proposing structural measures to control the flood in the downstream of the basin. This alternative consists of two main parts; upgrading the existing structures and proposing new measures, see figure 13. Consequently, all structures could work together for water harvesting purposes and reducing the flood risks. These measures are described as follows:

Existing structures

For the existed earth fill barrier, it is proposed to rehabilitate this barrier through the following four steps. First, compact the soil layers in the main body of the barrier. Second, rebuild the collapsed parts in the barrier. Third, strengthening the whole barrier using stones, bricks and cement. Fourth, leveling and paving the natural land parallel to the barrier.

For the existing six diversion barriers, it is proposed to rehabilitate these barriers through the following three steps. First, heighten these barriers with 1.50 m from the actual level of natural land. Second, strengthening them using stones, bricks and cement. Third, build spillways in the middle of each barrier at a height of 1.0 m.

New measures

A series of five diversion barriers is proposed in front of the existing earth fill barrier, perpendicular to the flood water direction, see figure 13. The height of each one is 2.0 m. in addition, construct spillways in the middle of each barrier at a height of 1.5 m.

Furthermore, an Irish crossing is proposed on the coastal road, where the road intersect with the natural wadi stream, see figure 13. The level of the road should be lowered by 30 cm in Irish crossing. This is to ensure that the excess water from any extreme event would freely and naturally flow to the Mediterranean Sea.

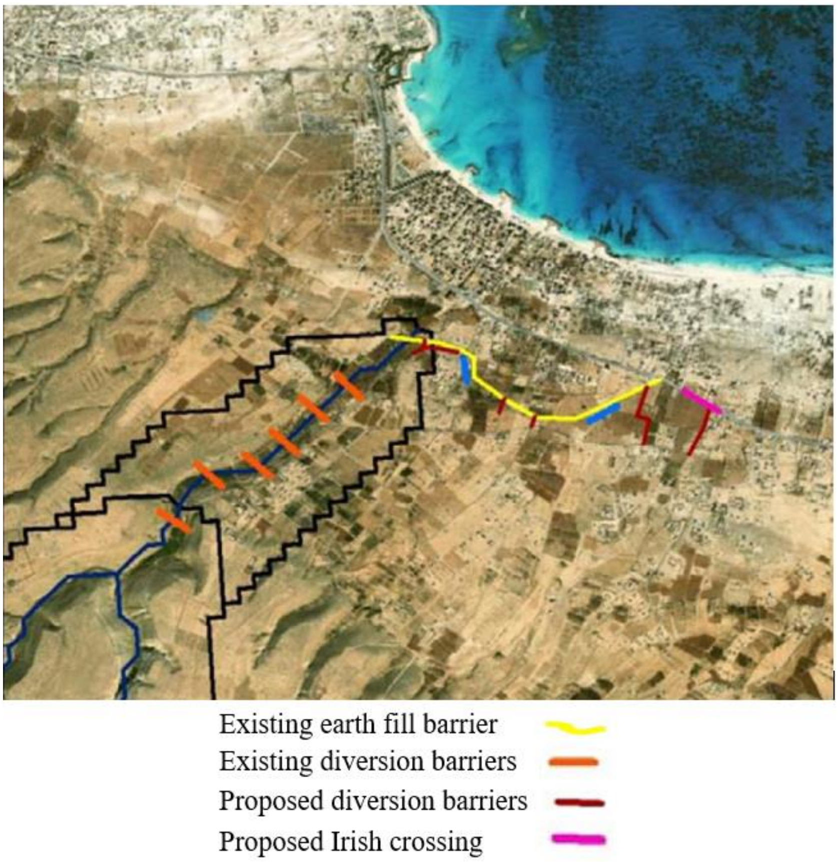

Figure 13. Location of the existing and proposed structures

3. CONCLUSION

Flash floods are affecting the Om Lashtan Village, located in the Egyptian North Coast. A recent extreme flood event caused great harms on the different activities and development projects in the village. A rainfall runoff model was developed to estimate the flood water volumes. In addition, different analyses were carried to investigate the possibilities of selecting flood mitigation measures.

The results show the high potential of rain water harvesting in the area. As the estimated water volumes from the hydrological analysis are massive. For instance, the total volume of the calculated runoffs 0.5 million m^3 for return period 2 years.

Regarding the extreme flood event in Nov. 2020, the resulting flood water was estimated to be nearly 3.1 million m^3. This explains the huge damage caused in the area.

According to the physical and social factors, flash flood mitigation is designed to satisfy the needs of the village's residents. It is decided to propose structural measures in the downstream of the basin for reducing flood risks and water harvesting purposes.

The outcome from this paper can help managers and decision-makers in their future development plans in Om Lashtan City. In case implementing the proposed mitigation measures, the harvested storm water would promote expansion the activities in the area and creates the appropriate climate for the implementation of development plans in the area.

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