PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume (2) No. 2 September 2016 pp: 89:95

Hydrogical Analysis of Flash Flood using GIS in AL-Saff Area, Helwan, Egypt

A. Amin[1], , *A. El Hattab*[2], *M. El Bastawesy*[3], *A. Sharawi*[4], *Marwa Azzam*[5]

ABSTRACT

Through the current research, a systematic methodology, for estimating flood hazard and risk maps, based on a geographic approach using Geographical Information System (GIS) and Remote Sensing (RS), has been developed. It concludes that GIS and modern ground surveying techniques are a valuable tool as they are capable of integrating all the other techniques of flood risk assessment. The research results can help developers, planners and engineers for flood management and land use planning in many fields, such as:

- Calculate the amount of water resulting from the storm.
- Guide in risk and its level associated with a particular hazard at areas under investigation.
- Calculate the storage capacity of water to determine the level of mitigative structures of the proposed dams in a better position for protection with the help of GIS (disaster managers).

However, in the current research, one Complete- Hydraulic Model is presented, namely: Interactive-GIS Based Model.

Keywords: GIS, DEM, Resolution, Topographic Map, Drainage Network, Basin

1. INTRODUCTION

Domestic risk maps in the community can contribute in reduction of hazard risk and loss/damage caused by these types of disasters.

Linking community knowledge with modern techniques to record and analyze risk related data is one way of engaging and mobilising community capacity. This research discusses the use of the GIS at the local level and the need for integrating modern technology and indigenous knowledge into disaster management. It suggests a way to mobilise available human and technical resources in order to strengthen a good partnership between local communities and local and national institutions.

GIS is regarded as a technical developments to help with planning, management and making decision. GIS has been used as scientific tools in water resources and environmental management. Assessing geographic data has become easier than ever before, that's why land managers, planners, resource managers and engineers are using these data proficiently to make decision and analysis. In the GIS technology, there is a link between maps and data bases where attributes of particular place are described. A decision maker can access to data and witness corresponding location at the same time to suggest the effects and general trends **(Sherief, 2008 and Quarantelli, 1997)**.

1 Prof. of surveying, Civil Eng. Dept., Faculty of Engineering, Suez Canal University, Egypt.
2 Prof. of surveying, Civil Eng. Dept., Faculty of Engineering, Port Said University, Egypt.
3 Associate Prof. Head of the Geological application department, Geology division, (NARSS), Cairo, Egypt.
4 Researcher, Aerial Photography and Aviation Department, National Authority for Remote Sensing and Space Sciences (NARSS), Cairo, Egypt.
5 Demonstrator, Civil Eng, Dept., Faculty of Engineering, Port Said University, Egypt.
E-mail address:Mazzam4444@gmail.com

GIS enables managers of disaster to locate the elderly or disabled persons (for example) that reside within a community. This will make organized assistance on their behalf more efficient and time saving.

Maps can be produced to highlight more "high risk" areas that are particularly prone to disasters. This kind of information helps with planning (before the occurrence of the disaster) and also facilitates the coordination of efforts during and after the event **(Warfield, 2005)**.

2. INTERACTIVE-GIS BASED HYDRAULIC MODEL:

Studying the hydrology of catchments involves an understanding of the interaction of climate, vegetation, hill slopes and soil in the determination of runoff process. It is also important to consider the spatial distribution of channel networks such that the propagation of water through them can be understood. The complexity of a catchment increases with the interaction of the system components over the spatial and temporal domain and the presence of randomness in most hydrological systems **(Rodriguez-Itrube, et al, 1989)**.

Calculating the drainage area of a catchment requires an accurate delineation of the boundaries. This delineation can be made either manually from topographical maps, aerial photographs, remotely sensed images, and by field survey, or automatically by GIS from a Digital Elevation Model (DEM). Manual delineation of the catchment divide can be subject to problems if several divides are discordant and is also dependant on the source scale and reliability.

The standard procedure within Arc Info, for delineating drainage networks and associated hydrological parameters using DEMs, consist of four steps, namely: Pits Processing, Flow Direction, Flow Accumulation, and

Stream Network Delineation and Time Area Zones (Hydrographs).

2.1 Pits Processing

True sinks or closed depressions are considered to be rare on natural surfaces and restricted to particular geomorphological environments such as those developed on karst topography in limestone, on landslide debris and/or in areas of Aeolian sand dunes. Therefore, the occurrence of spurious pits in DEMs is considered to reflect inherited errors from either the data sets or the interpolation algorithms themselves **(Mark, 1988)**.

Sinks usually contribute about 1% of surface area in the higher resolution DEMs and can increase up to 5% with lower resolution DEMs. A given sink is filled to reach the nearest lowest elevation; the boundaries of the filled area may be a part of new sinks, which then need to be filled and this procedure is repeated until all of the pits are removed **(ESRI, 1997)**.

2.2 Flow Direction

One of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the flow direction tool.

There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8). **(Jenson and Domingue 1988)**.

The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell. This is calculated as follows:

Maximum drop = change in z-value / distance * 100

The distance is calculated between cell centres.

2.3 Flow Accumulation

Flow accumulation can be expressed as the number of upslope cells that flow into each cell.

Within the flow accumulation function, cells with high flow accumulation values are areas of concentrated flow and may be used to identify stream channels.

Flow accumulation is physically based hydrological model. Therefore, at any location of the watershed, the area contributing to a flow into that point can be easily and quickly expressed **(Greenlee, 1987)**.

2.4 Stream Network Delineation and Time Area Zones

Drainage network (streams network) is determined by applying the critical values (threshold values) at which the first ranks of the Wadies start to appear.

Stream ordering is applied with the aim of assigning a numeric order to links in a stream network. This order is to identify and classify types of streams based on their numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order.

The Stream Order tool has two methods that can be used to assign orders. The method proposed by Strahler is the one used in this research **(Tarboton, Bras and Rodriguez-Iturbe, 1991)**. The Strahler method is the most common stream ordering method. However, because this method only increases in order at intersections of the same order, it does not account for all links and can be sensitive to the addition or removal of links.

The catchment is then subdivided into cascading time-zones, which deliver its runoff to the outlet at consecutive time steps. The delineation of time zones is based on the flow length functions and the estimation of surface runoff using open-channel flow equation such as Manning.

The hydrograph is defined as the rate at which the catchment runoff occurs as a result of one inch of effective rainfall generated uniformly over the basin area during a specific time period.

The hydrograph provides the rate of flow versus time relationship from a catchment due to a rainfall event rather than just estimating the peak flow.

3. TEST AREA AND DATA SETS

In this research, GIS flood risk mapping project are applied through Al-Saff area in Helwan southern of Cairo, Egypt, on the bank of the River Nile. A map of Scale 1: 25k is available as shown in figure (1).

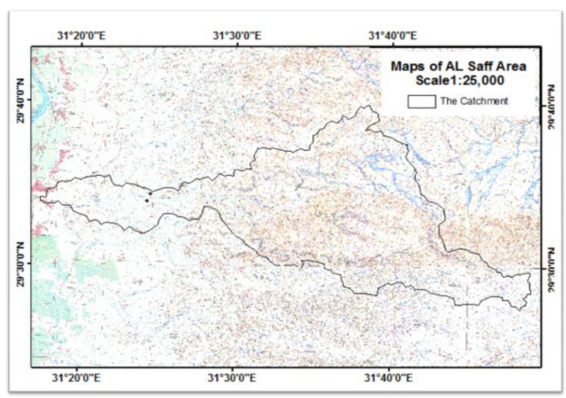

Figure 1: A map of Scale 1: 25k of AL Saff

This area was subjected to study since it has been exposed to recent destructive flash floods.

The latest one was in May 2014 where the area was severely affected by the cumulated extensive amounts of water due to the lack of drain systems or collection pools infrastructure.

So, the objective is to carry a field survey for the area to determine the potential amount of water that would be resulting from floods and to provide some scenarios for constructing reservoirs and dams to enable storing water as well as decreasing or eliminating the unwanted impacts of uncontrollable floods. This field survey consists of about 648 points with X,Y and Z coordinates.

The resulting flash flood of May 2014 has accumulated in the oxidation pool and the depression upstream of it. The surface areas of water ponds were digitized from the satellite image of Landsat 8 (USGS.com) of resolution 15m.

This has been adopted for several resources of digital elevation models (DEMs), compared and then analyzed.

3.1 Acquisition of DEMs by Different Techniques

In addition to the open source data archive ASTER DEM and SRTM DEM as shown in figures (2) and (3), available eight topographic maps of Helwan of scale 1:25,000, are digitized. Then, extracting Wadi Al-Saff Catchment is done to get layer of: Points Elevation and contours. The output of the topographic digital elevation models as shown in figure (4).

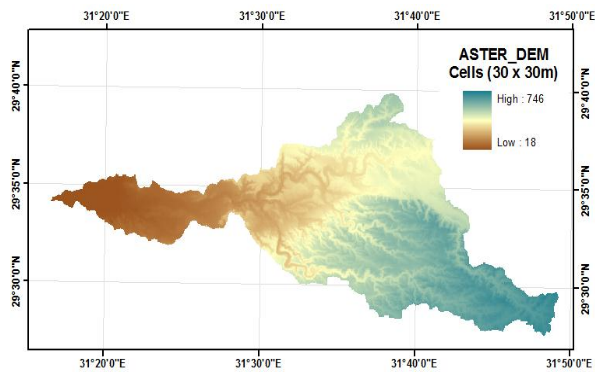

Figure 2: ASTER Digital Elevation Model of Wadi Al-Saff

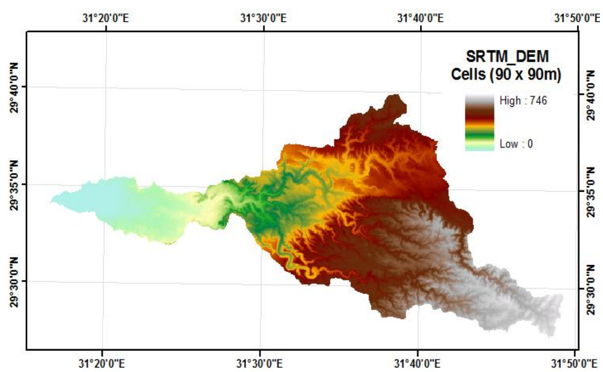

Figure 3: SRTM Digital Elevation Model of Wadi Al-Saff

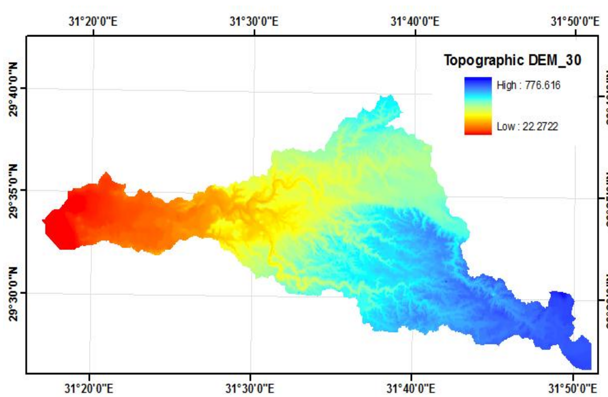

Figure 4: Topographic Digital Elevation Model Cell size 30m of Wadi Al-Saff

3.2 Processing of DEMs

3.2.1 Pits "Filling"

The ASTER's Filling ranges from 18 to 746 m, and the SRTM's values fall in the range of 0 to 746 m, while the topographic maps show this range from 21 to 776 m.

3.2.2 Flow Direction

In this method eight trends was used in the spatial analysis of cells and modules for digital elevation model to create rasters of flow direction from each cell to its steepest down slope neighbor for all DEMs as shown in figure (5).

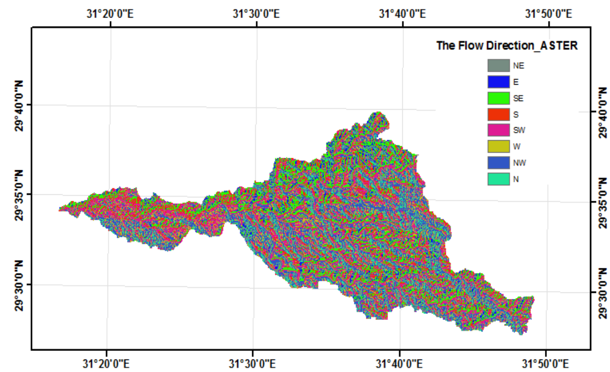

Figure 5: Flow Direction of the ASTER Digital Elevation Model of Wadi Al-Saff

3.2.3 Flow Accumulation

After identifying directions, slopes for each cell to its neighbouring accumulative values (flow accumulation) to the number of cells (area) that supply to the main Wadi along its course is determined. The ASTER's Flow Accumulation ranges from 0 to 67541 cell, and the SRTM's values fall in the range of 0 to 52939 cell, while the topographic maps in the range from 0 to 509302 cell in 30m resolution, and in the range from 0 to 48051 cell in 90m resolution as shown in figure (6).

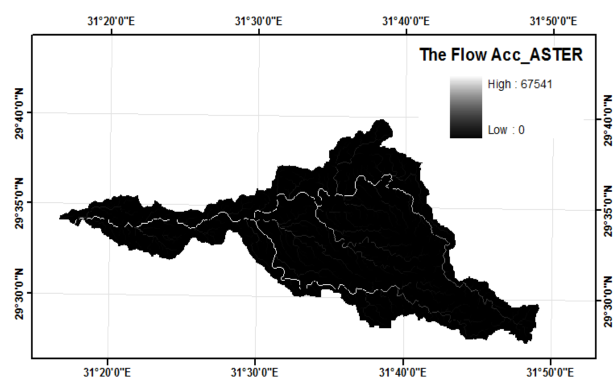

Figure 6: Flow Accumulation of the ASTER Digital Elevation Model of Wadi Al-Saff

3.2.4 Thresholding (Drainage Networks)

Drainage network is determined by applying the critical values (threshold values) then begin the first ranks of the Wadies to appear for all DEMs as shown in figure (7).

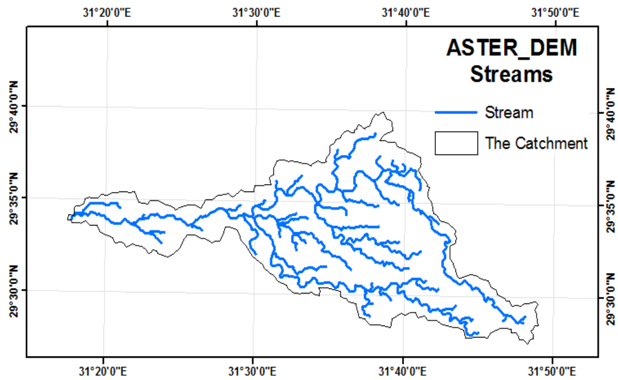

Figure 7: Networks and Paths (Streams) for the basin of Wadi Al-Saff of the ASTER DEM

3.2.5 Time Zones

The ASTER and SRTM DEMs produced very consistent time zones, as the variations in relief pattern among them is very small. The changes in slopes classes are negligible, thus the velocities of runoff are consistent. The delineated time zone is composed of 11 units.

However, the interpolation of topographic contours 30m and 90m DEM has produced significant changes to the resulting time zones. First, the 30m topographic DEM varies slightly than their ASTER and SRTM counter parts. The delineated time zone map is composed of 11 units as shown in figure (8). Indeed the distribution of same catchment areas over 11 units will slightly decrease the area of each zone when compared with their counterparts from the other DEMs. But the interpolation of 90 m DEM from the topographic maps gives striking differences than the other data sets. The number of time zones were reduced to 9 units.

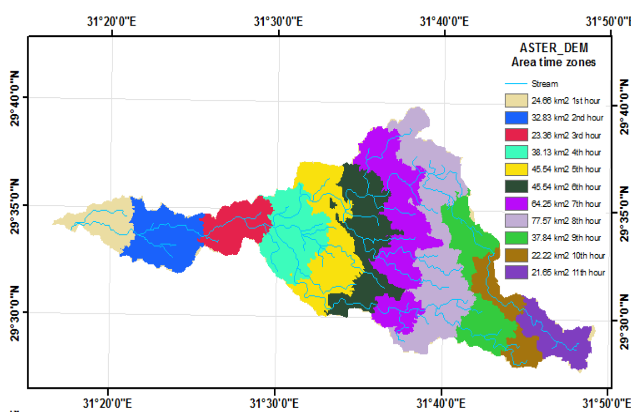

Figure 8: Time zones for the entire drainage basin of Wadi Al-Saff using the ASTER DEM. Flood takes approximately 11 hours in the event of a rainstorm cover all parts of the drainage basin until the water reaches the upper drainage basin to the outlet at the oxidation ponds.

3.2.6 Hydrographs

Herein, the resulting hydrographs, given the estimated flow parameters and catchment hydrological properties from different DEMs, will be presented. All the hydrographs except the developed one from the 90 m topographic are more or less similar in configuration, time to peak and total flow times as shown in figure (9).

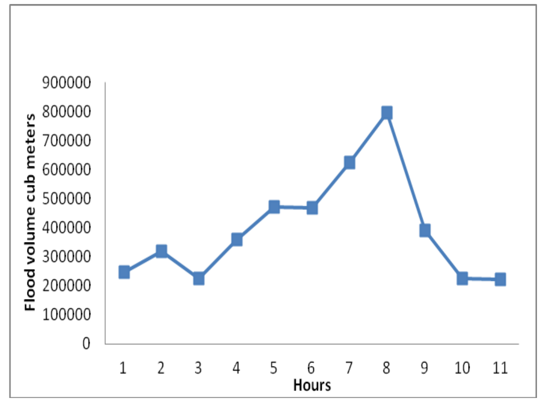

Figure 9: Estimated hydrograph for the catchment using the ASTER DEM parameters. The total flow duration is 11 hours and the peak discharge will occur in the 8th hour at rate of 77.56 km3 / hour.

3.3 Sensitivity Analyses

3.3.1 Stream Orders of Different DEM Sources

Table 1: Stream Orders of Different Sources of Al-Saff.

DEM Source	Order No. 1 Smallest streams (pixel)	Order No. 2 (pixel)	Order No. 3 (pixel)	Order No. 4 Largest streams (pixel)
ASTER	1472	781	559	266
SRTM	1256	671	479	237
DEM_30	3674	2790	1339	1005
DEM_90	1050	556	390	235

3.3.2 Time Zones Area of Different DEM Sources

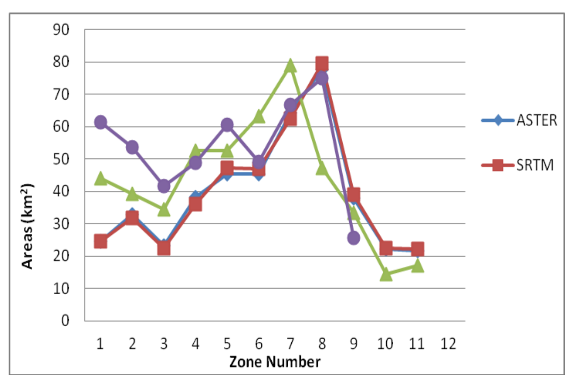

Figure 10: Time Zones Area of Different DEM Sources

3.3.3 Differences between DEM Sources

Table 2: Differences between DEM Sources of Al-Saff

Sources	NO. of Time area zones	Standard Deviation	Peak point	Max. discharge (Km2)	Total Area (Km2)
ASTER	11	17.64	8th hour	77.56	433.49
SRTM	11	17.27	8th hour	79.51	434.48
DEM-30	11	18.04	8th hour	79.12	477.21
DEM-90	9	13.77	7th hour	75.06	483.26

The application of ASTER DEM, SRTM, and Topographic for wadi AL-Saff gives very comparable results. However, the interpolation of topographic data to coarser resolution (i.e. large pixel sizes) gave a different results.
Therefore, it is recommended to use multiple DEMs into the hydrological analyses to investigate the consistency of topographic data. The subtle variation in wadi topography among the different sets of DEMs should be investigated via detailed field survey.

4. RESULTS

- The flood water of May 2014 was accumulated in pools and depressions which have been surveyed to estimate the depths of water at each point. Therefore, the surface areas appear on satellite images were integrated with the depths to estimate the volumes.
  Approximately, 1.9 million cubic meters were delivered to the trapping areas in wadi Al-Saff as shown in table (3) and figure (11).

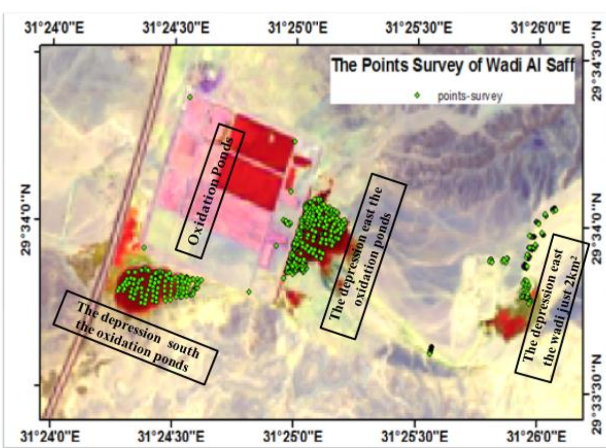

Figure 11: Distribution of Points location using field survey of Wadi Al-Saff inside the storage depressions that received the flash flood in May 2014.

Table 3: The Amount of Water Resulting from the Storm of Al-Saff.

Location	The volume of water (m^3)	Mean Ground Level (MGL)
Oxidation ponds	800,000	119m
The depression east the oxidation ponds	750,000	116m
The depression south the oxidation ponds	300,000	113m
The depression east the wadi just 2km²	50,000	137m

- The peak discharge (according to the field measurements) is approximately 110 m3 / second.
  The storm water drainage curve as shown in figure (12), which is calculated to grade the wadi, indicates that the total depth of rain, that actually turned out to flood (effective rainfall), was 5mm over the entire basin.
- Transmission Losses are controlled by the near surface shale deposits in the wadi beds.
  Therefore, the water ponds remained into the depressions at the outlet of Wadi Al Saff for several months, and the consequent diminishing of these ponds was mainly due to evaporation and minimal infiltration.

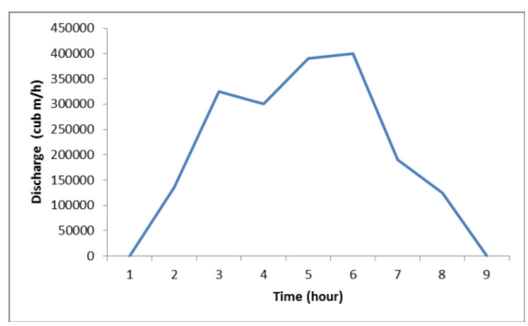

Figure 12: Discharge curve of Wadi ALSaff for May 2014 storm

- First Scenario: A proposed dam can be constructed to control most of the water in the basin as shown in figure (13).
  The establishment of a dam (different scenarios of elevations) in this site will control the floods resulting from the 81% of the total drainage basin.

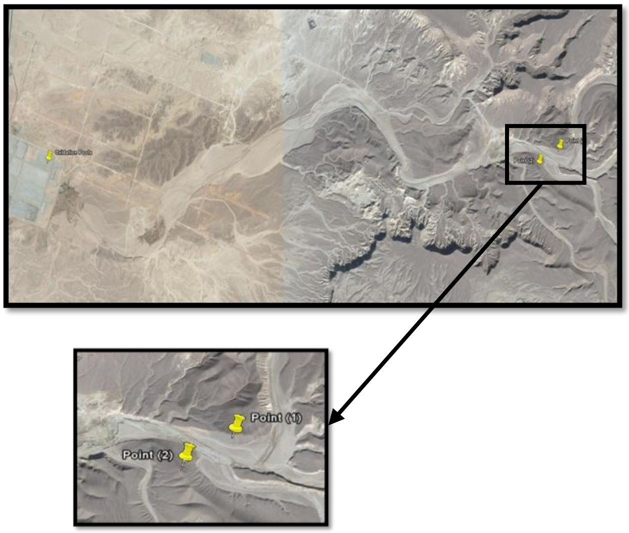

Figure 13: Proposed Locations for Dam Site of AL Saff

Table 4: Scenarios Proposed Dam (The Most Appropriate Place) of Al Saff.

Proposed Locations for Dam Site	Point 1	Point 2
Dam on the main gorge of the stream wadi almost 350 meters long	29 ° 34 ' 16.06 " N 31 ° 29 ' 38.03 " E	29 ° 34 ' 10.08 " N 31 ° 29 ' 26.70 " E
Scenarios of Dam Heights	Storage Capacity (m^3)	
10m	1,320,000	
15m	3,200,000	
20m	6,500,000	

- Second Scenario: The discharge of this flows safely outside the drainage basin require the construction of a channel south of the oxidation pools capable of transferring the peak discharge, and thus protecting the structures from flash floods.
  So it must be designed in engineering and hydraulical way to be able to discharge 165 meters cubic / seconds) with a safety factor 150% of the storm in May 2014 since there is no historical records of the hydrological data.

5. CONCLUSIONS

1. The use of GIS gives useful information about the collection of rain water and floods to avoid possible damages. This is through hydraulic models to get drainage networks workflow.
2. The result of the streams network accumulation from the highest to the lowest level according to the topgraphy of the studied area versus the real "DEM" of the same area, consequently, both figures provided an approximitally identical result in terms of the final collection area of the flood.
3. The calculation of flash flood hydrographs of vulnerable areas using field survey, satellite images and DEM analyses.
4. The determination of flash flood risk of occupations in wadi beds, and suggesting the optimum mitigation measures.

6. RECOMMENDATIONS

1. To investigate the wadies in Egypt and the landuse, landcover in the active channels, and to determine the status of vulnerable_areas and existing mitigation (if any) in order to update the risk map using some techniques provided in this research.
2. For culverts, the routes of flash floods must be ensured upstream and downstream of them in order to prevent any flooding to the neighboring areas to the covering channels of flash floods.
3. For dams, constructions it is necessary to execute geotechnical studies for the bearing capacity, overturning and sliding to ensure the sustainability of the structures. Additionally, safety factors regarding the estimated flow volumes must be considered in order to avoid the undesired over flow of flash floods as happened in AL Arish in 2010.
4. It is utmost importance to evaluate the socioeconomic aspects of mitigation measures and harvesting of flash floods in order to achieve local sustainable development in the wadi systems.

8. REFERENCES

ESRI, 1997. “Watershed delineator application - User's Manual”, Environmental Systems Research Institute, Redlands, CA.

Greenlee, D. D., 1987. "Raster and Vector Processing for Scanned Line work." Photogrammetric Engineering and Remote Sensing 53 (10): 1383–1387.

Jenson, S. K., and Domingue, J. O., 1988. "Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis". Photogrammetric Engineering and Remote Sensing 54 (11): 1593–1600.

Mark, D.M., 1988. “Network models in geomorphology”. In Anderson, M.G., (Ed), Modelling in Geomorphological Systems. John Wiley, Chichester, 73-97.

Quarantelli, E. L., 1997. ‘*Research based criteria for evaluating disaster planning and managing’*. Accessed on 14/01/2008.

Rodriguez-Itrube, I., de Power, B.F., Sharifi, M.B., and Georgakakos, K.P., 1989. “Chaos in rainfall”. Water Resources Research, 25, 1667-1675.

Sherief, Y., 2008. “Flash Floods and Their Effects on the Development in El-Qaá Plain Area in South Sinai, Egypt, a Study in Applied Geomorphology Using GIS and Remote Sensing,” PhD Dissertation, Mainz University, Germany.

Tarboton, D. G., Bras, R. L., and Rodriguez–Iturbe, I., 1991. "On the Extraction of Channel Networks from Digital Elevation Data." Hydrological Processes 5: 81–100.
Warfield, C., 2005. "*The Disaster Management Cycle"*. Accessed on 23/01/08