American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-5, pp-172-181
www.ajer.org
Research Paper Open Access

Developing Flash Floods Inundation Maps Using Remote Sensing Data, a Case Study: Wadi AL-Arish, Sinai, Egypt

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Abstract*: Due to the importance of Sinai as one of the major development axes for the Egyptian government which try to increase/encourage the investment in this region of Egypt, the flood protection arise as a highly important issue due to the damage, danger and other hazards associated to it to human life, properties, and environment. Flash flood, occurred at the last fiveyears in different Egyptian cities, triggered the need of flood risk assessment study for areas highly affected by those floods. Among those areas, AL-Arish city was highly influenced and therefore need a great attention. AL-Arish city has been attacked by many floods at the last five years; these floods triggered the need of the evaluation flood risk, and an early warning system for the areas highly affected by those floods. The study aims to help in establishing a decision support system for the study area by determining the flood extent of wadiAL-Arish, so the damages and losses can be avoided, to reduce flood impact on the developed areas in and around wadi AL-Arish and to improve the flood management in this area in the future. To estimate the runoff, which will be further used for developing the inundation maps, hydrologic model had been developed to investigate the response of watershed to rainfall events. Through the hydrologic modeling some parameters had been considered like soil type and cover, land use which will change water behavior. A historical event data was used during analysis and the response of the study area was modeled to define the flood inundation extents. A flood inundation maps for wadi AL-Arish for the historical event had been developed. The hydraulic model results was translated to flood inundation maps showing water depth and velocity along the wadi with a maximum values of 3 meters, 4.49m/s. The stream power was calculated and*

Keywords*; Inundation Maps, Flash Floods, Arid, Sinai, ElArish*

INTRODUCTION

Flooding is considered one of the major natural disasters which affect many parts of the world not only in the undeveloped countries but also include developed nations. Besides losing millions of dollars in the destroyed infrastructure and damaged property, hundreds of human lives are lost each year due to extreme flood events. One of the main keys in preventing/reducing losses and casualties is to provide reliable information to the public about the flood-risk this could be made through flood inundation maps which can help identifying future flood-prone areas and are very useful in rescue and relief operations related to flooding.**(*Aaron Cook, Venkatesh Merwade, 2009*)**

One third of land area is assumed as arid or semi-arid regions where potential evapotranspiration exceeds average rainfall ***(McKnight and Hess 2000)***. These areas are called 'the arid zones and/or semi-arid zones', much of the Earth's land, mostly between latitudes 18 North and 40° South of the equator, falls within this classification including African Sahara, the Middle East, western USA, most of Australia, part of the southern areas of South America, large parts of central Asia and small parts of Europe.Arid and semi-arid areas, having a complicated hydrological cycle, face the greatest pressure globally to deliver and mange water recourses with such a strange nature of the storms' formation and generation which areusually classified as high intensity and short duration storms. The overlapping between ground water hydrology and surface hydrology add more difficulties for studies of such areas. Over 3000 flash flood disasters were recorded by the Centre for Research on the Epidemiology of Disasters since 1900 making it the most common natural risk. Despite the availability of advanced technologies, societies are still attacked by flash floods all over the world and are continuing to claim lives of many people and causingeconomic losses and serious damage to infrastructure.

Sinai falls in an arid and semi-arid region and is undergoing a rising development, leading to an increase of population. Wadis *"flood paths"*commonly provide the most suitable routes for roads and infrastructure; leading to an increasing pressure for construction in flood prone areas, **(*Elsayad, M. A, et al., 2013*)**. Although infrequent, floods can be extremely damaging and willrepresent a threat to life and property. Furthermore, such threats are likely to increase due to climate changessignificantly affecting the Middle East (ME) region which is currently subjected to above average and more frequent rainfall events during the last decade in several places/countries in the ME.

Flash floods in arid mountainous regions are considered a highly destructive natural disasters. A flash flood can be generated during or shortly after a rainfall event, particularly when high intensity rain falls on steeply hills with exposed rocks and lack of vegetation **(*Wheather, 2002*)**. Flash floods are usually categorized by raging torrents resulting in flood waves sweeping everything before them. As a result, the debris load could be high, which magnifies the destructive power of a flash flood.***(COOLS, Jan, et al. 2012)***.

Sinai has a special topography, as a towering plateau from south to north composed of old igneous rocks, it has a lot of high volcanic peaks. The most important Mountains are St. Catherine, Oum Schumer, and Al-Thabt. At the edge of these mountains towards the north Al Teeh plateau, which descend to the north, representing two-thirds of Sinai area with average height of 1000 m. The land of TeehSailiya plateau also slopes towards the East and the West, where deep valleys make their way toward Gulf of Aqaba and Gulf of Suez. Wadi AL-Arish stems from the plateauAjkah then crosses it, and takes its way towards the Mediterranean with the outlet near the town of AL-Arish.

Hydrologic characteristics of the Wadi AL-Arish are not fully understood due to lack of the detailed hydro-meteorological information. Therefore, Remote Sensing (RS) data and Geographic Information System (GIS) tools and techniques are widely used to provide better spatial understanding of basin response to storm rain events (***Moawad Badawy Moawad, 2013***).

On the 17th and 18thof January 2010, severe flash floods hit Sinai Peninsula, Egypt owing to heavy rains from which flood of wadiAL-Arish was the worst. The flood led to the death of six victims and dozens of people were wounded and many missing. It fully devastated 592 houses and partially damaged 1487 houses as the water level reached 2 m above the ground in some locations. The water washed away cars, auto-trucks, trees, roads, electric towers and water lines. Damages were estimated as 137 million Egyptian pounds **(*Official governmental spokesman, 2010*)**.

The study aims to establish an early warning system to the area by defining the wadi inundation maps and determine the right of wadi to prevent any development in it to avoid damages and losses. Theoretical storms will be assumed during analysis and the response of the study area will be modeled to determine the flood inundation.

MATERIALS AND METHODS

Study Area

Sinai is a peninsulalocated in the northern east of Egypt and has a triangle shape occupying an area of 61,000 km^{2}and is stretched out between the Gulf of Suez in the west, the Gulf of Aqaba on the east and the Mediterranean Sea in the north. The largest dry wadi in Egypt (WadiAL-Arish), located within 33° and 35° longitude 29° and 31.25° latitude, Figure1, represents around one third of Sinai area and will be considered in this study.

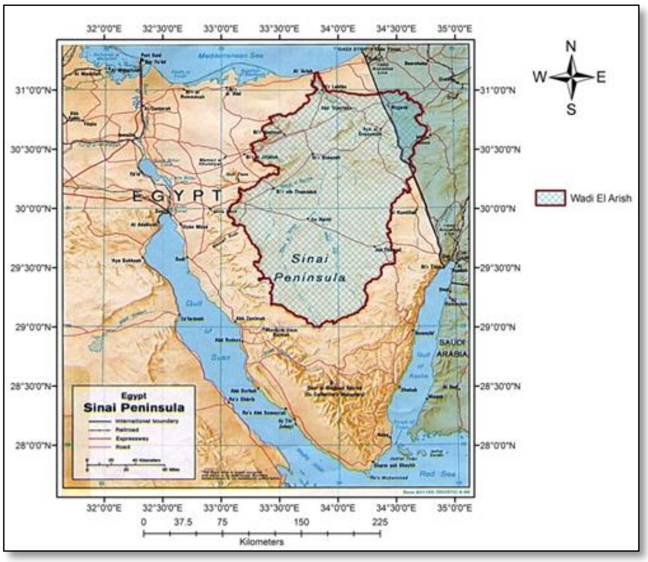


Figure1; Sinai Location

The average summer temperature, in Wadi AL-Arish varies between 25° Cand 29°C, reaching a maximum of 43° C. The average long term winter temperature is 10° C to 11° C with a minimum of 3°C. These variations are expected because of the differences in position, elevation, and distance from the coast and the environment around the stations **(*Ghanem 1999*)**. The temperature increases from north to south and from east to west. The summer daily temperatures are relatively constant whereas they fluctuate in winter hence, warm and nice days are quickly followed by cold cloudy ones with potential of short rainfall events with high intensity that may result in flash floods.

A variety of soils can be found in Sinai. The causes for this variety are related to the extreme conditions that formed these soils. Physical weathering from both water and wind also modified the soils. It includes sedimentary rocks, volcanic rocks, Granite rocks, sand dunes, alluvium, Limestone, etc., Figure2.

Being a very rich area with resources and raw materials, Sinai is one of the major development axes in Egypt, but in the same time it's highly affected by floods due to its topography. Therefore, flood protection is a highly important issue due to the damage, danger and other hazards associated to floods to human life, properties, and environment.

The watershed delineation process deals with the influence of terrain on surface hydrology, the movement of water over the land surface. The process computes the local directions of flow, defines the stream network, the boundaries between watersheds, and the areas drained by particular stream systems. This process requires input elevation information in the form of a Digital Elevation Model(DEM) as a source for elevations. Recent and highly accurate topographic data are used for flood inundation studies, but this may not be always feasible given time and budget constraints, Therefore, the utility of several on-line (DEMs) is commonly used with a set of steady and unsteady flow problems **(*Brett F. Sanders, 2007*)**.

Wadi El- Arish drainage basin was delineated using the 90 m (DEM) available through the Shuttle Radar Topography Mission (SRTM) as a source for elevations and the basin boundary, Figure3.

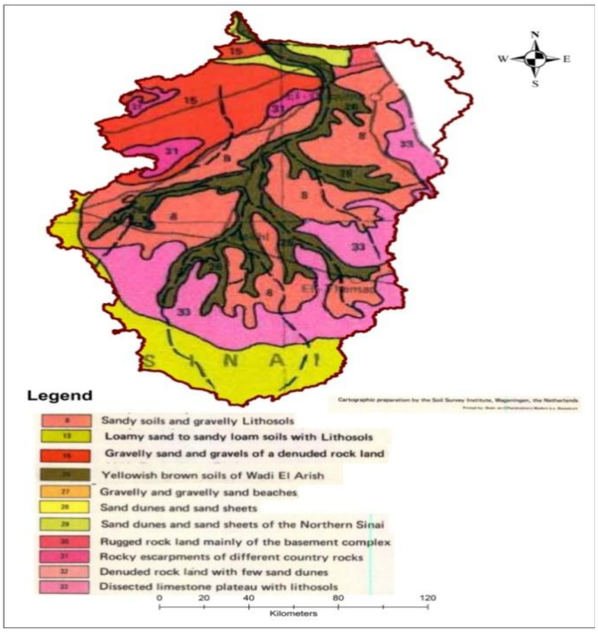


Figure2;Geological map for Wadi AL-Arish

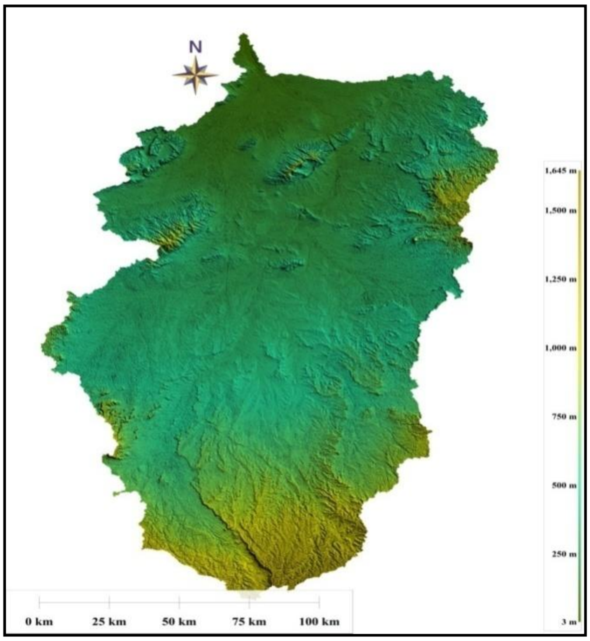


Figure3;WadiAL-Arish Digital Elevation Model

In February 1975 a unique rain event occurred in AL-Arish drainage basin and brought an extreme flood flow to the coastal city. The return period of such an event was estimated to be once in a century or even less frequent. The rain started during the evening of 19 February 1975, spreading throughout Sinai Peninsula except for the northern part. The rain strengthened during the early morning hours of 20 February, and continued throughout the day. During the rainstorm, the following amounts of rain were measured by rain-gauges in the area: St. Catherine Monastery (south of the basin), 73 mm; at the east of the basin 68 mm; Nekhel 48 mm; and only 8 mm in AL-Arish in the northern part of the basin. It is estimated that the average rain over the basin was 40—50 mm. As the northern part of the basin did not contribute to the flow, the total water volume on the basin was estimated to be around 800 x 10^6 m^3, the peak flow reached 1650 m^3/s and the total flood volume was 120 x 10^6 m^3.

During 18 January, 2010; Egypt was subjected to thunderstorms and heavy rains started at the West-North Coast, the Red Sea, and Sinai Peninsulacharacterized by "exceptional and extremely heavy rainfall". This extreme weather and intensive rainfall led to flash flood over Sinai Peninsula, and was fatal to some Bedouin tribes located in its path. The following pictures are showing some of its consequences, Figure 4.

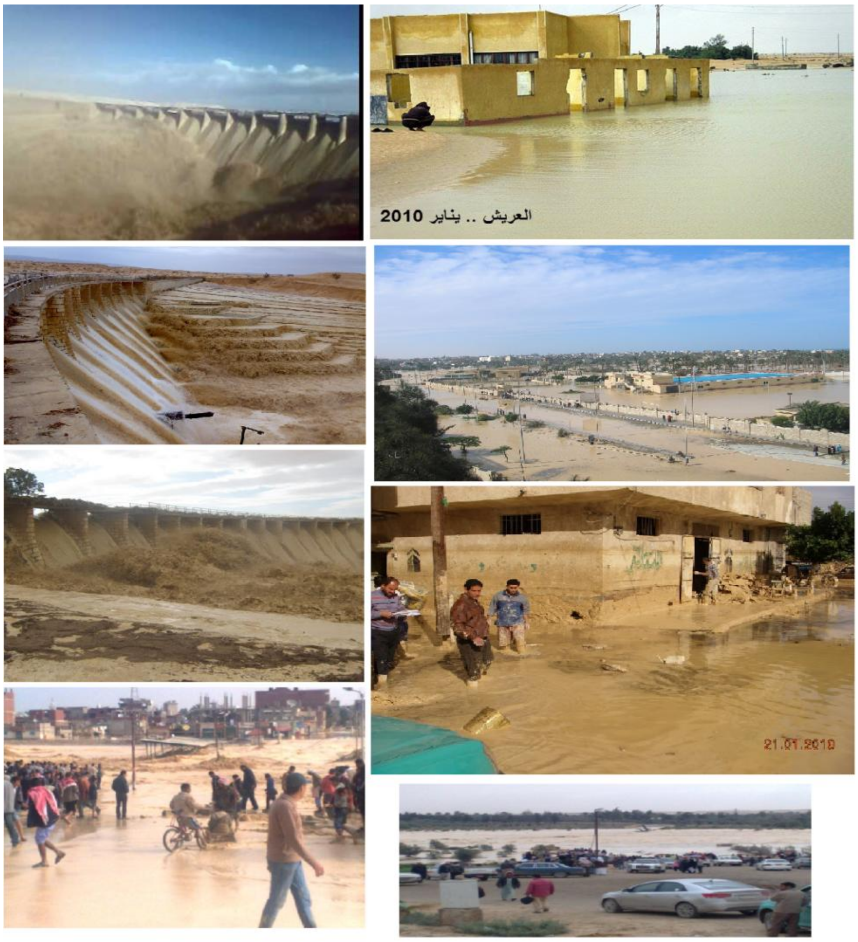


Figure4; 2010 Floods Consequences

METHODOLOGY

The study methodology flow chart, Figure5, describes several steps that was executed to achieve the results.The basic data available for this part of the country and for such huge area is mainly a Remote Sensing (RS) data such as, Soil Conservation Service (SCS) Curve Number (CN) grid, and (DEM). The available rainfall data were analyzed to compute rainfall depths of different return periods, in the same time the SCS-CN grid and DEM were used for morphological analysis and to generate the basin model using Geo-HMS tool for the hydrological model to study the response of Wadi AL-Arish for the varies rainfall events. The hydraulic modeling used in the study depends on two main inputs; the runoff data (the developed hydrographs from the hydrological model) and the geometric data (Cross sections generated from the DEM). The hydraulic model results include water depths, velocities, and stream power.

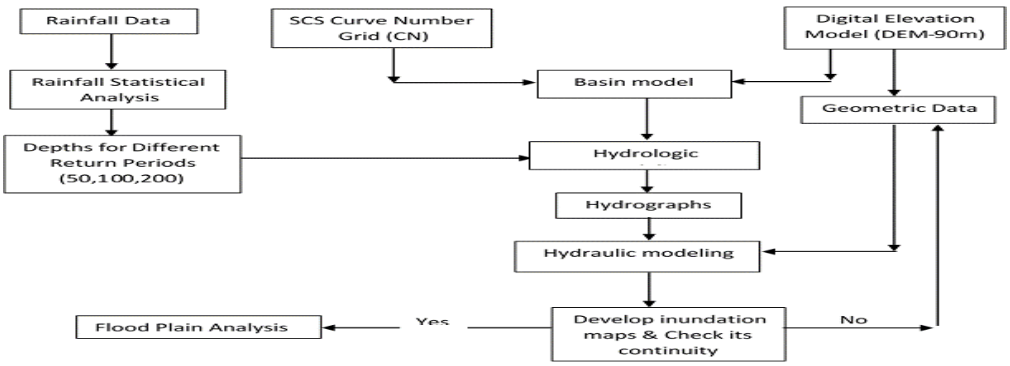


Figure5;Study and Analysis Methodology flow chart

DEVELOPING THE HYDROLOGIC MODEL

Hydrological modeling is the first step that should be taken prior producing flood plain maps, the modeling process starts with preparing the basic data which will be used as input to the model (i.e. rainfall depth, CN data for the study area, and topographic data used to define the morphological parameters of the watershed). The hydrologic model data were preparedusing the Geo-HMS tool operated under ArcGIS, the tool enables developing a full morphological input files to be used directly in the Hydrologic Modeling System(HMS), developed by the Hydrologic Engineering Center (HEC) of the US corps of engineers,to calculate the runoff hydrographs at different locations.

The infiltration parameter is an important parameter in the runoff estimation and flood hydrograph prediction. The Soil Conservation Services (SCS) method is considers one of the widely used methods in this filed that uses curve number (CN) as an indicator of the soil infiltration capacity that could decrease the runoff. The lower the CN of a watershed is the less the runoff generated from it as a result to rainfall events. (***HaithamAbdelhakiem et al.,2016***) has generate a CN grid for entire Egypt during which is used in this research as a source for CN values.

Topographic data isa critical input data for flood inundation modeling, thus recent and accurate topographic data should be used for flood inundation modeling. However, given time and budget constraints,this is not always feasible **(*Lorenzo Begnudelli and Brett F. Sanders,2006*)**. A (DEM)with a pixel size of 90x90 meter has been used as a source to obtain the morphological parametersof the study area using the Geo-HMS tool.

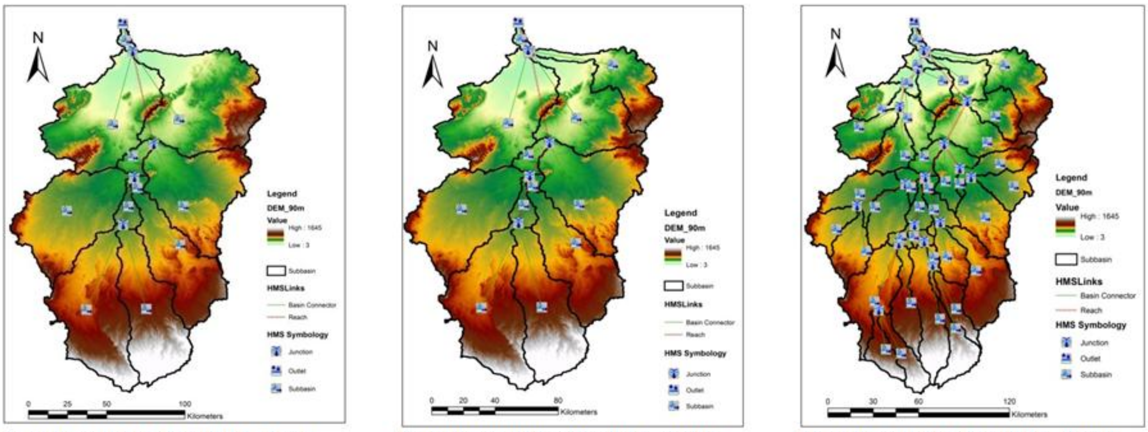
HEC-HMSuses the basin model to predict the response of a watershed due to certain rainfall event.It predicts the generated runoff by determining the losses, computing runoff volume, then transform the runoff depth into surface flow, and final flow routing through the mainstreams to the outlet. HMS includes various models for each stage that can do the same job but in different way and using different approaches/parameters; the used models in this case study for the different stages are listed in the following table;

Table 1The used models in HEC-HMS

Stage	**Selected Model To Be Used**
Losses Model	SCS Curve Number
Direct Runoff Flow	SCS UH
Base Flow	None
Channel Flow (Routing)	Muskingum ($K=T_{lag}$, X=0.28, **M. Gad, 1996**)*

In ***1996 M. Gad*** had studied the hydrology of wadis in Sinai;the research used coupled measured rainfall runoff data for wadiEl Meliha experimental basin to calibrate HEC-1 model. The unit hydrograph and loss rate parameters were optimized and new parameterizations have been developed.

A huge basin, like the one understudy, should be divided into smaller sub-basins when analysed for rainfall-runoff to capture the routing behavior of mainstreams. Flow from each sub-basin is to be routed producing flood waves flowing through the basin's mainstreams. Sub-basin threshold has a significant effect on the accuracy/precession of the model. The runoff flow will be affected/changed by the reduction of the sub-basin area till a specific value at which reducing the threshold will have no significant effect on the resulted runoff hydrographs.Different threshold values were investigated/testedto find the best value resulting in a reasonable accuracy and minimize the simulation time as well.Three trials for thresholds were used for sub-dividing wadi AL-Arish into smaller sub-basins (2000 km^2, 1500 km^2, and 500 km^2), Figure6.



A: Subbasins for WadiAL-Arish with a Threshold of 2000km^2

B: Subbasins for WadiAL-Arish with a Threshold of 1500km^2

C: Subbasins for WadiAL-Arish with a Threshold of 500km^2

Figure6; Basin models with different threshold

Each trial resulted in different basins/streams network scheme that were then used in the rainfall runoff model (HEC-HMS) to obtain the resulted runoff hydrograph at the wadi outlet.

The resulted hydrographs, Figure7, showed that the rate of change in peak discharge due to change in sub-basin area (using a 50 mm Rainfall depth)is not of a significant effect, as the difference between the largest and smallest peak flow values didn't exceed 2%, Table 2.Therefore the largest threshold (2000 km^2) will be used in the hydrologic model.

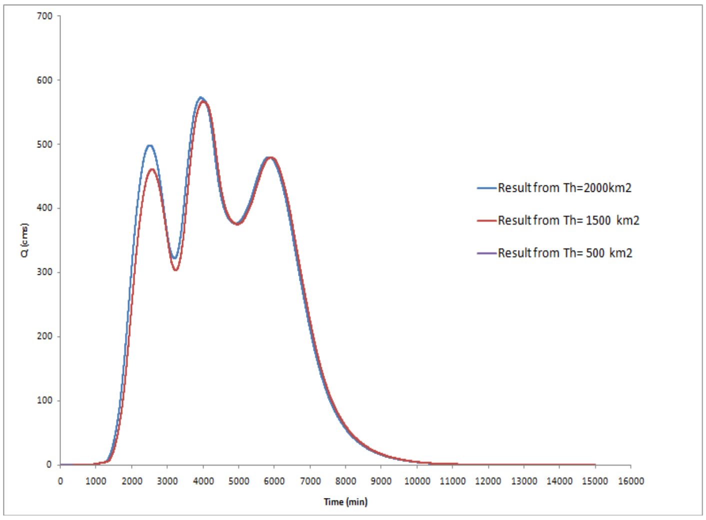


Figure7 Runoff Hydrographs at Wadi AL-Arish Outlet for different sub basinsthresholds

Table 2 Peak flows for the different thresholds

Sub-basin Threshold (km^2)	Peak Flow (m^3/s)
2000	572.9
1500	567
500	563.9

INUNDATION MAPS DEVELOPMENT

Flood risk warning,preparedness, communications, mitigation, and response can be enhanced by flood inundation mapping that displays flood water extent, velocity, and depth over the land surface. Digital geospatial flood inundation mapping is considered a powerful tool for flood risk management.

Flood is a temporary condition of surface runoff, in which the water levels and/or discharge exceed a threshold value, thereby escaping from their normal confines **(*Douben N, and Ratnayake RMW,2005*)**. Flood is a result of heavy/intense precipitation that causes overflow/overcapacity in streams, those affecting areas which are normally unsubmerged.

During the hydraulic model development;the Geo-RAS tool,operating under Arc-GIS, was used in stage one for data preprocessing derived from an existing (DEM) of the channel and surrounding land surfaceto prepare the necessary geometric data for hydraulic modeling like river alignment, and cross sections.The required Hec-RAS Layers created include the Stream Centerline and XS Cut Lines, figure 9. Geometric data and cross-sectional attributes are then extracted to generate a data file that contains:

- River, reach, station identifiers;
- Cross-sectional cut lines and surface lines;
- Main channel bank station locations;
- Reach lengths for the left overbank, main channel and right over bank;
- Roughness coefficients.

During the 2nd stage, HEC-RAS hydraulic model is used to simulate the behavior of water flowing through the main stream of Wadi AL-Arish for the given geometric data and the rainfall event of 1975. The Geo-RAS tools wasalso used in stage three forpresenting and mapping the hydraulic modelingresults, Figure 8.

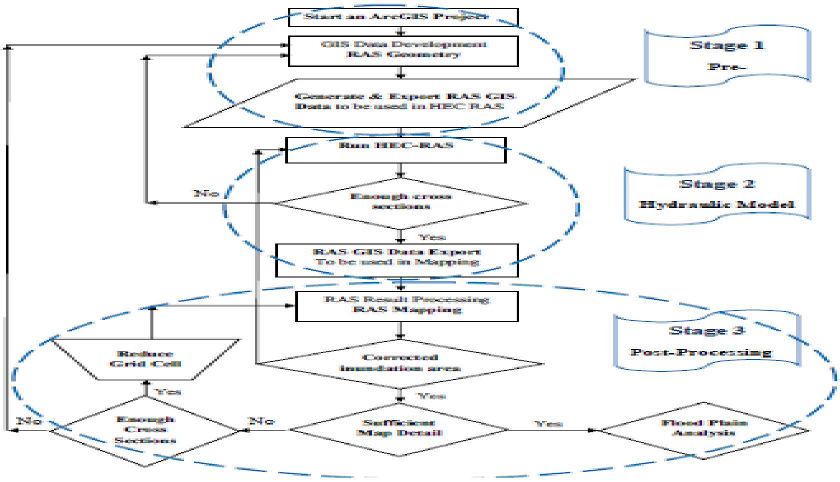


Figure8;Flood inundation mapping process stages

The Manning coefficient is a parameter that measures the effect of channel roughness on the flow of water through it. The values for the Manning coefficient vary based on channel terrain, and are published in most hydraulic engineering books (***Prasuhn, 1992***) and a value of 0.035 was used for the main flood channel and 0.045 for flood banks.

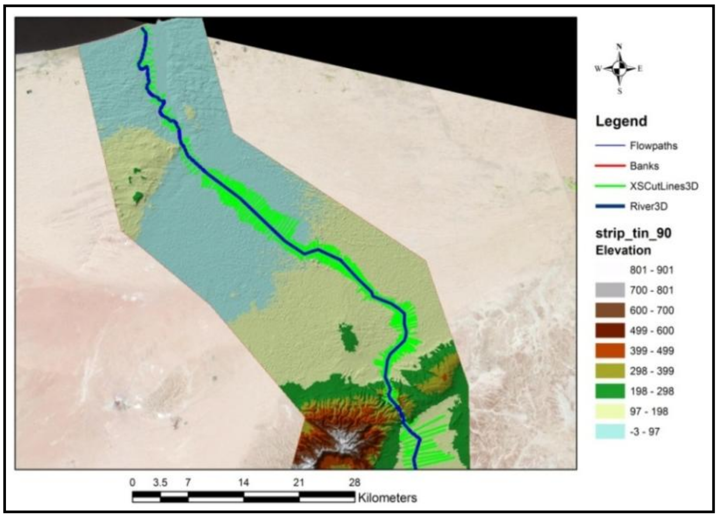


Figure9;Geometric Data processing using HEC GeoRAS

RESULTS AND DISCUSSION

Flood inundation maps, that accurately reflect observed and forecasted hydrodynamic conditions, enable officials to make timely operational and public safety decisions before and during flood events.To get the runoff for inundation maps for wadi Al-Arish main flow path, hydrologic model had been setup to get the response of the watershed for rainfall.Then flood mappingand inundation extent, water velocities, and water depthswere estimated using the hydraulic computational outputs from a HEC-RAS hydraulic model simulating the peak flow of 1975through the study area to estimatemaximum water depths and velocities corresponding tothis event and hence calculate the stream power. **(*Bagnold, R.A., 1966*),** definedthe available power supply or time rate of energy supply, to unitlength of a stream as the time rate of liberation in kinetic form of the liquid's potential energy as it descends the gravity slope S. Denoting this power by Ω, and it is given by the equation:

$$\Omega = \rho g Q S$$

Where;

Ω is the stream power, ρ is the density of water (1000 kg/m^3), g is acceleration due to gravity (9.8 m/s^2), Q is discharge (m^3/s), and S is the channel slope.

A flood inundation maps for Wadi AL-Arish for the 1975 historical event had been carried out as the highest recorded event ever occurred. The results of the hydraulic model were then used, through the post-processing tool of the Geo-RAS tool, to create flood extent, water depth, water velocity distribution, and stream power maps. Figure 10 shows the maximum water profile developed for main stream based on the steady hydraulic model analysis and results.

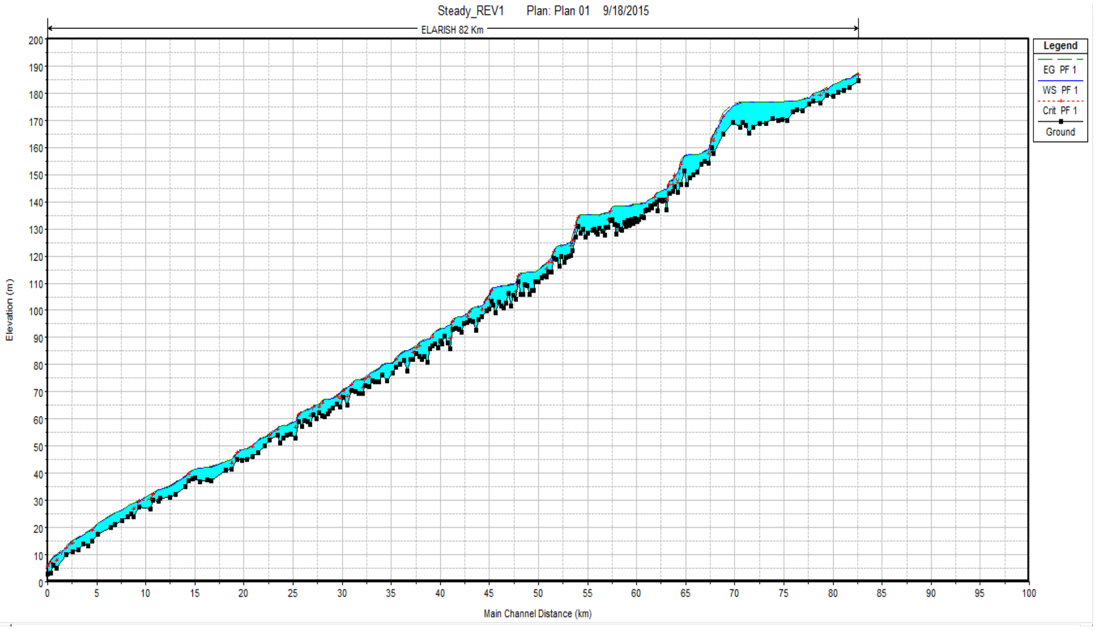


Figure10; Maximum water profile resulting from for the 1975 flood

An existing defined channel with about 500m width, starting from the shore line and extending about 20 km to the upstream, was designed and constructed to convey the expected flood. Yet, the majority of the channel was flooded over its banks and the flood wave extended to about 800m width, which is almost the twice of the channel width. The rest of the wadi, upstream the channel till El Rawafaa Dam, is a natural stream and is not well defined.In addition, the presence of farms,scattered along the main stream, increases the overall roughness and causes the water to extent even wider reaching 1,100m of a submerged cross section in some locations, Figure121.

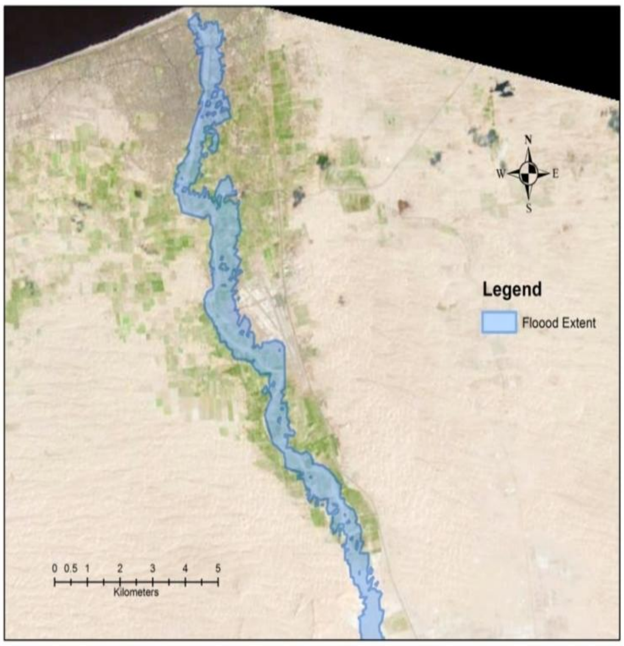


Figure11; Flood Inundation map of Wadi AL-Arish for the 1975 Storm

The maps showed that the water depths didn't exceed 3m along most of the study reach of the wadi and with average value of 1.8 m except for some local depressions where the water depth increasedto 8m, Figure12.

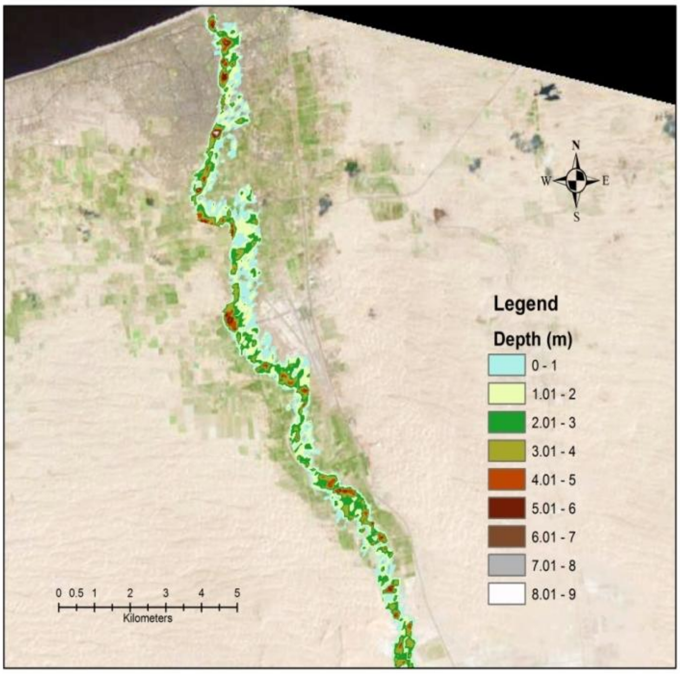


Figure12;Water Depths of Wadi AL-Arish for the 1975 Storm

The velocity near the flow sides was almost zero due to the small depth of water compared to the friction coefficients. The water velocities along the wadi are variable as the bed slope change from reach to another, the maximumcalculated flow velocitywas found to be at the artificial channel part in the downstream of the wadi.The velocities distribution showed the velocities varying between 0 and 4.49m/s with average value 1.12m/s, Figure13.

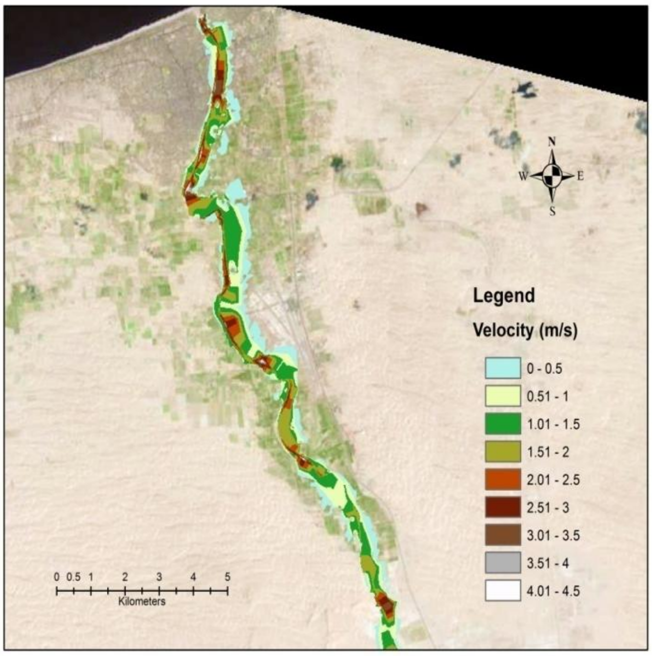


Figure13; Water velocities of Wadi AL-Arish for the 1975 Storm

The fundamentals of the stream power are velocity, water depth, and channel slope; and as theprevailing values for velocity and water depth didn't exceed 2m/s, 3m respectively, the prevailingstream power value are less than 100 watt/m.In local points where the velocity and/or water depth exceed prevailing values the stream power exceeds 100 watt/m (marked with circles on figure 14).

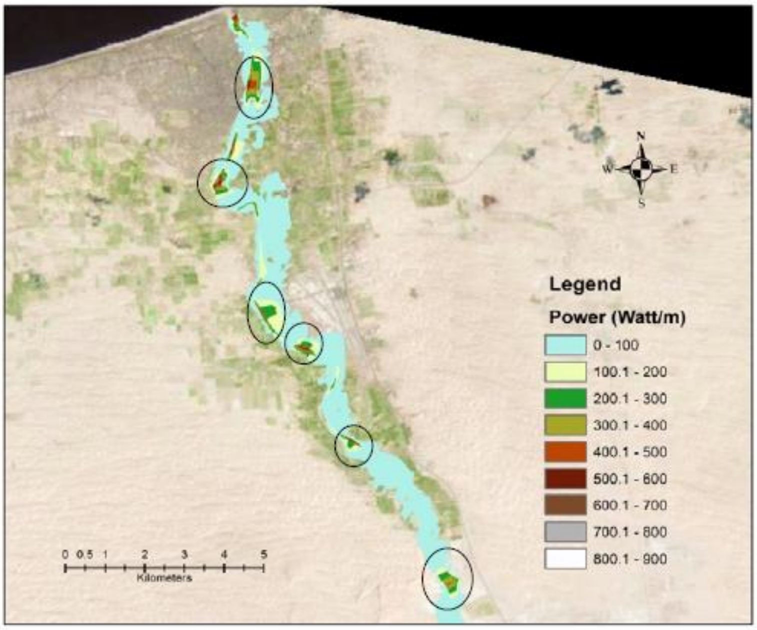


Figure14; Stream power of Wadi AL-Arish for the 1975 Storm

The model results indicates that the existing flood channel will not be sufficient to contain a flood wave similar to the one occurred during 1975 (before the flood channel construction). The results represent an important information to be used for a flood mitigation plan, however,more detailed survey data about drainage structures will represent a strong addition to include in the hydraulic model.2-D modeling may berecommended for more detailed results, yet the availability of detailed survey may restrict the development of this modelwith more accurate and reliable results.

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