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FLASH FLOODS VULNERABILITY ASSESSMENT USING GIS SPATIAL MODELING AND REMOTE SENSING DATA IN EL-ARISH CITY, NORTH OF SINAI, EGYPT

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ABSTRACT

Floods are a weather hazard and occur when water flows into a region faster than it can be absorbed into the soil, stored in a lake or reservoir or removed in runoff or a waterway into a drainage basin. Flash floods are the most dangerous kind of floods causing rapid rises of water in a short amount of time and can trigger other catastrophic hazards associated with damage, danger to human life, properties, and environment. In this study, flash floods were discussed in order to support the decision-making process concerned with water management as an essential prerequisite for Egypt sustainable development. Geographic Information System (GIS) are used to analyze the vulnerability of flash floods in El-Arish City. GIS not only can generate visualization, simulation and modeling of flooding, but also provide the potential to further analyze to estimate damages due to floods and for both the flood management and flood emergency response. The flash flood vulnerability mapping in this study integrates some of the flooding causative factors such as rainfall distribution (TRMM data), elevation slope and aspect (ASTER data), flow direction and drainage network (ArcGIS hydrology analysis) and land-cover (Landsat 8). Vulnerability was classified into five: very high, high, moderate, low and very low. The results show that El-Arish City has very high vulnerability to flash floods. The most prone-areas cover residential areas in El-Arish City. This reveals socio-economic vulnerability in terms of serious damage to property of infrastructures such as roads, bridges and other public and private settlements. The vulnerability varies from low values in the south to high values in the north and the north basin is the most vulnerable to flooding with very high vulnerability with about 5.4% due low elevation with both vegetation cover and urban areas. This study recommended the creation of dams as a solution to flash flood to control and harvest flood water to take the advantage of the water stored. However, geological structures have to be considered through the process of creating dams and determination of the possible dam sites have to studied well through GIS suitability analysis. It is also recommended that local authorities have to prepare against future occurrence of floods by early warning systems and effective urban planning measures that should be put in place in those areas that are vulnerable to floods.

Keywords: *Flash flood, Floods Vulnerability Assessment, GIS, Remotely Sensed, El-Arish City Sinai.*

1. INTRODUCTION

Flash floods in arid regions are considered a highly destructive natural disaster. It was reported in the EGYPT's REVIEW In depth Assessment of Progress in Disaster Risk Reduction that floods is the most

widely distributed natural hazard to life compared to all other natural hazards. Records indicates that many regions in Upper Egypt, Sinai and Red Sea area were hit by severe flash floods in 1976, 1982, 1984, 1994, 1995 and 2010 (El-Rakaiby, 1989; El-Shamy, 1992; El-Bastawesy *et al.*, 2013). Flash floods occurred at the last five years in different Egyptian cities, among those areas Sinai which is the most area in Egypt suffered from flash floods because of its huge variation in elevation and high-intensity rainfalls (Farahat *et al.*, 2017). In January 17, 2010, a destructive flash flood has swept Northern Sinai (Wadi El- Arish) and the Gulf of Suez (Wadi Wirdan & Wadi Sudr). Significant losses of lives and damage to properties and cultivated crops have occurred. The flash floods generated a severe destruction to urbanized areas founded downstream of Wadi El-Arish (Gabr & El-Bastawesy, 2015).

Flash floods are rapid surface water responses to rainfall, produced by extreme precipitation events of short duration affecting a limited area. The potential for flash flood casualties and damages is increasing in many regions due to the social and economic development (Wheather, 2002; Niyongabire *et al*., 2016). Sinai climate is characterized in general by volatile rainy winter, hot and no rain in summer. In autumn and spring, the climate is less volatile than winter with sometimes heavy rainfall. Many authors investigated GIS analysis techniques to study various aspects of drainage morphometry (Ghaffar *et al.*, 2015; Abduladheem *et al.*, 2015), geomorphology (Youssef Shawky, 2008), hydrology (Moawad, 2013; Gabr & El-Bastawesy, 2015) within and around Sinai. Arafat *et al.* (2014) studied land cover in North Sinai using SPOT4 (HRVIR) images with 20 m spatial resolution. (Farahat *et al.*, 2017) used remote sensing data to develop flash floods inundation maps in Wadi EL-Arish, Sinai, Egypt. (El-Bastawesy *et al*., 2013) used to estimate a range of hydrological variables and parameters such as rainfall and evapotranspiration. (El-Bastawesy *et al*., 2008; Milewski *et al.*, 2009; Abou El-Magd *et al.*, 2010; Al-Mazroui, 2011) used TRMM data to estimate various temporal ranges of rainfall for many dry land areas as it is considered one of the key meteorological satellites.

2. STUDY AREA

Sinai is a peninsula located in the northern east of Egypt bounded by the Mediterranean Sea in the north, the Gulf of Aqaba on the east and the Gulf of Suez from the West. The mean temperature ranges from 27.8 to 14.4 °C and 25.9 to 13.4 °C and the average annual rainfall is about 100.7 mm at El-Arish. Wadi El-Arish basin Figure (1) is the largest dry wadi in Sinai Peninsula, Egypt. It is located from latitudes 29° 00` to 31° 10` N and longitude from 33° 05` to 34° 40` E. It flows toward the Mediterranean Sea and its downstream part is El-Arish City and covers about 21,700 km2 which constitute about 36% of the total area of the Sinai.

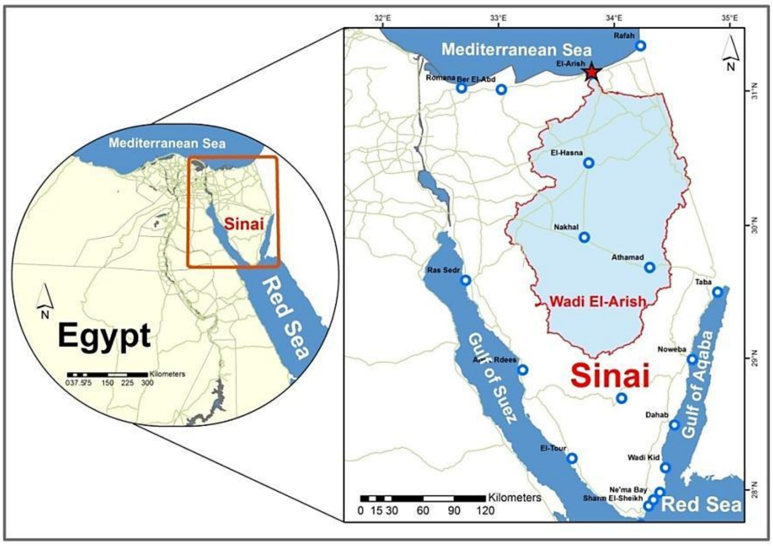


Figure (1) **Study area location map**

3. DATA AND METHODS

Different sources of data have been collected, processed and integrated together. Both of digital image processing and GIS software have been used to carry out the technical analyses of these data. These data are topographic maps, satellite images, ASTER DEM and TRMM data. Table (1) summarized different data used in this study.

Table (1) Data description

Input Data Type	Date	Derived Data
ASTER	2016	DEM, Slope, Aspect, Stream network
Landsat 8 OLI/TIRS	2016	Land cover map
TRMM	2016	Rainfall estimation

The digital elevation model (DEM) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with 30m resolution of the study area has been obtained from the http://gdex.cr.usgs.gov/gdex. ASTER data was used to extract the hydrographic parameters for GIS analysis Figure (2). Landsat-8 OLI-TIRS images with 30 m spatial resolution freely available from United States Geological Survey (USGS) websites (http://earthexplorer.usgs.gov). The cloud-free image was acquired on 24 December 2016 with a combination of path-row 175-38 as shown in Figure (3).

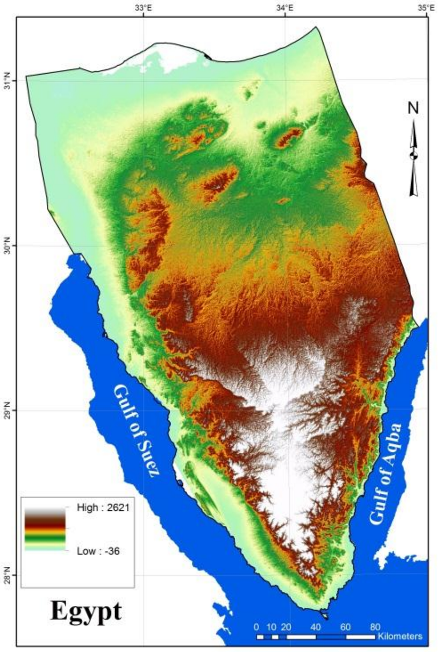


Figure (2) DEM of Sinai

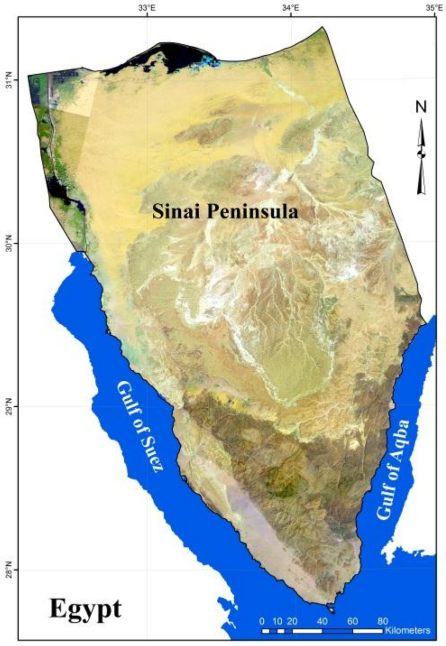
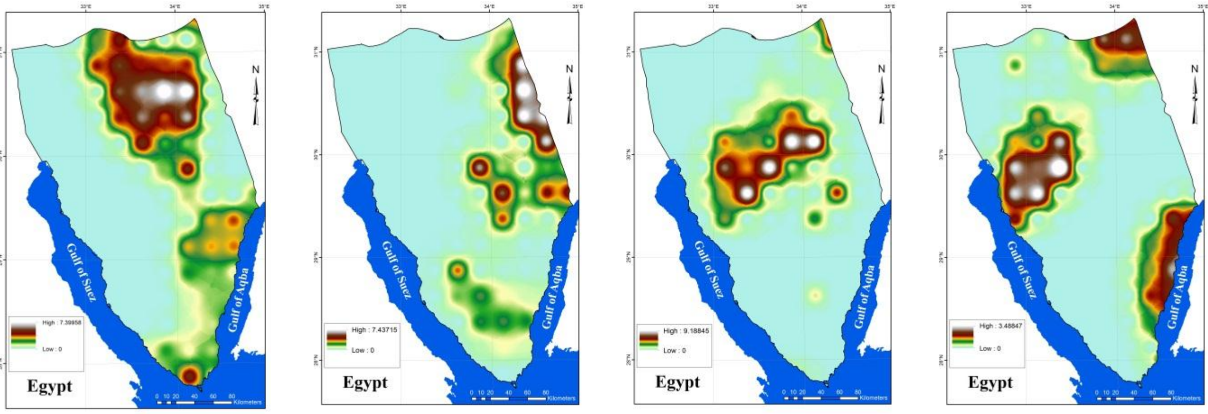


Figure (3) Landsat8 OLI image of Sinai

The Tropical Rainfall Monitoring Mission (TRMM) is a US–Japan satellite launched on November 1997. It has been used to estimate rainfall parameters for the catchments due to the absence of in situ data using the Precipitation Radar (PR). The images as shown in Figure (4) were downloaded in the format of Network Common Data Form (Net CDF) and obtained freely from http://mirador.gsfc.nasa.gov. Figure (5) presents the flowchart of research methodology used in this study



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18 January 2016 17 January 2016

Figure (4) TRMM data (rain intensity) for Sinai

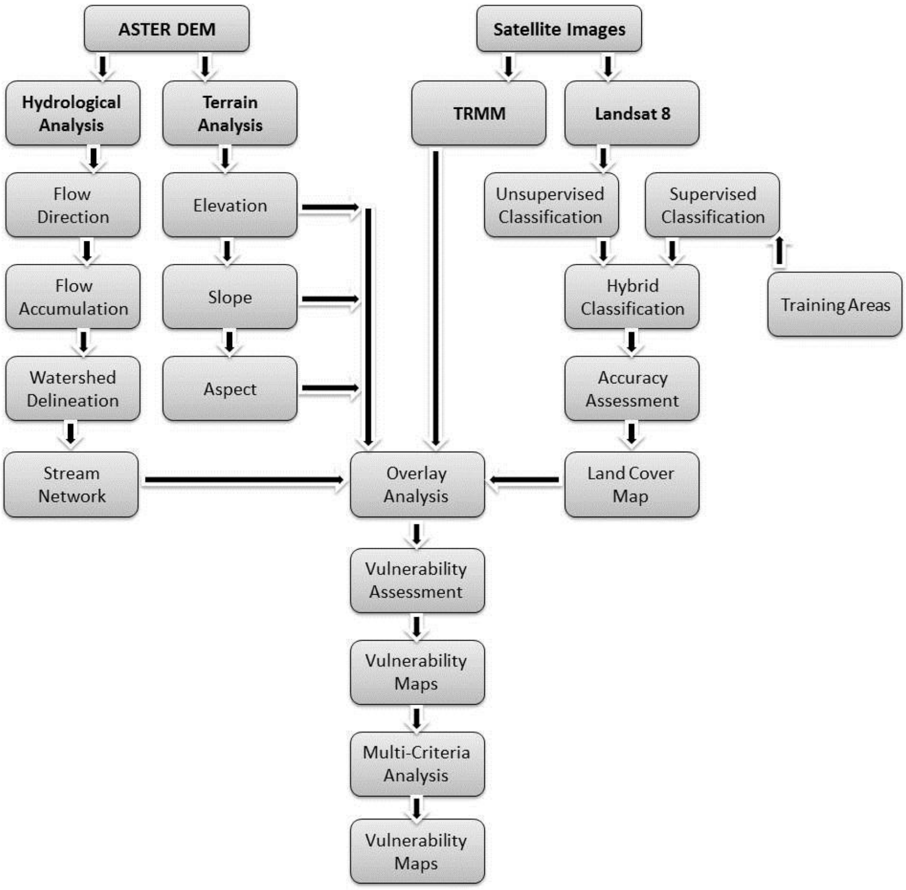

Figure (5) Study methodology flowchart

3.1 The extraction of topographic parameters

Digital Elevation Models (DEMs) are raster files with elevation data for each raster cell. DEMs are popular for extracting topographic parameters. ArcGIS Spatial Analyst tools are used to derive slope and aspect maps.

a. Slope

Slope is the most important and specific feature of the drainage basin form. Slope and height level maps are derived from ASTER DEM that allow the determination of areas which relatively receive more quantities of water input than the surrounding environment during precipitation period in general and flood event.

b. Aspect

Aspect refers to the slope direction and is derived from an ASTER DEM raster surface. The output raster will be the compass direction (north, northeast, east, south east, south, southwest, west and northwest) of the aspect with 8 colors. Each color represents a compass direction; the gray color always represents a flat area.

3.2. The extraction of hydrologic parameters

Hydrological analysis for Wadi El-Arish basin was carried out in GIS environment hydrology tool in Arc toolbox. Hydrologic analysis includes the extraction of multiple parameters including flow direction, flow accumulation, watershed delineation, and stream networks were extracted from DEM. All these parameters were extracted according to the following steps:

a. Flow direction

Flow direction determines which direction water will flow in a given cell. The direction of water flow is usually determined by finding which of the surrounding cells has the lowest elevation value. Flow direction raster is a raster grid cells, water can flow to one or more of its eight adjacent cells. Flow directions are numbered from east clockwise, and each direction is a power of 2 higher than the previous. Thus, when the flow direction is east out of a cell, that cell is given the value 1. When south-east the value is 2. Then, a cell with flow direction going south gets the value 4, and so on until north-east, which becomes 128.

b. Flow accumulation

Flow accumulation determines how much rain has fallen through each cell. The Flow accumulation operation is based on the flow direction map and performs a cumulative count of the number of pixels that naturally drain into outlets. The operation can be used to find the drainage pattern of a terrain. The results of Flow Accumulation can be used to create a stream network by applying a threshold value to select cells with a high accumulated flow.

c. Watershed delineation

Flow direction raster is analyzed to find all sets of connected cells that belong to the same drainage basin, it provides watershed boundary at pour point feature dataset. The delineation processor needs three grid layers: pour points, flow accumulation, and flow direction.

d. Stream networks

Stream ordering is a method of assigning a numeric order to links in a stream network. Stream ordering method is proposed in 1952 by Arthur Newell Strahler. A first order stream consists of small tributaries. Stream order only increases when streams of the same order intersect. When two first-order streams come together, they form a second-order stream. When two second-order streams come together, they form a third-order stream. Moreover, streams of lower order joining a higher order stream do not

change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream.

3.2. Analysis of TRMM rainfall data

Precipitation is the main climatic parameter that initiates and controls the occurrence of flash flood events in drainage basins of all climatic zones. TRMM data was used to estimate rainfall for the study area. The data were converted to ARCGIS raster data format using conversion and multidimensional tools. Then the data was clipped to match Wadi El-Arish and then converted to point features. As a next step point feature data was interpolated using inverse distance weighted method (IDW). IDW interpolation method is used in this study as it is an effective method and provides considerable estimates for areas where rain data is unavailable or unknown. The majority of precipitation events occur in winter months (November to March).

3.3. Image processing

Landsat-8 scene of 2016 was used to study land cover in Wadi El-Arish basin. Satellite images are analyzed to detect land cover and to map the vulnerable areas to flash flood event. Image processing in this study includes three steps. The first step is layer stacking of this software was used to combine seven bands from band 1 to band 7 together into a single image. Then image was masked by using the sub-set tool to get a sub-set image matching Wadi El-Arish. As a final step image classification was used to extract information from satellite image

a. Image classification

Unsupervised classification was performed using the ISODATA (Iterative Self-Organizing Data Analysis Technique) clustering algorithm, where 100 classes with their signatures were generated from the algorithm. Mean plot and divergence matrix are two separability analysis techniques applied to the signatures to test if they totally separable in the bands are being studied or not. Sixty polygons were drawn as training areas for available land cover. This process was performed for all land cover classes and saved as a supervised signature file. The final step in image classification was merging and appending signatures created from both supervised and unsupervised training areas. Maximum likelihood classification (MLC) approach is being used for land cover mapping. The generated classified land cover map was verified using ground truth data and Google earth.

b. Accuracy assessment

An accuracy assessment for the supervised classification was done using 130 that were generated randomly. All the randomly generated points were identified and assigned in different classes and then were considered as reference points. The correctly identified points were considered as classified values. Overall accuracy was calculated from the error matrix and found to be 92.2% which is was good enough to map land cover in the study area.

4. Results and Discussion

The study area consists of elevations due to the existence of high mountains in the northern part including El-Thamila, Halal (983m), El-Kosima, Maghara (775m), Yelleg (1094m), Arif El-Naqa (930m). In the middle and south regions of the study area there are At-Tih plateau (500 - 1000m) and Egma plateau (1200 m).

Slope affects the total runoff volume and time of concentration to the peak of hydrograph. Areas with steep slope generate a greater velocity and allow faster removal of the runoff from the watershed; therefore, shorter concentration times to peak of hydrograph. Figure 6 showed that the slope varies from 0^{o} near coastal and low lands to 64.06^{o}in the high lands with mean slope of 4.06^{o}.

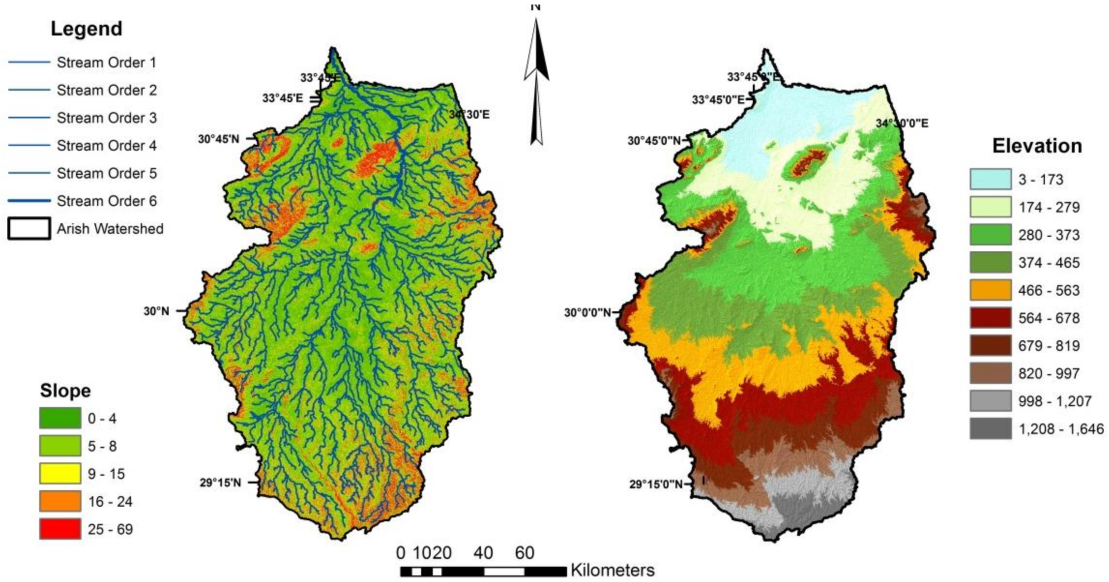

Figure (6) Elevation, slope and stream order in Wadi El-Arish

The hydrologic parameters include flow direction, flow accumulation, watershed delineation, and stream networks. Flow direction determine the flow path and associated drainage networks, and to define how many cells flow into any given cell (ESRI, 1997). Figure (7) show Aspect and flow direction in Wadi El-Arish.

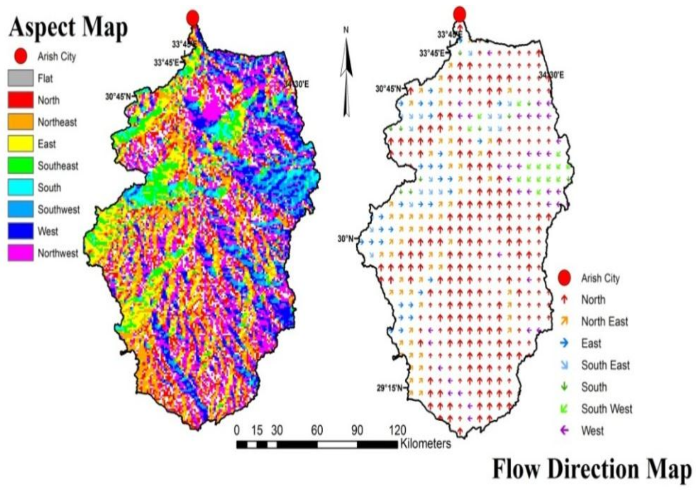

Figure (7) Aspect and flow direction in Wadi El-Arish

The maximum daily precipitation during this period has occurred on the January 17, 2016. The mean precipitation ranges from 7.3 mm to 9.2 mm in 17^{th} and 18^{th} January 2016 as shown by the cumulative precipitation in Figure (8).

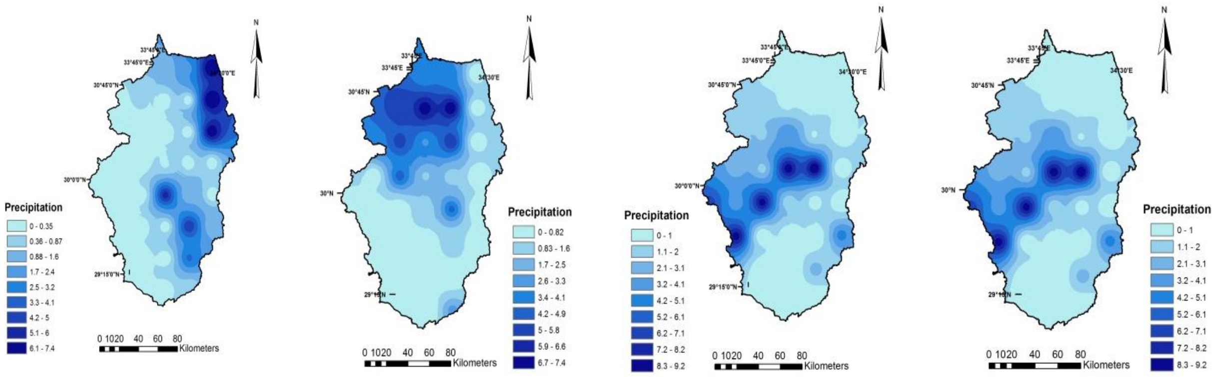

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Figure (8) **TRMM data (rain intensity) for Wadi El-Arish**

Eleven land cover classes were identified from the Landsat8 OLI using hybrid classification. The identified vegetative land cover classes of the study area are irrigated herbaceous crops, irrigated, tree crops and rain fed tree crops. The non-vegetated land covers include bare rocks, bare soils (stony, very stony and salt crusts), loose and shifting sands and sand dunes. The urban class is appeared in El-Arish City in the north. Figure (9) shows the final classification results Landsat-8 OLI 2016 image.

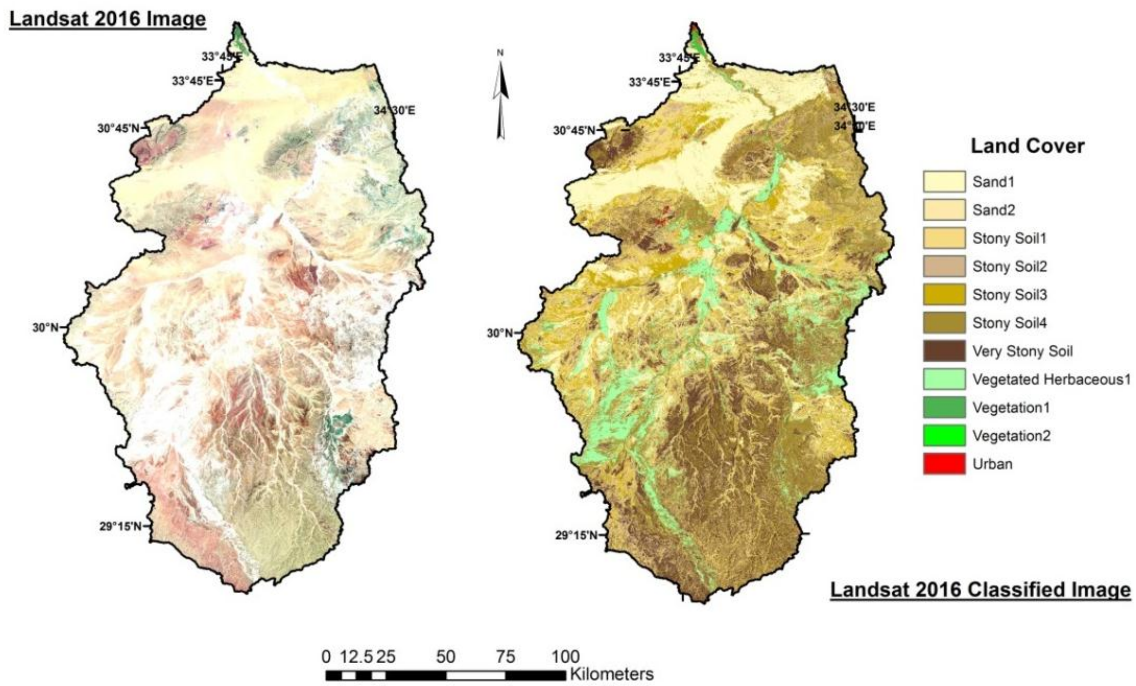


Figure (9) **Landsat image 2016 for Wadi El-Arish**

Vegetation of type 1 represents the smallest available land cover class in Wadi El-Arish with about (18 km^2) and located in El-Arish City. While, stony soil of type (4) concentrated in Mountains (Hala, Maghara, Yelleg, Arif El-Naqa and Kherim) and constitutes the predominant class with (4335.9 km^2). Table (2) presents the land cover area in km^2.

Table (2) **Land cover area in km²**

Land Cover	Area (km^2)
Sand1	3242.7
Sand2	1775.5
Stony Soil1	3570.9
Stony Soil2	1878.1
Stony Soil3	2375.6
Stony Soil4	4335.9
Very Stony Soil	3511.7
Vegetated Herbaceous1	1765.9
Vegetation1	24.3
Vegetation2	18.08
Urban	34.4

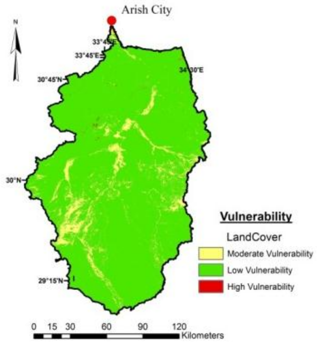
The layers were converted into raster format and reclassified by the "Spatial Analyst" extension tool of the ArcGIS 10.3© software. Equal weights and specific ranks were assigned to each raster according to Table (3)

Table (3) Vulnerability parameters and ranks

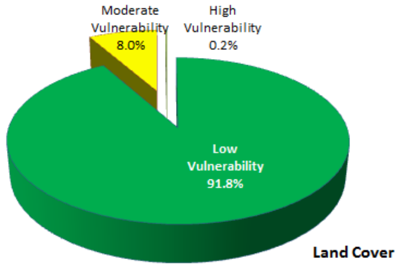
Vulnerability Parameters	Vulnerability Rank		
	Low	**Moderate**	**High**
Land cover	Sand Very Stony and Stony Soil	Vegetation	Urban
Elevation	More than 200m	200m -150m	150m – 3m
Rainfall	Less than 20mm	20 – 30mm	More than 30mm
Slope	More than 8°	8° - 4°	4° - 0°
Flow Direction	South, South East, South West	East, West	North, North East North West

The vulnerability varies from lower in the south to higher in the north. Thus, the vulnerability to flooding decreases as the elevation increases. The North of the basin is the most vulnerable to flooding: this is due to the fact that it is characterized by low elevation and flat areas with slopes inferior to 4°. Figure (10) shows:

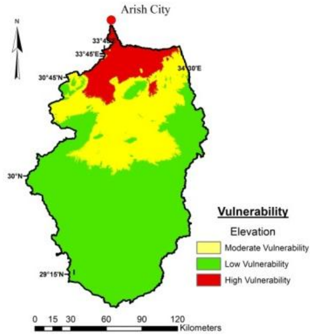
1. **Nearly about 91.8% of land cover has in low vulnerability, while 0.2% only has high vulnerability.**
2. **Elevation vulnerability ranges from high (9.2%) in north to low (64.8%) in south.**
3. **Rain fall has high vulnerability (17.4%) in the north and low in south (70.4%).**
4. **Slope has high vulnerability (47.1%) in low areas with low elevation.**
5. **Flow direction has high vulnerability in areas with high elevation especially above Sinai Mountains.**



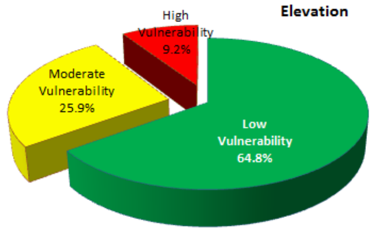
a. Landcover vulnerability



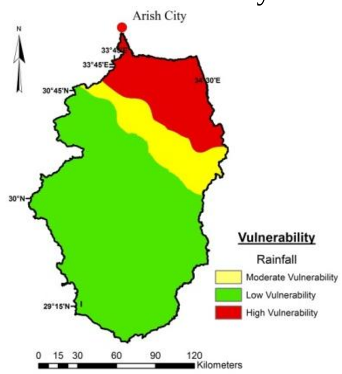
b. Landcover vulnerability chart



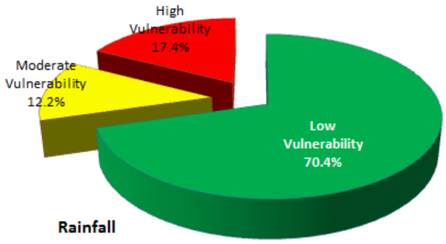
c. Elevation vulnerability



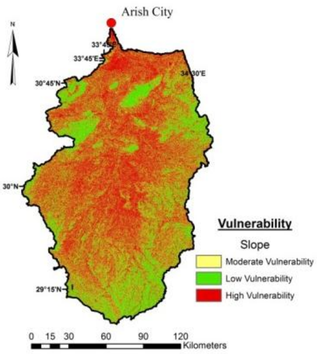
d. Elevation vulnerability chart



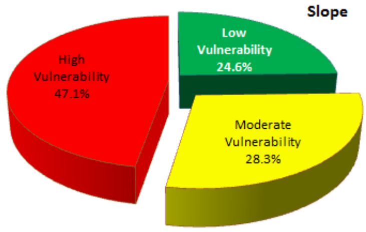
e. Rainfall vulnerability



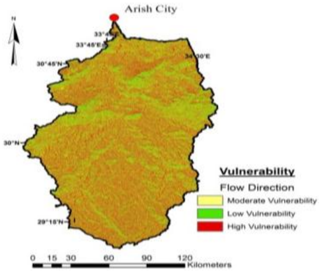
f. Rainfall vulnerability chart



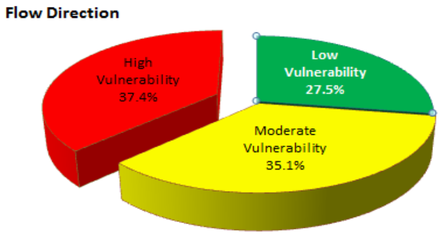
g. Slope vulnerability



h. Slope vulnerability chart



i. Flow direction vulnerability



j. Flow direction vulnerability chart

Figure (10) Vulnerability parameters in Wadi El-Arish

Final vulnerability map of flash floods in Figure (11) shows:

1. **Vulnerability decreases in south due to high elevation, rocky and stony environment with rare vegetation cover and urban area.**
2. **On the other hand, vulnerability increases towards north direction due low elevation with both vegetation cover and urban areas.**
3. **67.3% of the study area has very low vulnerability and concentrated in the south.**
4. **20.4% of Wadi El-Arish has low vulnerability and located in the middle.**
5. **About 6.4% of the Wadi has moderate Vulnerability and located in the north of the basin and in the south of El-Arish City.**
6. **Very high vulnerability constitutes about 5.4% and concentrated in El-Arish City.**

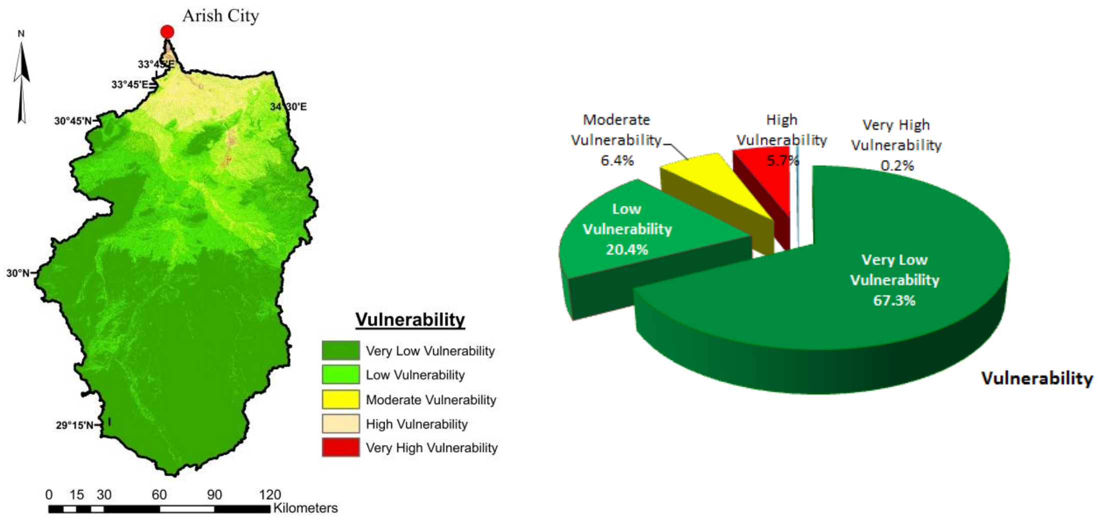


Figure (11) **Final vulnerability in Wadi El-Arish**

5. Conclusions and Recommendations

Sinai Peninsula is a strategic place for developing national developmental projects. The problem of flash floods in Wadi El-Arish has been investigated. Remote sensing data and their integration in a Geographic Information Systems contribute to a high advancement in flood studies and researches so that the damages and losses can be avoided. Furthermore, the multi-criteria and weighted overlay analysis presented the ability to distinguish areas with higher, medium and lower vulnerability to flash floods. The lowest and flattest areas are the most affected by the flash floods in EL-Arish City. The obtained vulnerability map shows that El-Arish City has very high vulnerability to flash floods. The most prone-areas cover residential areas in El-Arish City. This reveals socio-economic vulnerability in terms of serious damage to property of infrastructures such as roads, bridges and other public and private settlements.

It is recommended that the data obtained from this work might provide helpful information to the decision-makers, for better action plan and appropriate adaptation strategies. The rehabilitation of infrastructures after abnormal excessive rainfall and the consideration of resilient reconstruction have to be studied. This study recommended the creation of dams as a solution to flash flood to control and harvest flood water to take the advantage of the water stored. However, geological structures have to be considered through the process of creating dams and determination of the possible dam sites have to studied well through GIS suitability analysis. It is also recommended that local authorities have to prepare against

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تقييم آثار السيول على مدينة العريش بإستخدام نمذجة نظم المعلومات الجغرافية وتحليلات الإستشعار عن بعد

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الملخص :

تعتبر السيول من أخطرالظواهر المناخية، والتى تحدث عندما يتدفق الماء إلى منطقة ما بسرعة أكبر من سرعة أمتصاصه في التربة، أو تخزينه في بحيرة أو خزان أو جريانه إلى أحوض التصريف. وتعد السيول من أخطر أنواع الفيضانات والتي تسبب أرتفاعا سريعا لمنسوب المياه في فترة زمنية قصيرة. و يمكن أن تؤدي إلى إلحاق الضرر بالبيئة، الإنسان، والمنشآت البشرية. وتفيد دراسة هذه الظاهرة فى دعم إتخاذ القرار المتعلق بإدارة الموارد المياه والتنمية البيئية المستدامة. وقد تناول هذا البحث تقييم آثار السيول على مدينة العريش، وتقدير الأضرار الناجمة عن تلك السيول، فضلا عن العوامل المسببة للسيول مثل توزيع الأمطار، أرتفاع السطح والمنحدرات، أتجاه شبكات التصريف المائى (التحليل الهيدرولوجي)، ونوعية الغطاء الأرضي وذلك بإستخدام نظم المعلومات الجغرافية والإستشعار عن بعد. وقد تم تصنيف تأثير السيول على مدينة العريش إلى خمس فئات كالاتى: عالي جدا، عالي، معتدل، منخفض، ومنخفض جدا. وتشير النتائج أن مدينة العريش من اكثر المناطق تأثرا بالسيول، وتعد المناطق المنبسطة التى يشغلها السكان هى الأكثر عرضة للسيول، مما يؤدى إلى إلحاق الضرر بالممتلكات البشرية كالمنازل والبنية التحتية والطرق والجسور وغيرها من الممتلكات العامة والخاصة. وتختلف درجة التأثر من مكان إلى أخر بالمدينة، حيث يعتبر شمال العريش اكثر عرضة للسيول من الجنوب ويرجع ذلك لإنخفاض السطح فى الشمال مع وجود الغطاء النباتى والمناطق السكنية. وقد أوصت هذه الدراسة بإنشاء سد للتحكم في مياه السيول وجمعها للإستفادة منها فيما بعد، وتلافى الأضرار الناجمة عنها، مع الأخذ فى الأعتبار جيولوجية المنطقة لأختيار انسب المواقع لإنشاء السد.