

Application of Remote Sensing and GIS for Flood Risk Assessment : A case study of Al Kharj Valley Saudi Arabia

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Abstract— During the last few years, many flood incidents have occurred in different regions of the Kingdom of Saudi Arabia. These floods have caused serious damages over large areas including loss of human lives and economical consequences for Saudi Arabia. The evaluation of the floods constitutes the first step and the rational basis of management and mitigation measures against flood damages. Remote Sensing (RS) and Geographical Information Systems (GIS) provide information that has proved useful for a wide range of application in disaster management. The application of RS and GIS techniques for rapid flood mapping and monitoring is an important tools of information for decision-makers. Working methods for flood management and mitigation have been developed in this paper by using Geo-Eye and SPOT-5 satellites images. These methods have been used to map the flood-affected areas, to estimate the damages and design the hydraulic works needed. Data was collected from various sources. A methodology for flood forecasting, planning and management with the help of flood hazard maps for different return periods (25, 50 and 100 years) has been developed. The population and physical vulnerabilities of the lowest area subjected to floods in the downstream of Al Kharj Valley has been assessed and the necessary solution to avoid the flood specially closed Al Kharj city has been proposed.

Index Terms— Flood, GIS, RS, Geo-Eye Satellite Images, Geo-processing, Damage assessment.

2 INTRODUCTION

The south of Al Riyadh experienced a flood during 2003 which affected the downstream area of Al Kharj valley due to large quantity of water. Many difficulties have been index near urban area close to the valley. In fact, Ministry of Water and Electricity of Saudi Arabia Kingdom attached a great importance to fight against the unexpected flood in the future. There is need to explain the true scenario by modeling flood ([10], [11]) in the downstream area of Al Kharj valley based on the geospatial data from satellite images. Since flooding is the most frequent natural disaster, the Ministry of Water and Electricity has been focusing its attention to Flood Hazard Mapping (FHM) as one of the priority tasks to be accomplished in order to avoid the flood damage ([6], [7]) close to the urban area at the downstream valley of Al Kharj. Application of Geographical Information Systems (GIS) and Remote Sensing (RS) technology to map flood areas will make it easy to plan measures that may result in reducing the flood damages and risks involved. Implementation of flood management program, that may consist of flood forecasting, flood hazard and vulnerability mapping; may be very helpful in saving precious human lives and property.

Therefore, benefits of this project are very much timely for inhabitants Al Kharj living on downstream side and in valley basin as well as for governmental organizations. This paper focuses on analyzing the flood risk in the downstream area, which is very close to the rapidly expanding urban planning area.

Study area : The study area is Al Kharj Valley basin in the south Al Riyadh region. This valley is located in the western hill slopes of Al Kharj and being reached Al Hota in direction of Wadi Al Dowasser about 100 km, which receives most of the south-west monsoon rainfall making the Wadi network basin vulnerable for frequent floods. Al Kharj valley watershed sets cover about 5,000 km² and major land-use covers are soil and shallow rocks mainly consisting of sand, silty sands, gravel and limestone as a bed rock. Moreover, substratum is also affected by underground voids called "karsts". Geographically the basin lies between 663341 m and 750964 m E, and 2618055 m and 2693852 m N referring to W.G.S.-84 (World Geodetic System 1984) coordinate system and flows from a height of about 650 m above S.A.L.S. (Saudi Arabia leveling System). The figures 1 and 2 show the study area and different zooms highlight different components within the study area.

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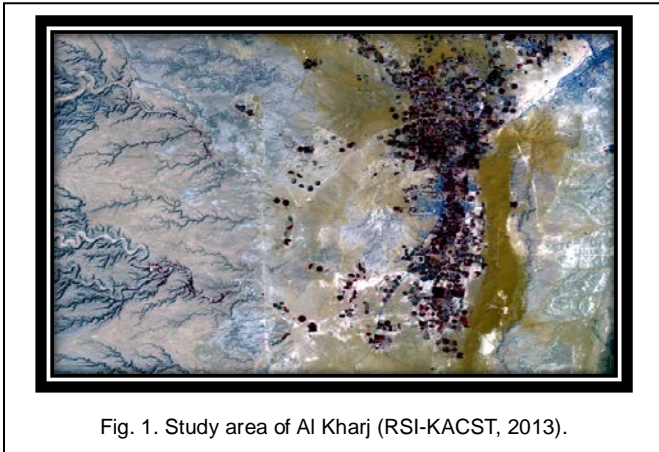


Fig. 1. Study area of Al Kharj (RSI-KACST, 2013).

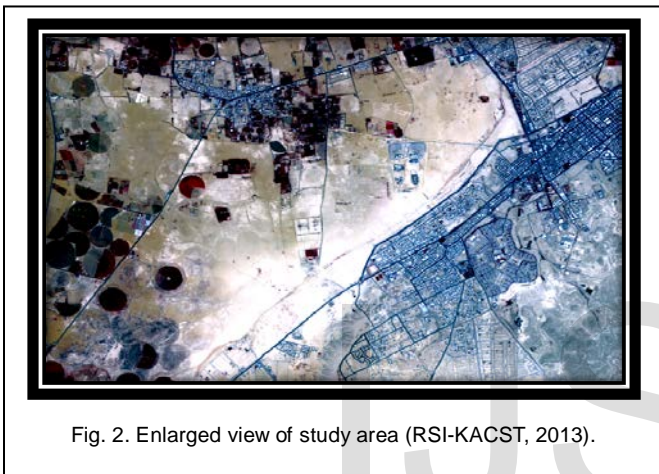


Fig. 2. Enlarged view of study area (RSI-KACST, 2013).

2 MATERIELS AND METHODS

The approach to this study involved data collection and geo-processing which are required for Hazard analysis and Vulnerability analysis. Based on the Hazard analysis and Vulnerability analysis, the Flood Risk analysis is carried out using Remote Sensing and Geographical Information Systems tools ([15]). In order to quantify the main variable used in the simulation of flood risk, a Digital Elevation Model (DEM) has been performed using Remote Sensing software (Erdas-2011) ([8], [19]) and the range of flood was estimated for return periods of 25, 50 and 100 years. A GIS application (ArcGIS-9.3) ([1]) was used to propose necessary solutions in the form of hydraulic works to stop the flood in the downstream area of Al Kharj Valley, and to estimate the range of flood area especially close to the urban zones. Hydrologic analysis consists of application of hydrologic model using HEC-HMS (Hydrologic Modeling Software) ([5]). As availability of stream flow data was limited, a calibrated rainfall - runoff model for the sub-basins based on HEC-HMS was used to predict runoff for rainfall having 25, 50, and 100 years return period. The drainage facilities should be designed for very rare storms to minimize the chance of overflowing. Designing for this condition, however may result in very large facilities that

might result in raising the cost of the drainage facility. The decision on what frequency should be selected for design purposes must therefore be based on a comparison of the capital cost for the drainage facility and the cost to the public in case the urban area at the downstream is at risk by storm runoff. Factors usually considered in making this decision include the importance of urban area and its population density. The drainage area is that area of land that contributes to the runoff at the point where the open channel capacity is to be determined ([18]). This area is normally determined from a topographic map or Digital Elevation Model (DEM) after geo-processing satellite images using R.S. software. The runoff coefficient, C , is the ratio of runoff to rainfall for the drainage area. The runoff coefficient depends on the type of ground cover, the slope of the drainage area, storm duration and the slope of the ground. In cases where the drainage area consists of different ground characteristics with different runoff coefficients, a representative value C_w is computed by determining the weighted coefficient using following relation ([21]) :

$$C_w = \frac{\sum_{i=1}^n C_i A_i}{\sum_{i=1}^n A_i}$$

Where :

- C_w : weighted runoff coefficient for the whole drainage area;
 - C_i : runoff coefficient for watershed I;
 - A_i : area of watershed I;
 - n : number of different watersheds in the drainage area.
- Where :
- Q : peak rate of runoff (m^3/s);
 - C : a coefficient representing the fraction of rainfall that remains on the surface of the ground (runoff coefficient);
 - A : drainage area (acres, 1 acre = 4047 m^2);
 - I : average intensity for a selected frequency and duration equal to at least the time of concentration (cm/h).

For any given storm, the rainfall intensity neither usually remains constant over a large area, nor during the entire duration of the storm. The rational formula therefore uses the theory that for a rainfall of average intensity, I , falling over an impervious area of size A , the maximum rate of runoff at the outlet to the drainage area Q , occurs when the whole drainage area is contributing to the runoff and this runoff rate is constant. This requires that the storm duration be at least equal to the time of concentration, which is the time required for the runoff to flow from the farthest point

of the drainage area to the outlet. This condition is not always satisfied in practice, particularly in large drainage areas. The hydraulic design of drainage upon earth dams for a given storm entails the determination of the minimum cross-sectional area of the hydraulic works that will accommodate the flow due to that storm and prevent water from overflowing the sides of the hydraulic works. The most commonly used formula for this purpose is Manning's formula, which assumes uniform steady flow in the open channel and gives the mean velocity in the open channel as following :

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where :

v : average discharge velocity (m/s);

R : mean hydraulic radius of flow in the open channel (m);

$$R = \frac{a}{P}$$

a : channel cross-sectional area (m²);

P : wetted perimeter (m);

S : longitudinal slope in open channel (m/m);

n : Manning's roughness coefficient.

The flow in the open channel is then given as following :

$$Q = va = \frac{1}{n} aR^{\frac{2}{3}} S^{\frac{1}{2}}$$

Where :

Q : discharge a long an open channel (m³/s).

Based on the DEM modeling provided by RS software and referring to available topographic maps of the study area, the figure 3 illustrates a long profile along the flood area in which we observe at the middle of this flood area a basin where the water accumulates temporarily. This situation can be easily shown in the figure 4 where a cross section within the flood area has been taken. To confirm the existing basin at the middle of flood area we have carried out three long profile and cross section (along axis of Wadi, one kilometer at right side and one kilometer at left side of the flood area). This topographical analysis can be used to estimate the quantity of water accumulated in the flood area.

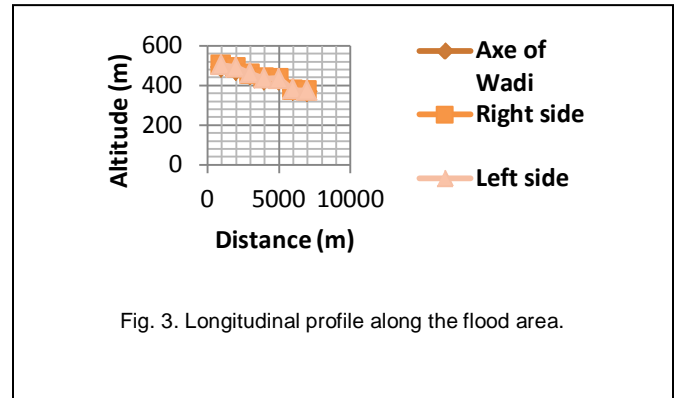


Fig. 3. Longitudinal profile along the flood area.

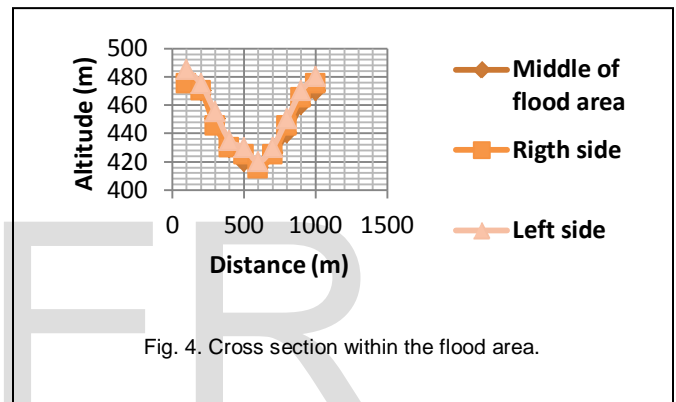


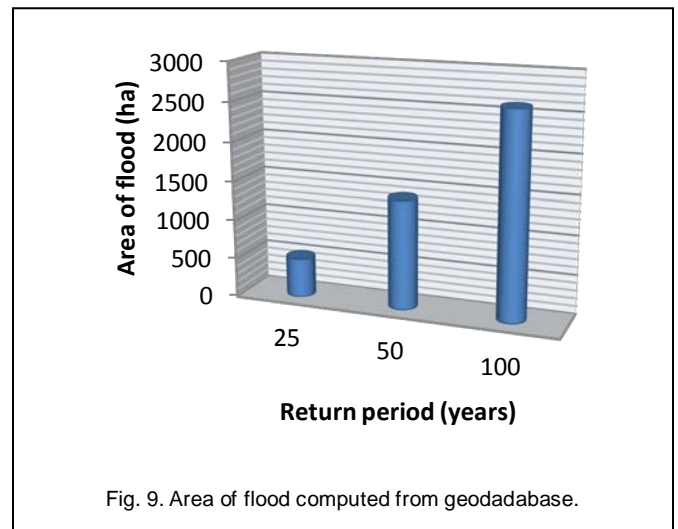
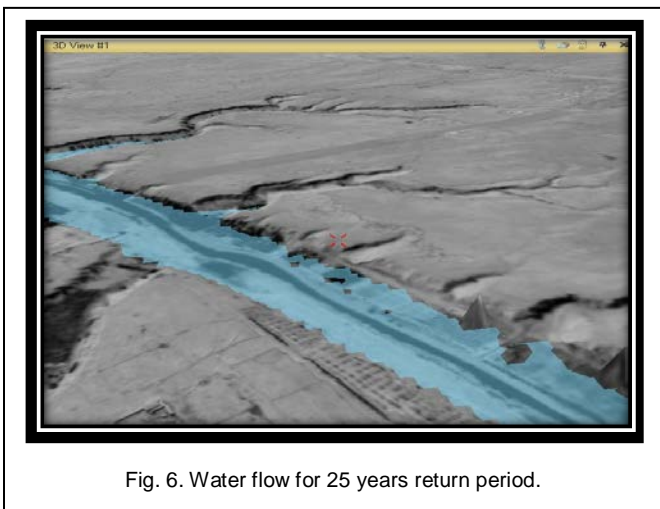
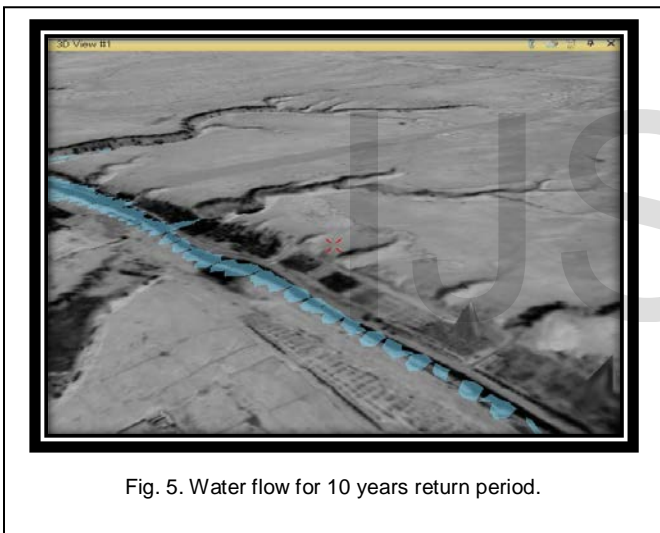
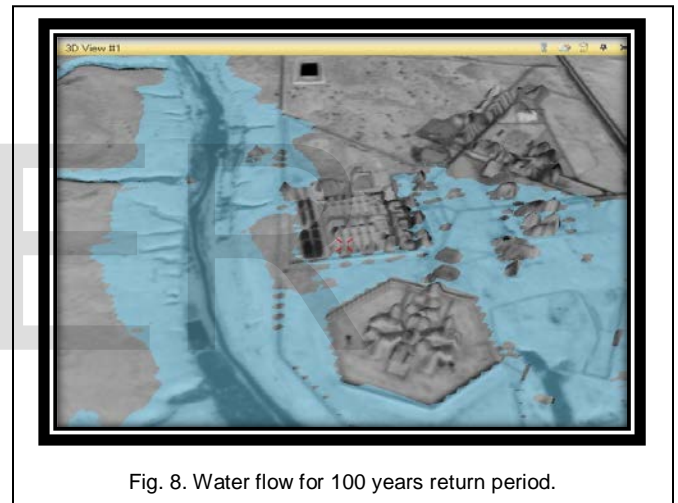
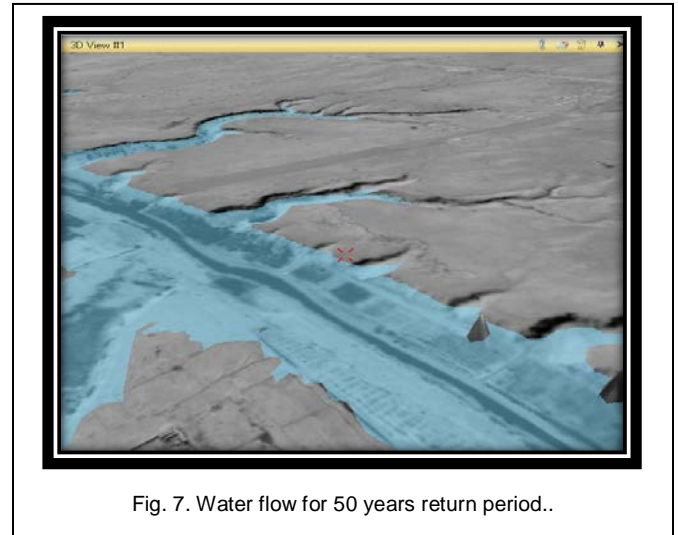
Fig. 4. Cross section within the flood area.

The process of risk assessment of flood is summarized as follows :

- Elaborate a geometric correction based on the accuracy image satellite;
 - Make a mosaiking procedure to join satellite images;
 - Carry out a Digital Elevation Model (DEM) based on stereo images ([13], [14]);
 - Simulate the water layer by flowing it on the DEM ([20]);
 - Transfer simulated flow to geo-database and visualize it by ArcMap as vector layers.
- To assess the risk of flood at the downstream area of Al Kharj Valley, a simulations using GIS. software was performed. Summary of step is as shown below :
- Digitization of the layers (buildings, Wadis, agriculture, wastewater, karsts, etc...);
 - Building of a geo-database based on these layers ([2]);
 - Making of a geo-processing procedure to simulate the flood by intersecting layers;
 - Comparison of the results with the flood simulation given by R.S. software;
 - Proposing of the hydraulic solutions based on the HEC-Geo-RAS ([12]).

3 RESULTS AND DISCUSSIONS

It was observed that depending on return periods of 10, 25, 50 and 100 years, the water flow inundates the residential area (Figure 5 to 8). For 100-year return period the situation is aggravated when the flood overruns a wide area of building close to the wadi. To quantify the flooded area, the return periods data was transferred from Erdas 2011 to ArcMap-ArcInfo and a geo-database was built to estimate the area flooded in each case. Figures 9 and 10 show the flooded area and total residential area that was flooded. We observed that the area covered by flood can reach 2600 ha in which about 1600 ha falls in the residential area for return period of 100 years. This situation requires the designing of hydraulic solutions, taking into account the hydrologic, hydraulic and topographical analysis results.



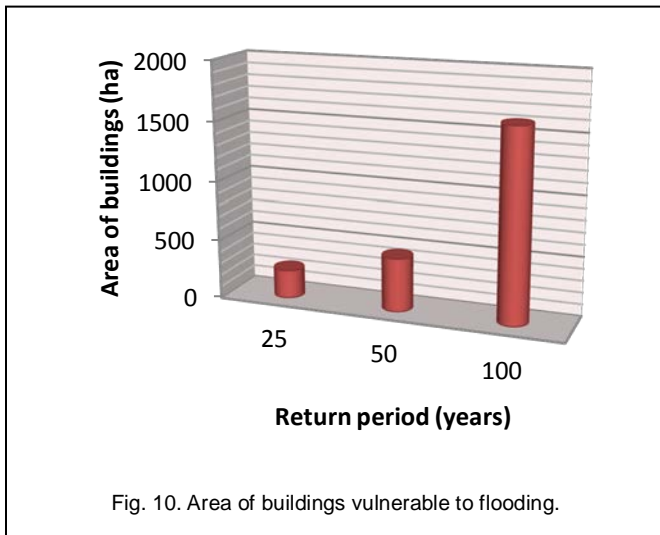


Fig. 10. Area of buildings vulnerable to flooding.

Table 2 : Designing hydraulic works referring to Geo-database : Open Channels.

(O. C.: Open Channel)

Watershed name	Volume of flood (m ³)	Type and form of hydraulic works	Flow depth (m)
Al Sout Wadi	4820760	O. C. Trapezoidal	4
Al Kharj Wadi	9641520	O. C. Trapezoidal	6
Al Kharj Valley	14462280	O. C. Trapezoidal	7

Referring to the geo-database, many data layers were overlaid to indicate the most hydraulic solution works in order to keep the floods away from the residential area. These layers are the network of wadis, the agriculture, the wastewater, the karts, the sand dunes and the buildings. Depending on return periods of 25, 50 and 100 years, the water flow can reach the residential area (Figure 11 to 13). Figures 14, 15 and 16 show the hydraulic solution works that can be designed to monitor the quantity of water which can flow into two open channels along the downstream valley especially close to the residential area. Table 1 and 2 indicate the dimensions of the hydraulic works proposed and the quantities of flood volumes in the main Wadis of Al Kharj valley. Regarding to Geo-database from 2003 until 2011, we observed a decreasing trend of agriculture area from about 34,000 ha to 10,000 ha. These hydraulic solutions allow for the improvement of the agriculture activities close to it.

Table 1 : Designing hydraulic works referring to Geo-database : Earth Dams.

Watershed name	Max. area of basin (m ²)	Max. depth of water (m)	Length of dam (m)	Max. Flow out (m ³ /s)
Al Sout Wadi	3434395	1.5	250	165
Al Kharj Wadi	3138831	3.0	400	415

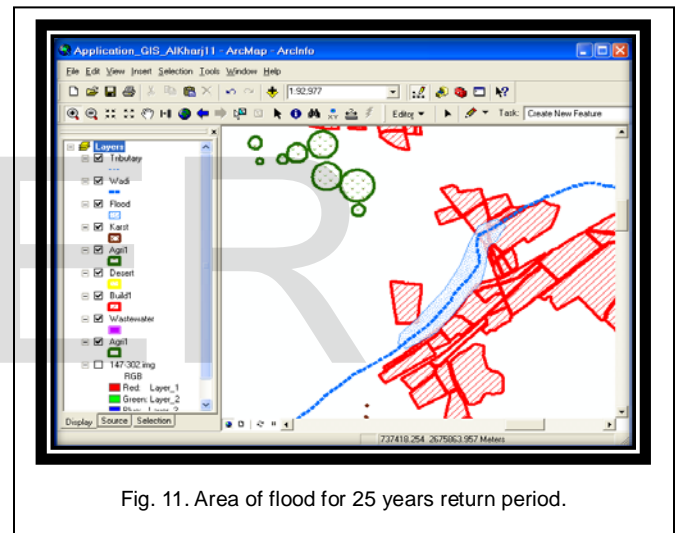


Fig. 11. Area of flood for 25 years return period.

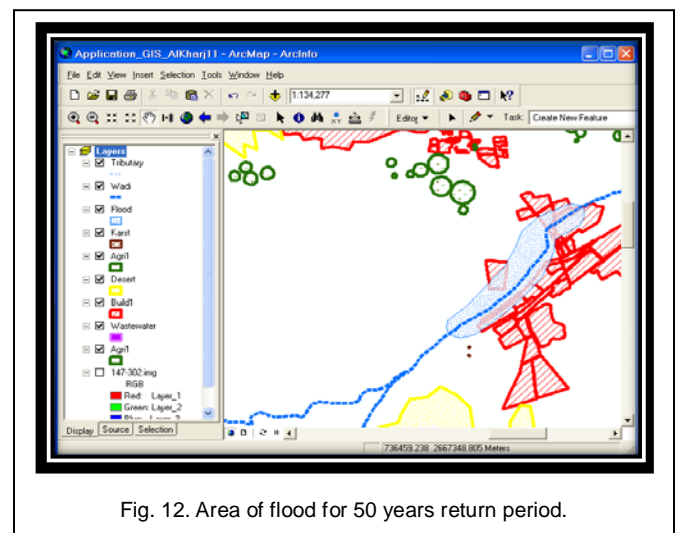


Fig. 12. Area of flood for 50 years return period.

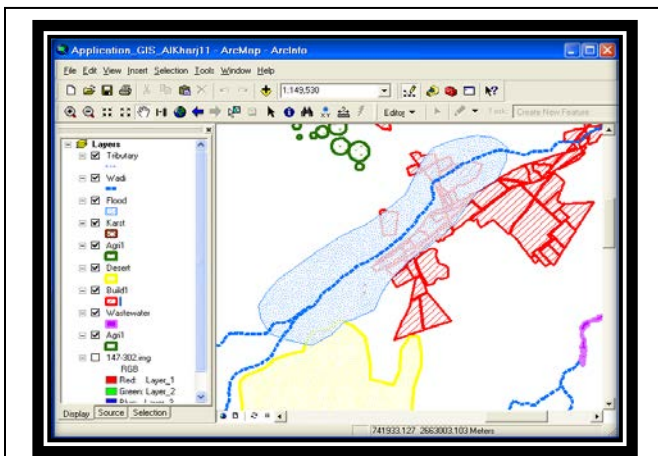


Fig. 13. Area of flood for 100 years return period.

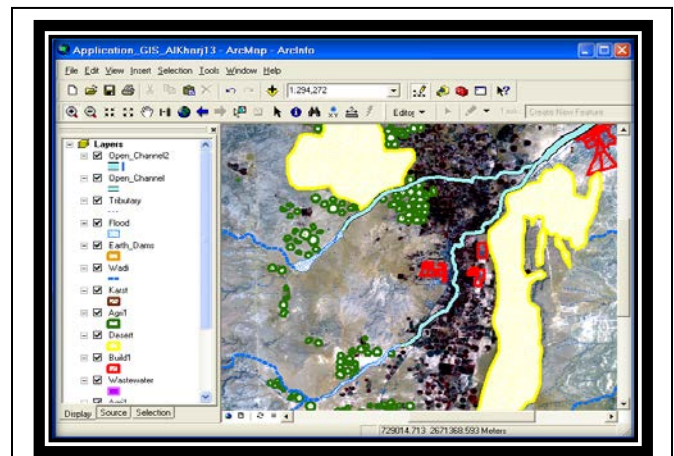


Fig. 16. Earth dams and open channels in the flood area.

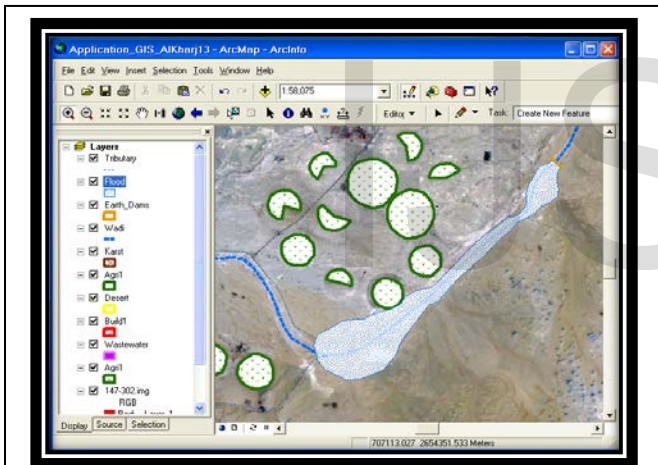


Fig. 14. Earth dam on the first tributary.

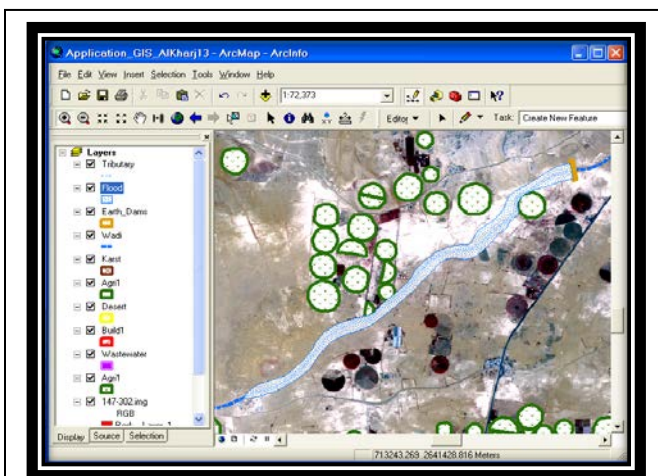


Fig. 15. Earth dam on the main Wadi.

4 CONCLUSIONS AND RECOMMENDATIONS

Technologies as a Remote sensing (RS), Geographical Information Systems (GIS), and hydrologic modeling techniques have been successfully applied to prepare a set of Flood Risk Maps for Al Kharj Valley in Saudi Arabia. GeoEye-1 and SPOT-5 satellite images were utilized successfully for extracting flood extent and thereby to calibrate/validate HEC-GeoRAS model output. The study had produced a series of (25, 50, 100 years return period) simulated digital maps considering the layers of network of wadis, agriculture and buildings. The study reveals that about 2600 ha and 1600 ha of area is at high risk with respect to floods. The buildings are flooded for a 100 years return period flood event. To avoid this flood risk hydraulic solution works have been proposed close to this area. Two earth dams would be built close to the agriculture areas and two open channels are also proposed to allow the flow around the building area. This applied research has been focused on the RS, GIS, and Hydrologic modeling techniques. We recommend continuing this study by geological and hydro-geological aspects in order to simulate the seepage of water regarding the network of fractures, faults and karsts. In order to design the hydraulic solutions works a Civil Engineering study will be required in order to evaluate the stability of these dams and select most economical materials for the construction of these dams and open channels.

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