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Flood risk prediction using DEM and GIS as applied to Wijj Valley, Taif, Saudi Arabia

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Abstract: Flood causes about the third of all natural disasters in the world. Geographic Information Systems (GIS) and digital elevation models (DEM) are now commonly used for flood analysis and flood risk prediction. This paper illustrates the methodology and procedure for flood mapping and associated risk using GIS and DEM. A flood risk zonation was carried out for the Wijj Valley which crosses the center of Taiff city in the western region of the Kingdom of Saudi Arabia. The number of houses that would be affected was also estimated for different flood zones.

Keywords: Digital elevation model, Geographic information systems, Flood prediction, Flood zone, Flood map

1. Introduction

Floods are considered as one of the most common disasters and probably the most devastating (Baoyin and Hailin, 2009). Over the years the flood events have greatly increased. One of the factors responsible for this is the population pressure on the urban areas. This not only impacts the urbanization but results in tremendous socioeconomics losses (Yahya, et al., 2010). One of the key inputs to flood disaster planning is the use of the digital elevation model (DEM). This is a digital representation of the terrain using a modeling algorithm based on sampling (reference or base) of elevation data. Significant improvements in the hardware and software technologies and modern data collection methods have increased the use of the DEM in engineering surveys of the urban areas. The essential part of a DEM are the finite number of reference points which have three dimensional coordinates (x, y, z) in an orthogonal coordinate system or two-dimensional horizontal coordinates (x, y) and height (h). The reference points can have regular or irregular (scattered) distributions on the surface depending on the data source (field data, contour map, aerial photography and satellite images) and data collection method (classical survey methods along with GPS). DEMs are typically represented in two formats viz. contour maps; where the surface is represented by lines of constant elevation at even intervals; or point heights, where the surface elevation is sampled on either regular or irregular bases. The choice of the DEM format is dependent on the application and availability of data (Lynn and Collins, 2006).

Geographic Information Systems (GIS) technology has developed rapidly over the past two decades and today has become a powerful and effective tool for collecting, processing and analyzing geographic data. DEM is an important input source to the GIS for the 3-D analysis. DEMs have been used along with GIS for watershed modeling and stream gradient determination (Marianne et al., 2010).

The main objective of this paper is to generate DEM and use high resolution IKONOS data in mapping features of the flood plain. Based on the flow directions and height of the water level using the flood plain was mapped into different zones of severity using various GIS tools. An estimate of the number of buildings likely to be affected due to floods was estimated.

2. DEM data structure and output techniques

The most common DEM data formats used are triangular irregular networks (TIN). There are several methods that can be used to create DEM's. These include ground surveying (leveling and total stations), scanning contour maps, generating digital elevation model photogrammetrically from stereo data (both aerial and satellite imagery), LIDAR and interferometric radar data (Hazmadi and Kamaruzaman, 2006). U.S. Geological Survey (USGS) in the late 1970s and early 1980s made use of Gestalt Photo Mapper 2 (GPM 2), a photogrammetric instrument. With the advent of computing and imaging technology, the photogrammetry has stepped up from analog to digital (softcopy) photogrammetry. The primary products of digital photogrammetry are digital elevation models (DEMs) and ortho-rectified images. The secondary products are contour maps as vector output, raster image contour maps (ortho-images with vectoroverlays) and DEMs with draped images and 3-D features (Tao, 2002). In this work, however, DEM has been created using photogrammetric approach.

3. Study area and materials

The study area is Wijj Valley basin crossing the center of Taif City which is located about 80 km east of holly city of Makkah in the western region of Saudi Arabia (40^o 15' N to 40^o 30' N and 21^o 15' E to 21^o 30' E) (Fig. 1). TAIF region shows the basin of Wadi Wijj, which is covered by new color aerial photography at 1:45000 scale.

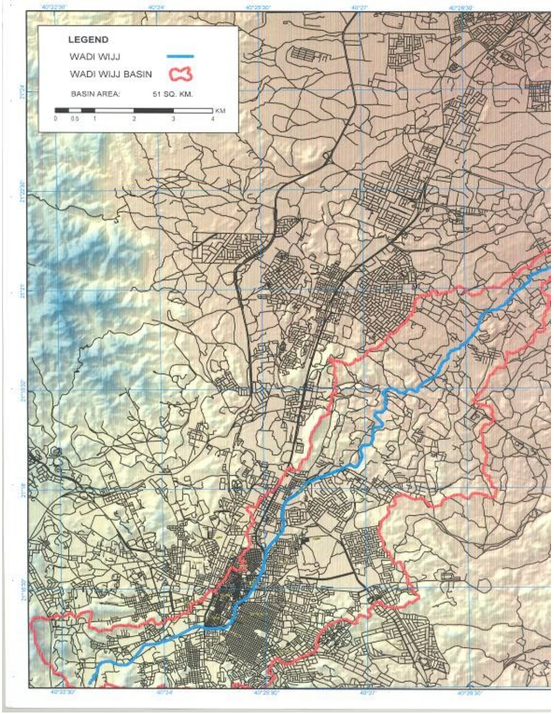

Figure 1: Wijj valley basin

4. DEM of the study area

The Photogrammetry department in the General Directorate of Military Survey (GDMS) performed the aerial triangulation using 39 ground control points and produced 178 models for the whole region. Automatic Terrain Extraction (ATE) procedure, which uses correlation based algorithms for model orientation, was used at GDMS to generate the DEM which required intensive editing because of the nature of the terrain in that area. Editing of the DEM was done using photogrammetric workstation. Contour of 10, 25 and 50 m were generated and color coded. A color coded DEM of the area is shown in Fig. 2.

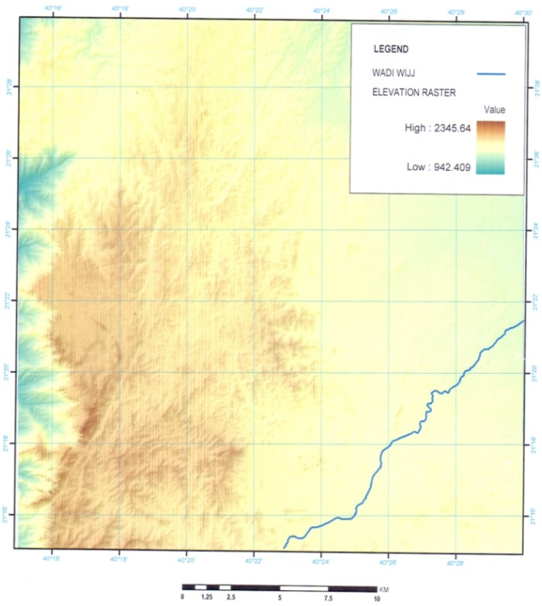

Figure 2: A color coded DEM of study area

5. GIS analysis for flood prediction

In this study, DEM of Wijj valley was generated and interpreted along with IKONOS image to determine possible flood zones corresponding to water levels of 3.0, 5.0 and 10.0 meters. Based on information of buildings and other urban infrastructure provided by GDMS, the area at risk of flooding corresponding to these 3 water levels were computed. The flood map included the interpretation of buildings and other urban infrastructure. Arc GIS (spatial analyst – Hydrology tools) software was used for the analysis and identification of the area at risk of flooding using the following steps (Kopp and Noman, 2008).

5.1- Creating a DEM free of sinks

The first step was to convert the DEM to elevation grid followed by editing the DEM to fill any spurious sinks that may result in an erroneous flow-direction. This step of finding and fixing sinks is a tedious but interactive process that include (i) the Flow Direction tool to determine flow, (ii) the Sink tool to find the sink and (iii) the Fill tool to fill the sinks. Unfortunately, filling a sink may cause another to be created and therefore the process was repeated until no more sinks were found.

5.2- Determining flow direction and flow accumulation

The second important step was measuring the direction of flow through each cell of the data. The Flow Direction tool calculates the direction of flow for each cell with respect to its steepest down slope neighbor. Flow direction, which is required for all hydrologic analysis, is calculated directly from elevation data. This was followed by creating the flow direction raster using the Flow Accumulation tool. Flow accumulation is a count of all the up gradient cells that contribute flow through a cell. Most cells will have small accumulations, but those that represent major streams and rivers will have large values.

5.3- Delineating streams network

From the flow direction result it was possible to calculate the amount of water that would flows through each cell. It was followed by extracting the cells with highest flow to delineate the drainage network or streams.

5.4- Delineating drainage basin for Wijj valley

Drainage basin refers to the area that contributes to flow. It can be generated by analyzing the flow direction to find pour point. From the flow direction it was possible to delineate the drainage basin for Wadi Wijj.

5.5- Defining stream network and stream order

As indicated in sections 5.2 and 5.3, the stream networks were derived. This along with that the flow direction raster were used to create the streams order for the study area as shown in Fig 3. Each level is given a number and specific color to specify its order based on the accumulated value. Table 1 shows a summary of the lengths of the streams of the different orders.

Table 1: Lengths of streams within Wijj valley basin

Stream order	Maximum length of attribute (km)	Total lengths of streams (km)
1	1.0	14.0
2	2.5	21.0
3	1.0	8.4
4	4.9	11.2
5	9.8	9.8

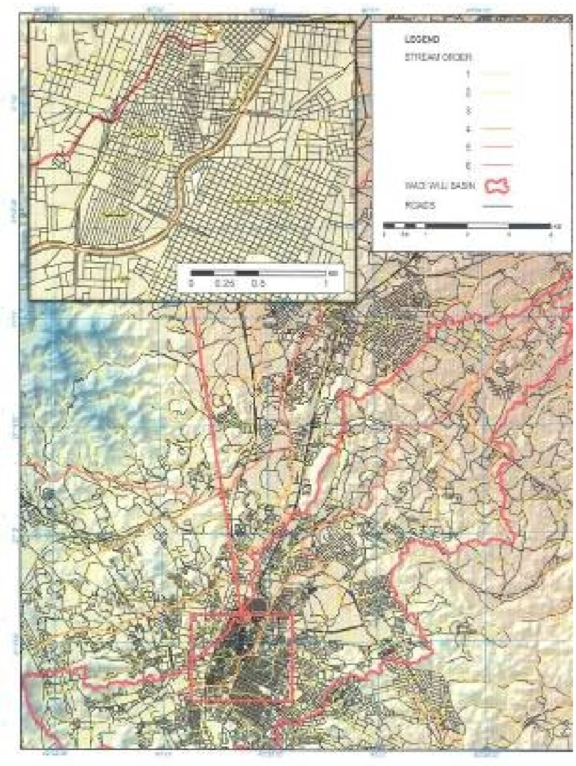

Figure 3: Stream order map of the study area

5.6- Creating flood zones

The flood zone of the Wijj valley was extracted from the shape file of stream network and the ground sample points along the valley line were added. These were used as pour points for the watershed calculations. Zonal statistic tool and raster calculation tool were used to delineate the flood zones into different water levels viz. 3, 5 and 10 meter. Flood zones so created are shown in different color (see Fig 4). This figure also shows that part of the populated places which will be affected by the flood. A table that shows the number of buildings that will be at risk for each flood zone was generated and shown on the same map. Table 2 shows the area covered by each flood zone:

Table 2: Flood zones covered area

Flood zone	height (m)	covered area (km^2)
1	3.0	11.0
2	5.0	14.0
3	10.0	26.0

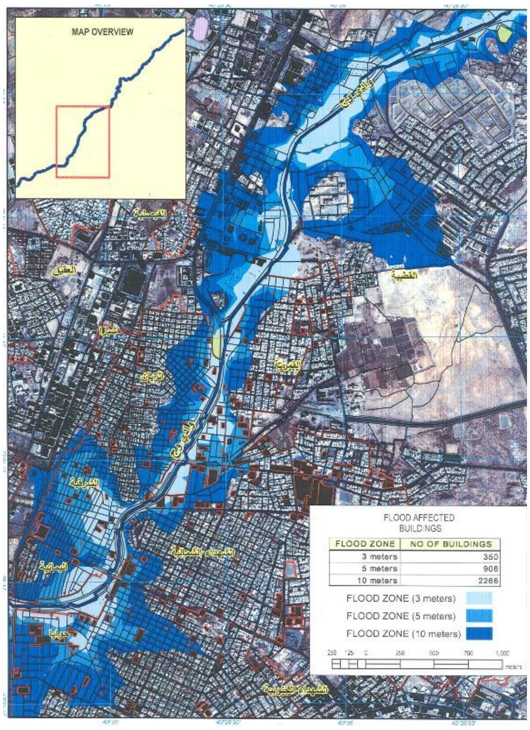

Figure 4: Flood map showing risk zones

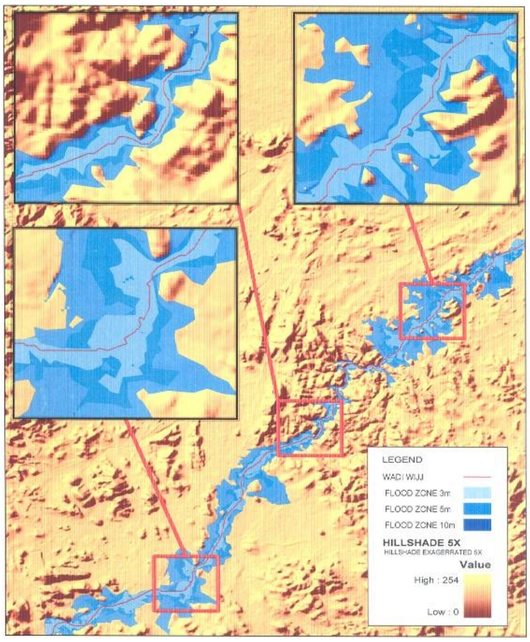

Figure 5: Hill shades of flood affected areas

The 1m resolution IKONOS image was geo-referencing and subsequently superimposed with the mapped flood zones on the image as shown in Fig 4. This allowed preparation of a map with statistical data of the affected buildings in different flood zones.

From the DEM data, a hill shade map was formed. Flood zones were then overlaid on the hill shade map as shown in Fig 5. This gives a comparison between affected flood plain and the surrounding relief.

6. Conclusions

The analysis of IKONOS data along with DEM was found useful in the flood analysis of the Wijj valley basin. A flood risk zonation map based on water depth was produced. A total of 350 buildings were likely to be affected in 3 meters depth followed by 906 in 5 meters and 2266 in 10 meters. It is concluded that this data will be very useful in not only flood damage assessment but in preparedness which is one of the most important element of disaster management.

Acknowledgement

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References

Baoyin, H. and Z. Hailin (2009). GIS-based risk evaluation for regional disaster. Journal of Environmental Technology and Engineering, 2 (3), 87-91.

Hazmadi, M. and J. Kamaruzaman (2006). Techniques for creating DEM/DTM/DSM. Bulletin GIS, No.2 pp 1-13.

Kopp, S. and N. Noman (2008). Arc GIS Spatial Analyst Hydrographic Modeling. ESRI User Conference, Technical Workshop, 4-8 August 2008.

Lynn, D. R. and M. J. Collins (2006). The effect of error in gridded DEMs on the estimation of topographic parameters. Environmental Modeling and Software, Volume 21, pp 710-732.

Marianne, F., A. Daniel and L. J. Louis (2010). DEM and GIS analysis of the stream gradient index to evaluate effects of tectonics. Geomorphology Journal, 119(34), 172-180.

Yahya, B. M., N. M. Devi and B. Umrikar, (2010). Flood hazard mapping by integrated GIS-SCS model. International Journal of Geomatics and Geosciences, 1(3), 489-499.