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Assessing the risk of flooding in Central Tunisia

[1]Mounir Louhaichi, [1]Sawsan Hassan and [2]Selma Etteieb

[1]International Center for Agricultural Research in the Dry Areas (ICARDA) P.O. Box 950764 Amman 11195, Jordan
[2] Laboratory of Water Sciences and Technology, National Agronomic Institute of Tunisia (INAT), Tunis 1082, Tunisia.

Abstract: Digital elevation models (DEM) can be used to derive a wealth of information about land surface morphology. When analyzed using GIS information about stream channels and watersheds it can determine the flow of water over the Earth's surface. Manipulation, analysis, and graphic presentation of the flooding risk and hazard data can be done within a GIS system, and their spatial interrelationships can be determined and used for computer based risk assessment models. We used panchromatic 10m SPOT and 30m Landsat 7 images to digitize stream channels, dry washes, and salt flats in the central part of Tunisia. We then employed a DEM with a resolution of 90m to determine watersheds and theoretical surface water flow patterns. Watersheds were determined using a minimum surface area of 65km^2. We analyzed the DEM by removing pits then determining cells that received runoff assuming an impervious surface. The areas receiving runoff were then classified into cells receiving high, moderate, and low amounts of runoff precipitation. Areas receiving high amounts were considered "at risk" for flooding. Generated maps can be used by government planners and insurance companies to identify areas prone to flooding and encourage citizens to avoid building on these high risk sites.

Key words: Digital elevation model (DEM); GIS; remote sensing; hydrological units; risk assessment; map of flood risk

INTRODUCTION

Floods are inevitable natural phenomenon occurring when either the runoff exceeds the infiltration rate or the cumulative infiltration exceeds the storage capacity of a drainage basin (Erickson 2001). The intensity of the runoff is controlled by diverse factors such as, intensity of rainfall, snow melt, soil type, soil moisture conditions, land use and land cover (Allen 1997). Moreover, flooding is the result of a combination of natural and human factors causing great damage and leading to a great loss of human life (Tchiguirinskaia *et al*. 2006). In addition, flooding damage has a particularly devastating effect in developing countries because it is generally the result of brief torrential rains in a mountainous hinterland resulting in catastrophic flash floods with very high peak discharges (Dewan *et al*. 2005).

Nevertheless, flooding risk can be assessed and appropriate measures taken to be protected from the consequences as flood prone areas can be identified on remotely sensed imagery (Brakenridge *et al.* 2005) and mapped using Geographic Information System (GIS) (Saatchi *et al*. 2000). Furthermore, the integration of remote sensing with GIS makes it an extremely powerful tool to identify indicators of potential disasters (Verstappen 1995; Stancalie *et al.* 2005; 2009) and for resource mapping (Louhaichi *et al*. 2010; Alaci *et al.* 2011). In fact, they can be employed to prepare spatial databases, monitor the situation, predict the natural phenomenon and suggest appropriate contingency plans (Pradhan 2010). On one hand, satellite imagery can be very effective for developing a larger scale view of the general flood situation within a river catchment and the production of hazard assessment maps delineating the areas at greatest risk and in the need of immediate assistance **(**Lyon and Hutchinson 1995; Uddin and Shrestha 2011). On the other hand, GIS is a crucial tool for making use of remotely sensed data and analysis of spatial information which is available in a variety of data models such as the Digital elevation models (DEMs). A DEM gives a representation of the earth's surface and can be used to derive a wealth of information about land surface morphology (Dinesh 2010). DEM offers a versatile tool for application in many disciplines which utilize GIS technology as a potent risk assessment tool. These disciplines include hydrologic delineation and risk assessment to property and life stemming from floods risk (Maidment 2002). Moreover, the analysis of DEM in conjunction with GIS information about the stream channels made it possible to automate the watershed-delineation process and the potential flow of water over the earth's surface, which represents consequently an important input to flood mapping (Lanza and Conti 1994). Also, within GIS environment it's possible to automatically identify hydrological units of interest instead of considering the entire terrain or river network at once (Dinesh and Ahmad Fadzil 2007).

Corresponding Author: Mounir Louhaichi, International Center for Agricultural Research in the Dry Areas (ICARDA) P.O. Box 950764 Amman 11195, Jordan
E-mail: M.Louhaichi@cgiar.org; Tel: (963-21) 221 3433; Fax: (963-21) 221 3490

The main objective of this study was to delineate hydrological units derived from natural watersheds and to predict the risk of flooding for the study area of Kairouan located in the central part of Tunisia.

MATERIALS AND METHODS

Study Area And Datasets:

The governorate of Kairouan (35° 40′ 0″ N, 10° 6′ 0″ E) is located in the central part of Tunisia (Fig. 1). The climate is semi-arid, characterized by a very important year to year and intra year variability. Rainfall across the region has an extremely variable spatial and temporal distribution and it varies between 200 mm to 350 mm per annum, but actual evapotranspirative losses reach 600 to 700 mm per annum. The annual mean temperature is 19.6 °C (Abou Hadid 2006; Hill and Woodland 2009). Kairouan region is notable for the absence of relief, making a flat space namely the plain of Kairouan forming a large basin of 100 km length (north-south) and 40 km width (east-west). The terrain is characterized by a gentle slope having west-east direction and an altitude ranging from 40 to 150 m above sea level. The soils are deep and light consisting mostly of brown limestone soils and young or recent alluvial soils (Barbery and Mohdi 1983).

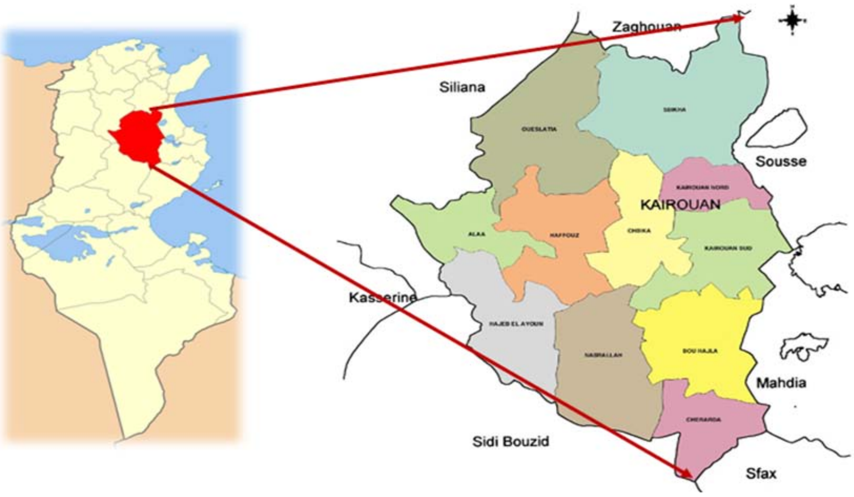

Fig. 1: Location of Kairouan study area in Tunisia

The surface water in our study area is defined by three main rivers which are Nebhana River in the north controlled by Nebhana dam, Merguellil River controlled by El Houareb dam and Zeroud River in the south controlled by Sidi Saad dam. The Kairouan plain aquifer is fed by the infiltration of surface waters during floods or during releases of Sidi Saad and El Haouareb dams. Surface and groundwater are drained into salt depressions. The landuse consists mainly of agriculture especially cereals and olive trees (Leduc *et al*. 2007).

In the current study, the datasets consist of a (DEM) with a resolution of 90 m collected by the NASA Shuttle Radar Topography Mission (SRTM) during February of 2000 (Fig. 2).

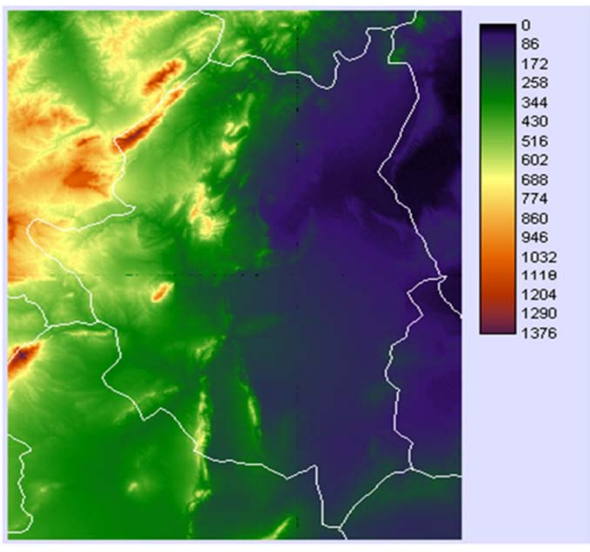

Fig. 2: DEM with a resolution of 90 m for the governorate of Kairouan

Also remote sensing satellite data covering the study area were used. These images are Landsat 7 and SPOT imagery. The characteristics of the used remote sensed data are summarized in the table below (Table 1).

Table 1: Satellite images characteristics

Sensor data source	Mode	Spectral band (µm)	Spatial resolution (m)
Landsat 7	Multispectral	Band 1, Blue, 0.450 - 0.515	28.50
		Band 2, Green, 0.525 - 0.605	28.50
		Band 3, Red, 0.630 - 0.690	28.50
		Band 4, Near IR, 0.760 - 0.900	28.50
		Band 5,Mid IR, 1.550 - 1.750	28.50
		Band 6, Thermal, 10.40 - 12.5	57.00
		Band 7, Far IR, 2.080 - 2.35	28.50
	Panchromatic	Pan, 0.52 - 0.92	14.25
SPOT	Multispectral	Band 1, Green,0.50 - 0.59	20
		Band 2, Red, 0.61- 0.68	20
		Band 3, Near IR, 0.79 - 0.89	20
		Band 4, Mid IR, 1.58 - 1.75	20
	Panchromatic	Pan, 0.61 - 0.68	10

Data Analysis:

Initially, the DEM for the governorate of Kairouan was processed using the Spatial Analyst and 3D Analyst Extensions in Arcview (ESRI 2002) to calculate slope, aspect and an analytical hillshade for the area of interest. Then, the DEM was employed to delineate hydrologic units which are small homogeneous sub-watersheds used for organization of hydrologic data for the purpose of floods risk assessment (Omernik and Bailey 1997). Hydrologic units were delineated by an automated procedure. In fact, DEM enables automated processing from many stream points (Band 1986). For instance, delineation points could be placed near stream confluences. Moreover, general guidelines on how to delineate the hydrological units can be fixed. For example, in our case study hydrologic units were determined for the entire country with a minimum size of 65 km^2.

Byafter, the DEM was employed to determine theoretical surface water flow patterns which enable the calculation of flow direction grids representing the direction of steepest descent (O'Callaghan and Mark 1984; Orlandini and Moretti 2009). Once the flow direction of each pixel was computed, the basin boundary and flow accumulation functions were run automatically. Accumulated flow is the number of cells flowing into each cell in the output grid (Freeman 1991; Jenson and Domingue 1988). To identify stream channels cells with high accumulated flow values were used (Hansen 2001). Ridges and drainage basin boundaries can be identified using cells having accumulated flow values of zero which are local topographic highs (Cederstrand and Rea 1996). Consequently, when processing the DEM using IDRISI Kilimanjaro (Eastman 2003) it was easy to determine cells that receive runoff assuming an impervious surface. The areas receiving runoff were then classified into cells receiving high, moderate, and low amounts of runoff precipitation. Areas receiving high amounts were considered "at risk" for flooding. The UTM projection with a WGS1984 datum in Zone 32 North was adopted for all used maps. We then employed 30 m Landsat 7 mosaic images to digitize stream channels, dry washes, and salt flats in Kairouan, Tunisia using ArcGIS. We used this information to produce a final map of flood risk. Areas at risk were overlain on 10 m SPOT mosaic imagery. Maps, hydrologic unit/watersheds and areas at risk from flooding, were converted to vector format and overlain on the original satellite image. These maps should be fine-tuned by ground truthing that takes into account soil infiltration potential and water control structures that are not visible on our DEM.

RESULTS AND DISCUSSION

Initially, the slope, aspect and the hillshade were derived from the DEM and represented in Fig. 3. To reach the target of delineating the flooding risk, firstly, the hydrologic units were determined from the DEM for the entire country with a minimum size of 65 km^2 (Fig. 4).

Secondly, two maps representing the flow direction and accumulation in the area of interest were generated by calculating the accumulation of rainfall units per pixel based on the DEM (Fig. 5). This step was achieved after an application of pit removal which was needed to create an adjusted "depressionless" DEM in which the cells contained in depressions are raised to the lowest elevation value on the rim of the depression (Hutchinson 1989). After that, the flow analysis calculates the flow direction from each pixel into its next "downhill" neighbor. Then, the runoff analysis computes the total cumulative precipitation on a per pixel basis as if one unit of precipitation was dropped on every location (Eastman 2003). The reclassification of areas receiving runoff permits to delineate areas receiving high amounts and which were considered "at risk" for flooding. Then, the digitized stream channels, dry washes, and salt flats were overlain on 30 m Landsat 7 mosaic images of Kairouan region in Tunisia are shown in Figure 6.

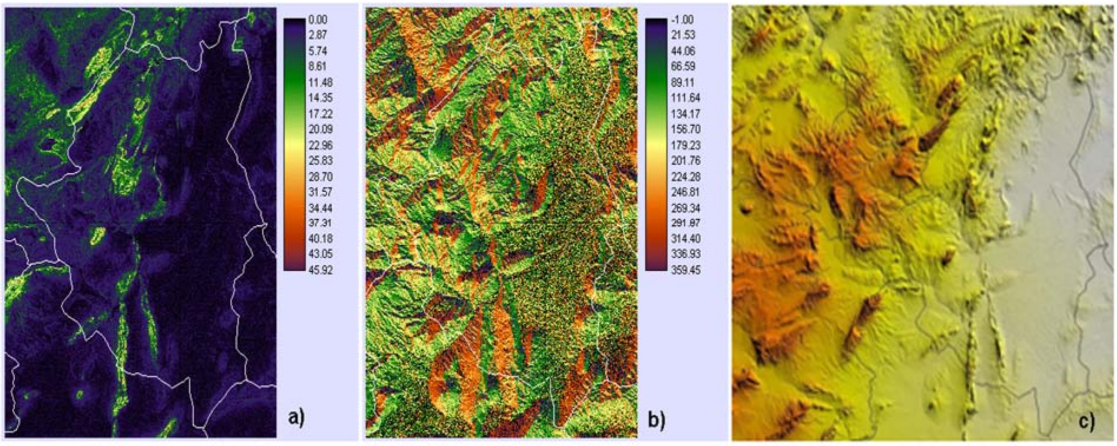

Fig. 3: The slope, aspect and the hillshade were derived from the DEM (a) Slope, b) Aspect, c) Hillshade)

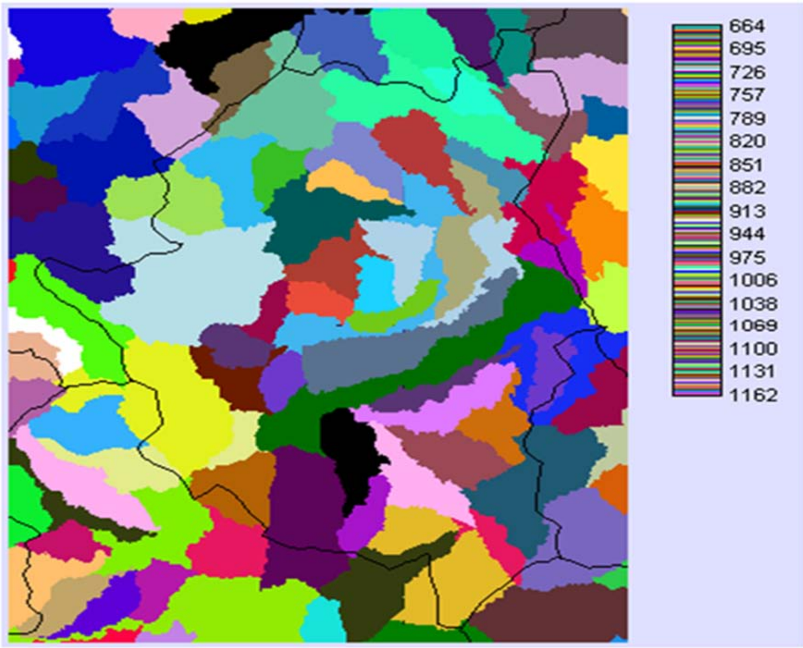

Fig. 4: The hydrologic units that determined from the DEM for the entire country with a minimum size of 65 km^2

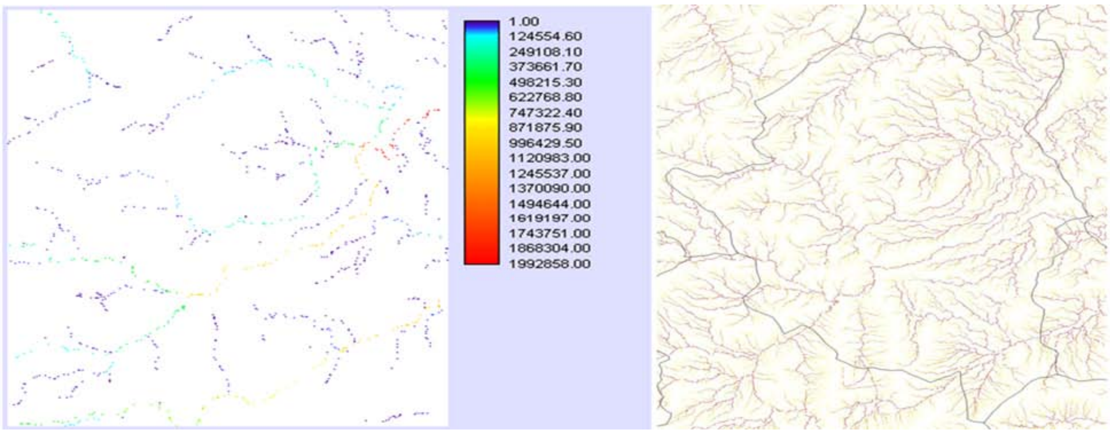

Fig. 5: Theoretical runoff based on the DEM

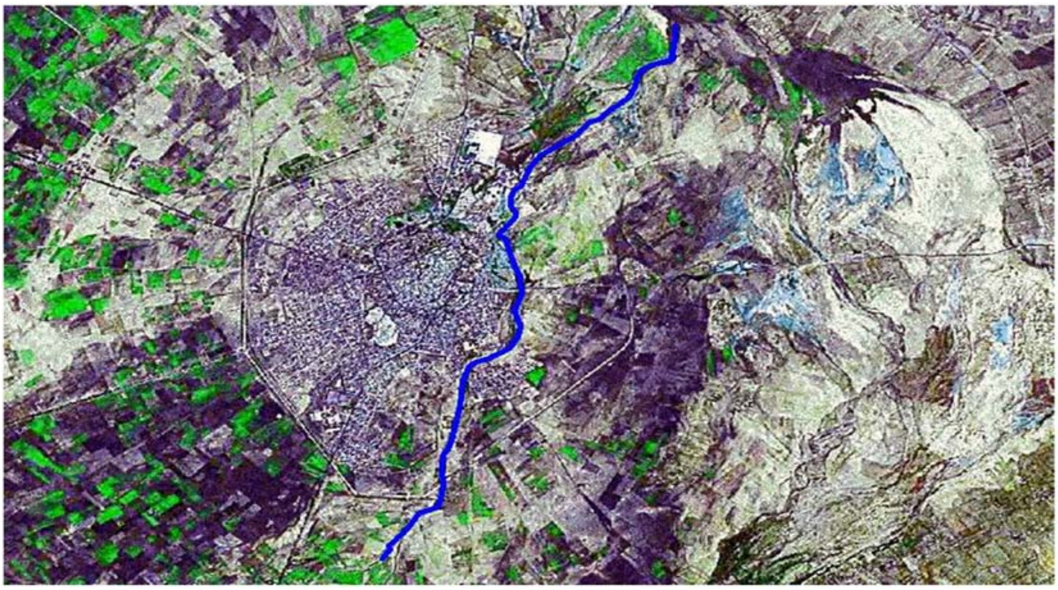

Fig. 6: On-screen digitizing with LandSat image

Finally, flood risk can be assessed using the map representing areas at risk which were overlain on 10 m SPOT mosaic imagery which was chosen to be most suitable for applications requiring fine geometrical detail (Fig. 7).

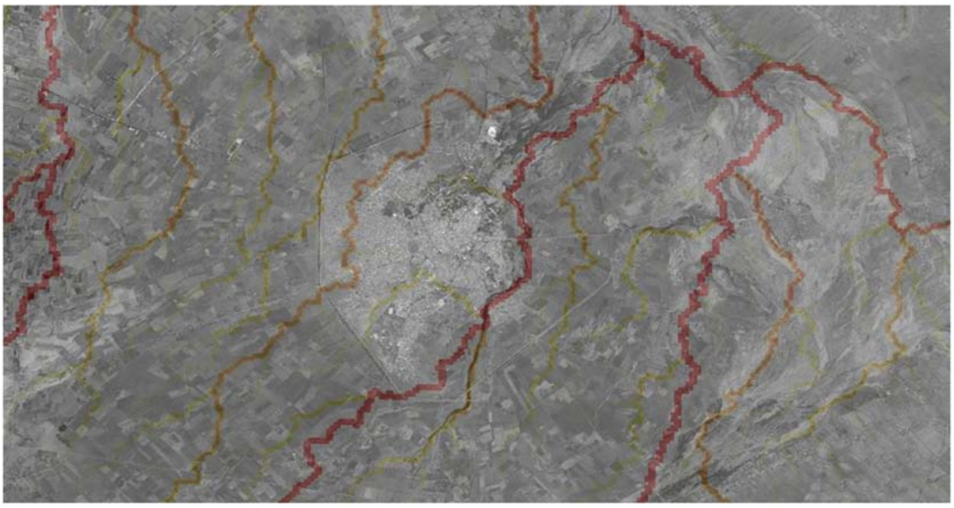

Fig. 7: Areas at risk overlain on 10 m SPOT mosaic imagery

The output maps representing areas at flooding risks overlain on remotely sensed scene are of great assistance for the regional planning authority of Kairouan region as this latter represents a vulnerable site for flooding risk (centenary flooding of 1969). In fact, with lack of plant cover and presence of steep gradients in the highlands, runoff is collected rapidly by wadis that descend from the Dorsale which is a range of mountains, aligned from north-east (Cap Bon area) to south-west of Tunisia (Algerian border) where the highest peak in Tunisia (Djebel Chaambi 1,544 m). In addition these wadis, especially Merguellil and Zeroud rivers are erosive systems that respond rapidly to high magnitude events (Hill and Woodland 2009). Therefore, the use of the thematic layer such as remote sensed data and DEM in GIS environment is very useful in terms of contributing toward more accurate flood hazard mapping and assessing damage to residential properties, infrastructure and agricultural crops (Uddin and Shrestha 2011). Indeed, DEM data can be considered as a component in the planning and construction of almost all types of physical structure. In addition, the usefulness of DEMs in hydrologic modeling is increasing with the availability of more accurate and higher resolution DEMs having wider global coverage (Hoffman and Winde 2010). Consequently the output maps of areas at risk can be used by rural and urban planners for multiple purposes such as to define areas with a high risk for flooding which permits to identify sites for water control and water retention dam construction. Also, these maps orient the decision maker to locate the monitoring stations for biological and chemical water quality and to identify sites that contain alluvial water that could be tapped with wells.

Also, as declared by Verstappen (1995) many applications resulted from the study of the role of remotely sensed geographic information in mapping and mitigating flood disaster. These applications consist mainly of mapping and monitoring of potentially hazardous situations and processes, providing advanced warning and the improvement in management of emergency situations following a disaster and the establishment of susceptibility of the land and vulnerability of the society. Moreover, remotely sensed data, hydrologic models and GIS techniques can be combined to simulate potential flooding with flood modeling software which is a cost and time efficient method for planning damage mitigation measures (Maidment 1996; Mustafa *et al.* 2005).

Conclusions:

The pressure on the earth's resources caused by increased population has resulted in increased vulnerability of human and their infrastructure to the natural hazards, which cause damage in various forms. Consequently the remote sensing and GIS technologies have emerged as powerful tools to map areas at flooding risk. In fact, the analysis performed in this study represents a first step toward the ultimate goal of floods management. Also, knowledge of what is happening on the ground is crucial to the accuracy of the final risk assessment maps. Furthermore, these maps can be used by government planners and insurance companies to identify areas prone to flooding and encourage citizens to avoid building on these high risk sites.

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