Flooding risk analysis of the central part of western Saudi Arabia using remote sensing data

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Abstract

Western Saudi Arabia is one of the arid areas which occasionally subjected to flash flooding effects due to excessive rainfall. The most important and holiest areas in this region are Makkah and El-Madeina which are of great importance not only to Saudi people, but also for whole Muslims all over the world are also affected by such flooding disasters. Studying and suggesting early warning flooding system is of great important for the decision maker to protected and mitigates the pilgrims and local inhabits from such flooding disaster. Flooding can't be prevented entirely, however can be managed, by reducing the likelihood in the first place and minimizing its impact. Geographic Information System (GIS) has been used for evaluating the ground slopes and automatic detection of the lineaments from the satellite images, aerial photographs and digital elevation models (DEM) maps. These linear features may represent natural morphological alignments and nature structural discontinuities of rocks, which can be represent valleys, linear slope breaks and ridgelines. Distribution of such features point out the dangerous areas that may store and accumulate the flooding water and then break it down to the low land areas. GIS can help in predicting water flood peak time, water flood range and level, therefore organizing rescue actions in proper time.

Key words: GIS, Makkah, Almadeinah, flooding

Introduction

The western region of Saudi Arabia is mountainous, except for the coastal plain bordering the Red Sea. However, this area has a great importance not only for the local people but also for the whole Muslims around the world. The area contains the most sacred places on the earth (Makah and Almadeina). Makkah is situated in the sandy valley of Abraham. The mountain ranges it on three sides; on the west, south and east (Fig. 1). On the other hand Almadeina is far away by 390km from Makkah and surrounding by mountains from the north and southwest sides. Almadeina area has many dry wadies and valleys, which represent ancient rivers, were taking place during the rainy ages (Almadinah Almunawarah Encyclopedia, 2009).

Generally, the rainfall takes place in winter (December and January), spring (April and May) and fall (October and November), (Hussain and Ibraheim, 1997). The rain events are scarce, irregular and the rainy days are very rare and scanty. Rainfall is generally characterized by its high annual and spatial variability through much of high intensity, short duration. However it produces flash floods in the foot slope

Figure (1): Topographic map of Makkah and AlMadinah areas.

areas around the mountains. Figure (2) shows the average distribution of the rainfall in the study area. In the last few years, the flooding events became very dangerous as geo-environmental and natural risk phenomena. As the flood is discharging from the wadi basins, it is threatening different cities, towns, villages, engineering structures and causing many deaths and casualties for the citizens.

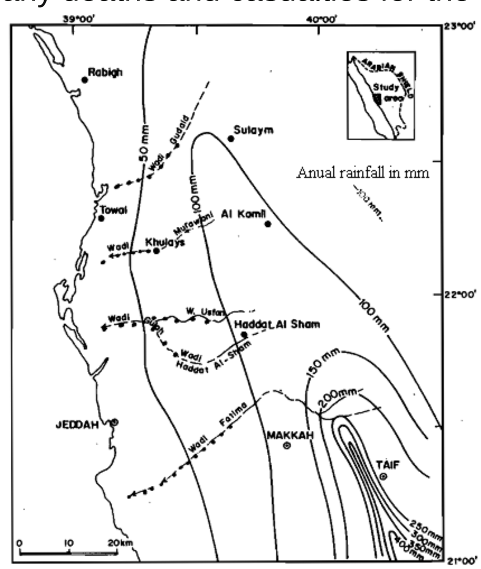


Figure (2): Location of major wadies in the western side of Saudi Arabia and average rainfall distribution, (after Hussain and Ibraheim, 1997).

Flooding can't be prevented entirely, however can be managed by reducing the likelihood of them occurring in the first place and minimizing there impact. The prediction of flood disaster can be applied by a collection of data and models used for monitoring, forecasting, simulation, evaluation and analysis such disasters. Geographic Information System (GIS) is considered a powerful technique and software used for evaluating the different factors reducing the damage in different stages even in the early stage. This can be done by studying different parameters that can be controlling the flooding areas. Therefore the main aim of this work is to make GIS analysis for the western part of the Saudi Arabia using the available remote sensing data sets to locate and identify the general trends of the wadeis, valleys and the slopped areas. Then, the output results are used for locating the most dangerous areas around the holly Makkah and Almadeinh cities. Therefore the decision maker can take the proper action in time for saving the pilgrims and citizens from the flooding dangerous.

Overview at the study area:

The topographic map of the study area (Fig. 1) shows that most of the western side of Saudi Arabia has two mountain ranges separated by a gap in the vicinity of Makkah. The northern range in the Hejaz seldom exceeds 2,100 meters, and the elevation gradually decreases toward the south to about 600 meters around Makkah. The rugged mountain wall drops abruptly to the sea with only a few intermittent coastal plains. The western slopes have been stripped of soil by the erosion of infrequent but turbulent rainfalls that have fertilized the plains to the west. The eastern slopes are less steep and are marked by dry river beds (wadeis) that trace the courses of ancient rivers and continue to lead the rare rainfalls down to the plains. Scattered oases, drawing water from springs and wells in the vicinity of the wadeis, permit some settled agriculture. Of these oases, the largest and most important is Almadinah. South of Makkah, the mountains exceed 2,400 meters in several places with some peaks topping 3,000 meters (Fig. 1).

Methodology:

Computer technology has recently been developed to convert maps into a computer-usable digital format and allow the simultaneous manipulation of both the geographic spatial data and related attribute data. This is what we called GIS technology (Demers, 1999). Geographic Information System (GIS) is a powerful information tool for decision makers. It is used as an important tool in increasing the efficiency of planning and decision making, leading to a more mitigating different disaster effects. It is promises high reliability and continuity for solving problems related to precise predictions for preservation of global environment, efficient use of energy resources, reduction of natural disasters, etc.

In this work digital elevation model (DEM), aerial photographs and aeromagnetic data sets have been analyzed and used to understand the drainage pattern and wadeis distributions around the holly areas in the western side of Saudi Arabia.

DEM map:

A digital elevation model (DEM) is a digital representation of ground surface topography or terrain. It is also widely known as a digital terrain model (DTM). A

DEM can be represented as a raster (a grid of squares) or as a triangular irregular network. DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. Figure (3) shows the DEM maps of the whole Saudi Arabia kingdom and detailed map for the western side where the study area is located.

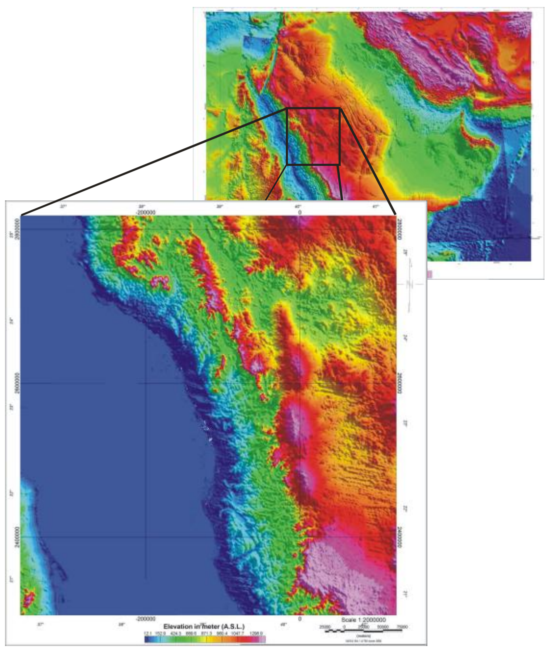
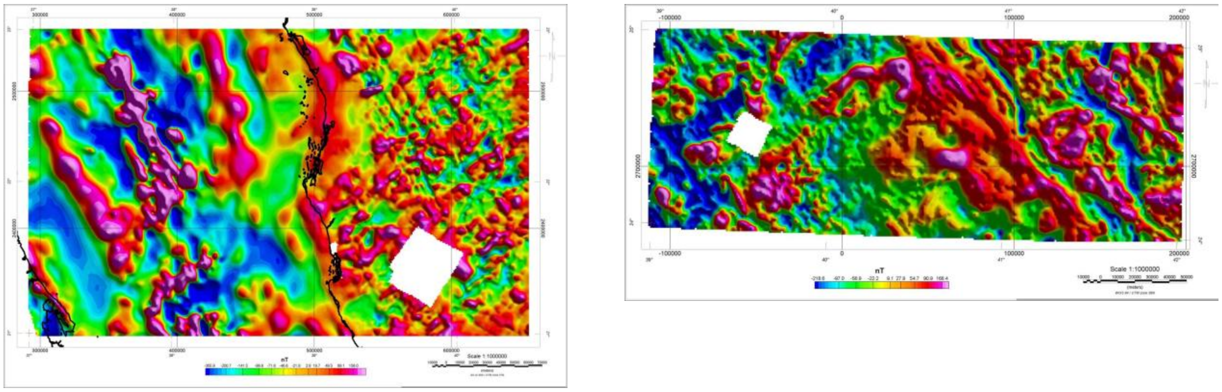


Fig. (3): SRTM Map for the Saudi Arabia and detailed for the study area.

Magnetic data:

The magnetic method is one of the best geophysical techniques to delineate subsurface structures. Generally, aeromagnetic maps reflect the spatial variations in the magnetic field of the earth. These variations are related to distribution of structures, magnetic susceptibilities, and/or remnant magnetization. Sedimentary rocks, in general, have low magnetic properties compared with igneous and metamorphic rocks that tend to have a much greater magnetic content. Thus, most aeromagnetic surveys are useful to map structures of the basement and intruded igneous bodies.

A conventional color scale or spectrum with low magnetic values shown as blue and high values as red has been employed on the reduction to the pole (RTP) map around Mecca and Medina areas. It is clear that most of the structure elements are parallel to the red sea rift (Figure 4). The magnetic data provide a large amount of information about the geology of central and western Saudi Arabia and adjacent parts of the Red Sea, showing structural elements such as faults, shear zones, sutures between Precambrian terranes, and Precambrian and Tertiary dikes, as well as prominent lithologic features such as plutons, dikes, and contrasted areas of magnetite-rich and magnetite-poor rock units.



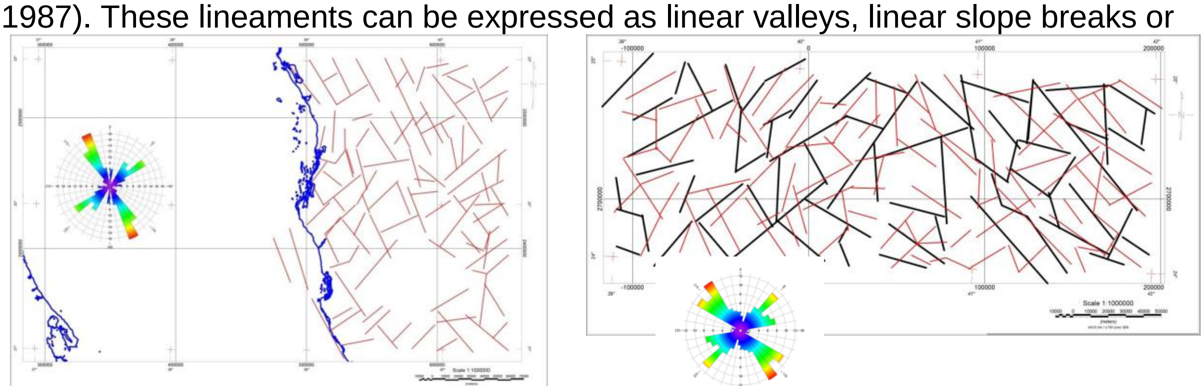
(a) (b)

Figure (4): Redu o The Pole (RTP) Magnetic Map C Mecca and Almadeinah Areas.

Extracting the linear futures from the regional magnetic map reflect the major subsurface geological structures, which are directly influence the surface futures. Surface futures are represented as the main wadies, dikes, faults, etc. Figure (5) shows the regional lineaments at Makkah and Almadeinah areas with the correspond rose diagrams. It is clear that the regional trends of the lineaments in both areas are coincident with red sea rift which has a northwest southeast direction. Another minor trend has a direction of northeast southwest direction. Bother those two trends are matching with the DEM extracted lineaments as will show below. The At this stage all possible linear features which fall within the terrain and magnetic maps characteristics were annotated without consideration of their tectonic nature.

Lineament Extractions

Lineaments are more or less rectilinear alignments that can be seen on satellite images, aerial photographs and digital elevation models (Gustafsson, 1994; Wladis, 1999). These linear features may represent natural morphological alignments or those of anthropogenic nature (roads, aqueducts, crops, etc.). Structural discontinuities of rocks and other features related to tectonic activity often results in morphological lineaments (fault scarps, joints, fold axis, etc.; (Ramsay and Huber, 1987). These lineaments can be expressed as linear valleys, linear slope breaks or



(a) (b)

Figure (5): Regional Lineaments of the Regional Magnetic Map of Makkah and Almedina Areas.

linear ridgelines. In digital elevation model images, lineaments are defined by drop in elevation for short distance (Wladis, 1999). Valleys are often associated with high negative values of profile curvature while ridges are associated with high positive values. Abrupt changes in slope gradient were highlighted taking the values above and below given thresholds value in the profile curvature cumulative histogram, selecting in this way the large positive and negative numbers (most convex and concave values).

The Hough Transform (HT) was chosen for automatic extraction of linear features from the enhanced images (Hough, 1962); cited in (Fitton and Cox, 1998)). It has the ability to extract shapes from isolated pixels or short segments that are truly aligned and forming a line. Therefore it is suitable for extracting geologic lineaments, which are often visible in short, non-continuous segments.

The resulting lineament maps (Fig. 6) have in general short and parallel segment lines. Parallel lines can be explained due to the presence of relatively thick areas in the binary images that were extracted in this way for the HT. Rose diagram for the most accurate lineament map extracted from pre-thinned slope gradient binary map is also shown in Figure 5. It is clear that most of the lineament futures have a trend north west south east, which is coincident with red sea rift. Therefore, most of the structure elements at the study area had been affected by the tectonic process in the red sea.

Drainage Pattern:

Drainage is one of the most important elements for evaluating the flooding hazardous. It can be studied using the three following aspects: a) drainage textures, b) drainage pattern and c) valley shape. In this study valley, shape is the least important. Drainage texture is primarily influenced by three factors: a) climate, b) relief and c) character of the bedrock. Drainage density and frequency are elements of drainage texture, where high density drainage implies impermeable lithology and low-density drainage implies permeable lithology. Drainage pattern, which is the special arrangements of streams, is a function of rock types and structures.

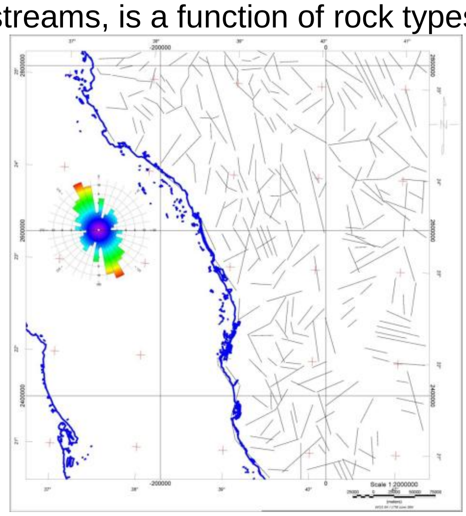
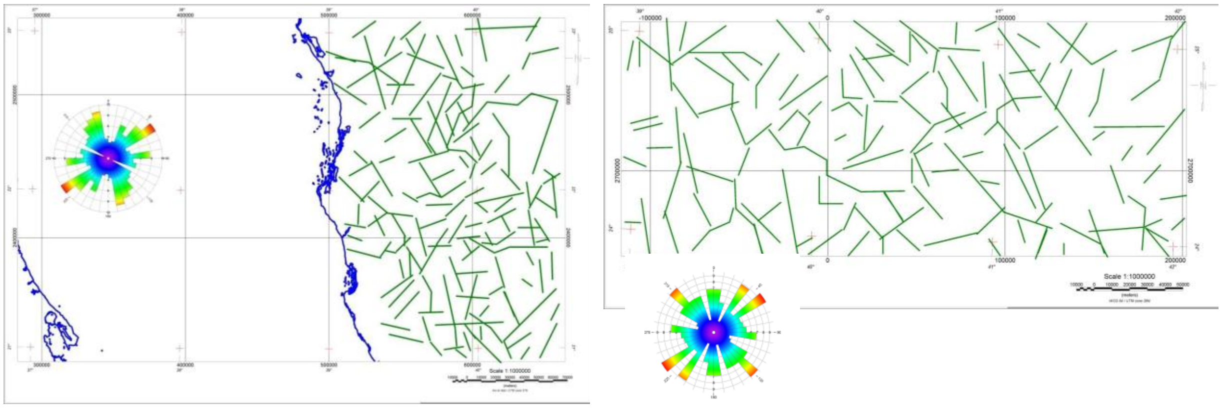


Figure (6): Automatic Lineaments Extracted From DEM For The Whole Study Area.



(a) (b)

Figure (7): Automatic Lineaments And Rose Diagram Representations Extracted From DEM of Makkah (a) and Almadeinh (b).

In this study the rectilinearity of the drainage pattern was a good indicator for lineament interpretation, as rectilinear streams appear as linear features on images (Fig. 8). Two types of features may be defined: major stream course changes and straight stream lines. A large number of these features are represented in the area.
a) Major stream course change: This type of feature is widely present in the area. It consists of a sudden change in the stream orientation. This type of change is important where the type of material involved is mainly of fluvial origin. It is important to note that the down-cutting of the river system in these materials is relatively facilitated by the soft nature of the sediments filling the basin. A sudden change of channel orientation is due to the geotectonic conditions of the underlying basement rocks.

b) Straight stream line features: These features are widespread throughout the study area, and it is one of the features which easily detectable on most of the processed images. Many lineaments were defined by these features since they appear as straight lines on images. Most of the mainstream courses appearing as lines were interpreted, while their branches were only interpreted selectively.

From the deduced drainage pattern it can be easily estimated the scenario for the expected flooding directions. In general there are two distinctive directions for the rainfall water, one toward the red sea in the east and the other to the east direction. Also, by comparing the DEM and its relevant drainage pattern it is easily to locate the boundaries and the wadies, valley and other lowland areas, which are considered dangerous areas during the flooding event (Fig. 8).

More investigation for the two holly places of Makkah and Almadeinah (Fig. 9), show that the drainage pattern is helpful in determine the directions of running water and the possible locations for storing it and also, the suitable sites for dam constructions. Moreover, the decision maker can take such maps for choosing the suitable site for evacuations.

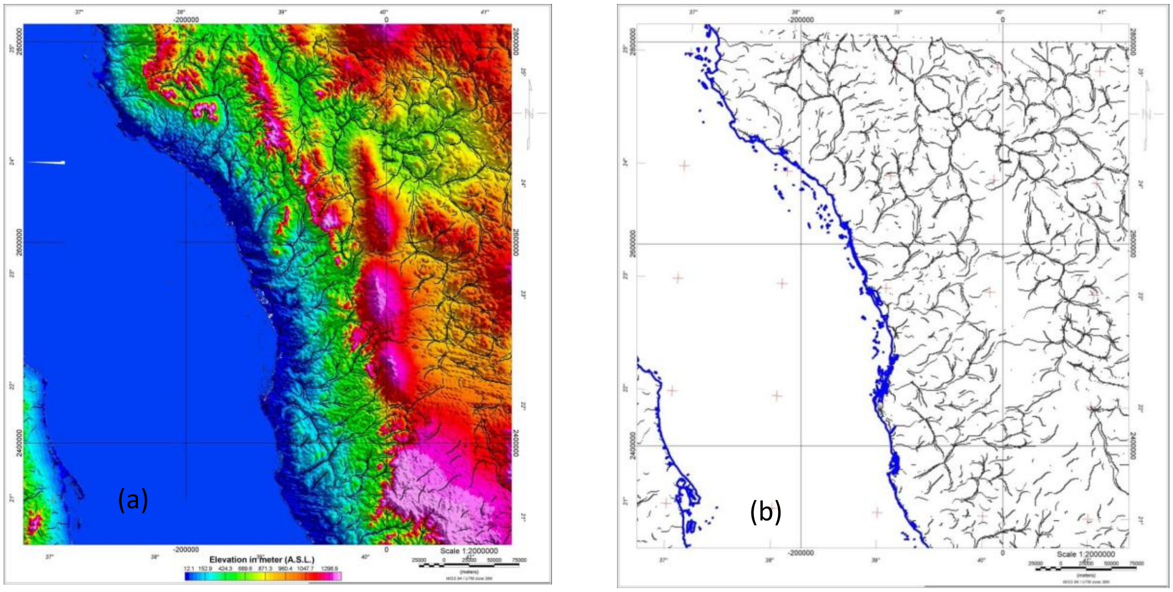


Figure (8): Examples of Drainage Patterns Appearance on DEM Images in the Area of Study. (a) DEM image and (b) The extracted drainage pattern from DEM image.

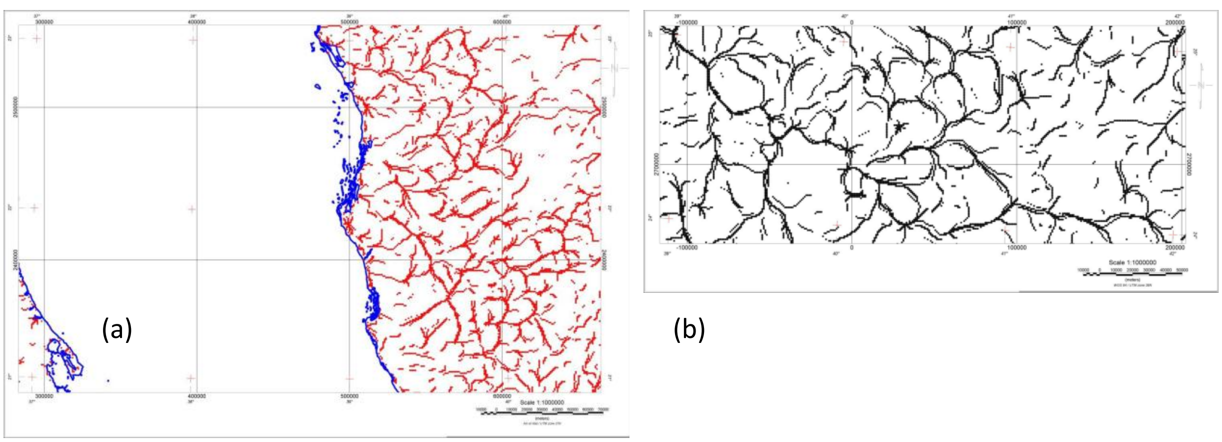


Figure (9): Examples of Drainage Patterns Appearance on Images in Makkah and Almadeinah Areas.

Conclusion:

The application of GIS for evaluating the expected flooding hazardous in the western side of Saudi Arabia in very important, critical and easily done. Utilizing different kinds of data to analysis the regional and local trends of the lineaments and drainage pattern in the holly areas of Makkah and Almadeinah is very helpful to get a good estimation for the trends of expected flooding events and make a good scenario for the possibility of evacuation and building the protected dams. Combining the DEM, aeromagnetic, and any other available data sets make the process and estimating the most hazardous areas very clear and introduce a fast and reliable help for organizing rescue actions in proper time.

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