العنوان: Use of GIS and Remote Sensing to Identify Flood Vulnerable Areas : a Case Study from Northern Riyadh

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Use of GIS and Remote Sensing to Identify Flood Vulnerable Areas: a Case Study from Northern Riyadh.

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Abstract:

Many areas in the city of Riyadh are subject to heavy rainfall, which leads sometimes to a rise in water level on roads and result in traffic disturbance as happened in 1995 and 2010. It's well known that floods are unpreventable, though it is possible to reduce their risks through taking mitigation measures. The most important is to construct a database and to produce analytical maps for sensitive areas, besides that to construct monitoring networks and early alarm systems. This study was carried out in order to locate drainage basins and water courses in areas subjected to flood, especially areas of possible urban growth in north Riyadh. A spatial analysis was conducted for these basins using remote sensing (RS) and geographic information system (GIS) for producing thematic maps. A spatial database was constructed and utilized for topographic and slope analysis using Digital Elevation Model (DEM).

Keywords: flood, remote sensing, GIS; Vulnerable, spatial analysis, thematic maps.

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Introduction:

Remote sensing & GIS-based analytical modeling are two key components for any flood management and mitigation plan. On Monday 3/5/2010, Riyadh witnessed an excessive rainfall that triggered a flood in the city. A 45-minute downpour on Monday, which included light hail and winds that gusted up to 42km/hour, caused flooding and hours-long traffic jams across the city. Meteorological officials in the kingdom gave warning that more storms could be coming on Tuesday. Saudi Arabia's Al Watan newspaper reported that two people were killed and that the flooding caused 275 car accidents. Authorities also announced a state of emergency, and told residents not to use their vehicles unless necessary. The drain from wadis and flooding resulted in road destruction, cars wrecking and traffic jams. Some buildings were trapped by rain water due to lack of effective drainage systems. Since previous planning is necessary, especially in fast growing areas like the city of Riyadh and due to repetitive flooding, the drainage system should be precisely located. A number of studies have acknowledged the significance of estimating people’s vulnerability to natural hazards, rather than retaining a narrow spotlight on the physical processes of the hazard itself (Hewitt, K., 1997; Varley, P., 1994; Mitchell, J. K., 1999). Even though most of the developed countries are well equipped with detailed flood hazard maps, there is hardly any detailed spatial database for flood prevention and mitigation. In recent years, efforts have been made to use remote sensing and geographic information system (GIS) for creating national-level flood hazard maps (Islam, M. M., and Sado, K., 2000a). Islam and Sado, 2002, and many other were undertaken studies on a regional level using coarse-resolution AVHRR imageries from NOAA satellites. The results of such investigations would only be valuable for national level macro planning. In this study, Satellite: IKONOS imageries are used in order to classify flooded areas and to delineate human settlements and then after, to produce analytical maps in the GIS systems. The high spatial resolution of satellite imageries enables us to obtain detailed classification results that are suitable for preparation measures on a medium to large scale. This would greatly enhance the capability of the spatial database to estimate vulnerability of individual settlements to an extreme flood event. Satellite imageries were useful to identify several vital places and projects on the level of the study area such as the Kingdom Hospital, Saudi-German hospital, Military Hospital (under construction), Princess Nora bint Abdulrahman University, University of Imam Mohammad Ben Saud, and many shopping malls. The study which included 15 Districts was based on a systematic analysis and modeling for areas threatened by flooding using GIS and Remote Sensing methods, and considered to be the most up to date means of spatial analysis for natural hazards.

Location and topography:

The city of Riyadh is located on the yellow hill in Najd area, which extends to the west towards Tuwaiq mountain range and east to the desert of Dahna, an area far from the sea and free from any lakes or rivers. The altitude levels range in the region between the level of (750) meters, and the level (632) meters above sea level. Figure (1) shows the geographic location of the study area in reference to the Kingdom of Saudi Arabia. Figure (2) is a satellite image of the study area shows the residential Districts.

"Typically, initial enhancements serve as input to further image processing steps; with thematic information extracted from the image. Selective image enhancement techniques were applied to the data to improve visual interpretation" (Fadda, , E. H., 2007). The analysis of the satellite image has identified four water basins in the study area, the first basin: Al'aysin Valley basin that covers the District of Hattin, Al Aqiq, Al Ghadeer, Al Rabee', Al Sahafa, Al Yasmin and Al Mlqa. Its highland prevails in the western and eastern parts and descends gradually towards the south. The streams of Al'aysin valley run towards the south and flows in the Eastern Ring Road. The second basin: Shoaib Abu Jerfan covers half Al Nrges District and part of the Al Yasmin and Al Qairawan Districts. Its heights prevail in the western and the north-western parts and descend gradually towards the east. Shoaib Abu Jerfan drain through the highlands towards the east-bound and flows across the airport road. Basin III: Shuaib Abu Smadh, it covers half Al Nrges District and part of the Al Aarid District. Its high places prevail in the western and eastern parts and descend gradually to the south. Shuaib Abu Smadh streams and Shuaib Al Oklah run through the heights and heading towards the south and flow in the King Khalid International Airport. Basin IV: Shuaib Abu Ghadar covering half of the Al Aared and Al Qairawan districts. Its high places prevail in the western and south-west parts and hills' slope descends gradually towards the north. The valleys cut the highlands to the north-bound, and the streams flow in Banban.

Figure (1): Geographic location of the study area in reference to KSA.

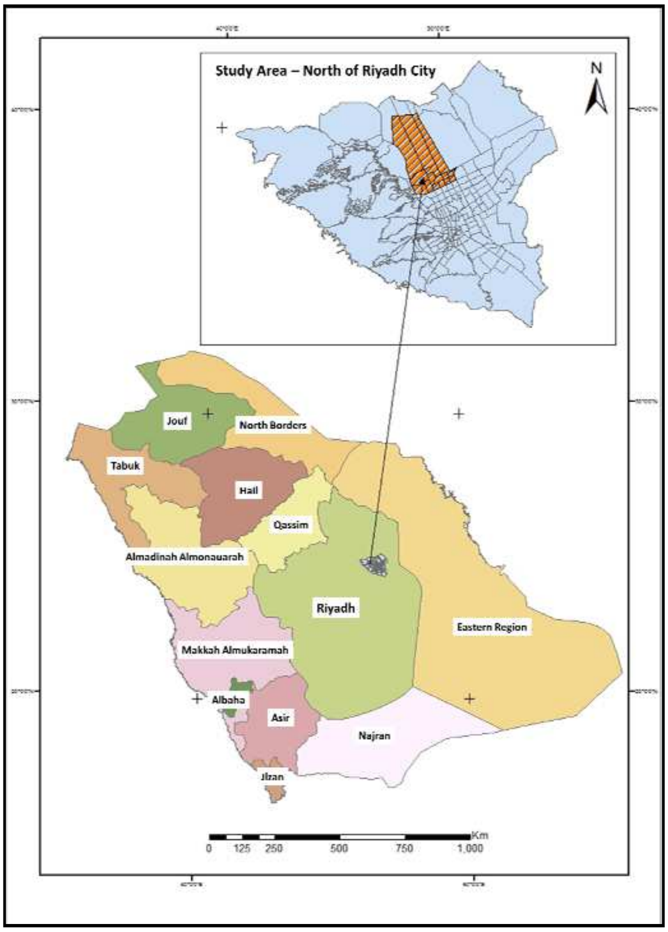
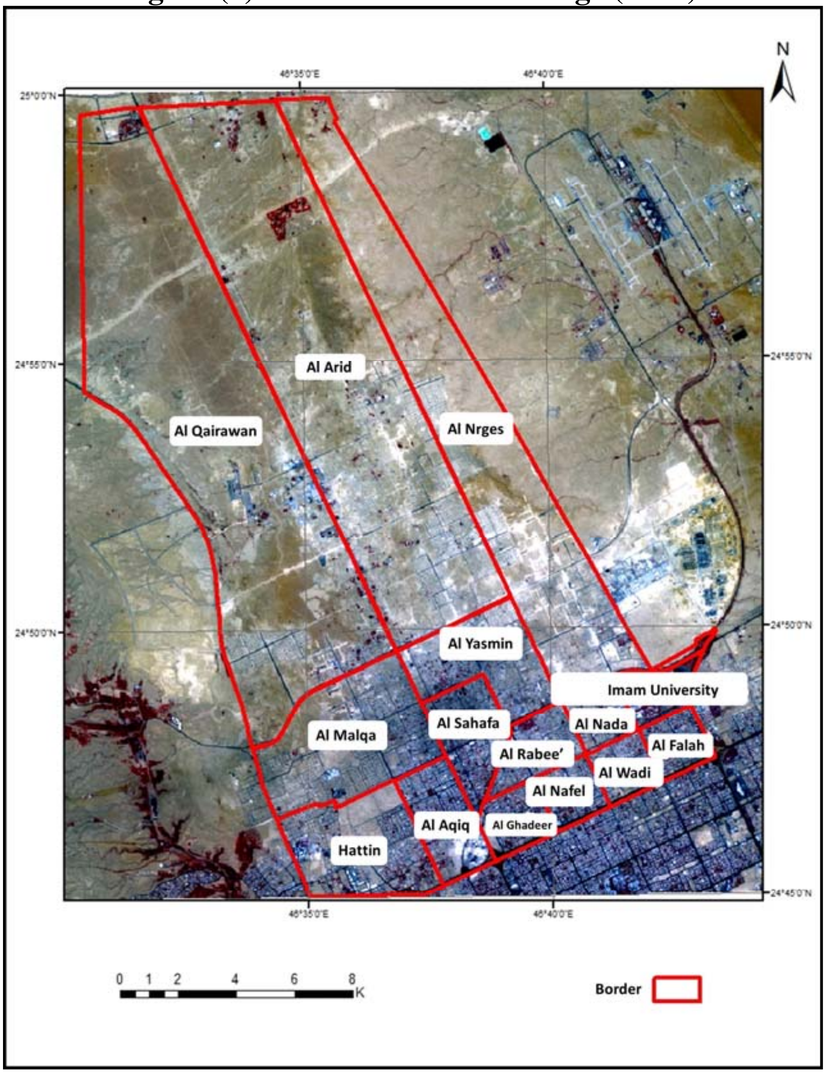


Figure (2): IKONOS satellite image (2009).



The objectives:

The objectives of this study are:

• Extraction of natural, man-made features and flash floods risk elements from satellite images, and represent them in the geographic information system in order to determine the sites threatened by the floods.

• Identify areas of housing and urban development and construction that are threatened by the danger of flood in the northern part of the city of Riyadh.
• Conduct spatial analysis and modeling within the GIS environment to evaluate the sites threatened by the floods.
• Production of thematic maps that can be used for mitigation, prevention and protection from flood damage and, to be adapted for serving the proper planning and to support decision-making.
• Suggest an information system database that includes all spatial data in the form of maps and attribute tables for the study area to be updated and used to establish monitoring networks and early-warning systems for flood risks.

Methodology:

Geographic studies research has been dramatically improved in the area of flood risk management. In this study, the analytical descriptive approach was adopted, a digital database was built, and the best analysis tools were used in a complete geographic information system. Methods of mapping technology were also used using computers to produce 3-D and 2-D maps, which illustrate the spatial relationships between flood risk location close to the residential area and the road network in order to employ the results to predict and prevent the risks in the future.

Several methods were used to achieve the objectives namely:

- Automated cartography method, because of their superior capabilities in the drawing, modernization and supply and storage.
- Map modeling by analyzing and study the spatial relationships between flood related features.
- Topographic analysis methods, in order to analyze the surface of the earth depending on the three-dimensional digital elevation model.
- The analytical method to find the location of flood and flood risk by modeling the cartographic and spatial analysis in geographic information systems.

The study was conducted on 15 districts in the northern city of Riyadh; the results were represented on maps to show the urban growth pattern to facilitate the comparison, and interpretation.

Imageries, Image rectifications and restoration:

IKONOS produces 1-metre black-and-white (panchromatic) and 4-metre multispectral (red, blue, green and near infrared) imagery that can be combined in a variety of ways to accommodate a wide range of high resolution imagery applications. It orbits the Earth every 98 minutes at an altitude of approximately 680 kilometers or 423 miles. IKONOS was launched into a sun-synchronous orbit, passing a given longitude at about the same local time (10:30 A.M.) daily. IKONOS can produce 1-metre imagery of the same geography every 3 days. For this research, IKONOS scene acquired in 2009 has been obtained in digital format from King Abdulaziz City for Science and Technology (KACST). The scene was geometrically and radiometrically corrected by KACST. The scene has been accurately georeferenced by ArcGIS software using GPS control points obtained from the topographic maps of the study area. Three spectral bands have been projected in RGB to generate a false color composition (FCC) of the study area. Therefore, all urban features (land use/land cover) can be effectively discriminated by adding bands 4(0.757–0.853 µm), 3(0.632–0.698 µm) and 2(0.506–0.595 µm) and there was no need for further spectral mixture analysis. Table (1) and Figure (3) shows parameters of IKONOS; spatial resolution and spectral Response.

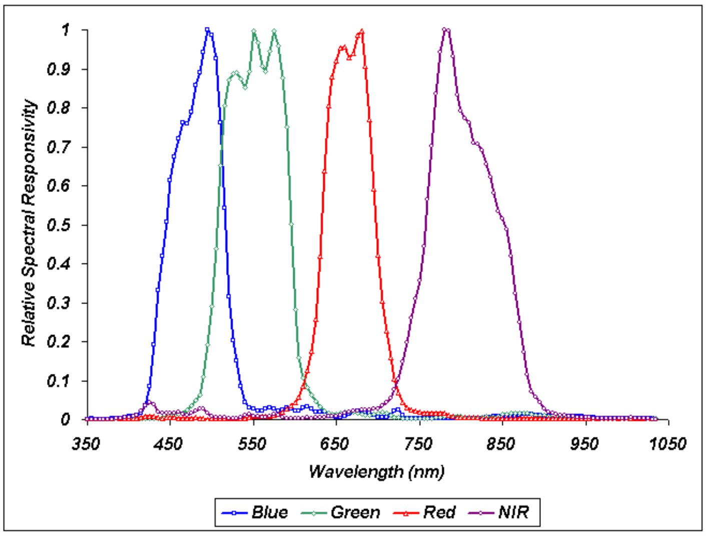
"Data entry can be very time consuming, but it is the most important task of the GIS process" (Chrisman, N.,1999). Satellite image: IKONOS of 4-meter spatial resolution that are geometrically corrected is used in this study to detect the drainage system network, the road network, and to identify the human and natural features and vulnerable areas. Maps: Digital and paper format were used in all analytical processes. The geometrically and radiometrically corrected multispectral bands of IKONOS data at 4 meters resolution, taken on 2009, have been used as base images. The subset area was then registered to a topographic map at a scale of 1: 50 000 using ground control points (GCPs). The data set was rectified to a Universal Transverse Mercator (UTM) Projection Zone N38.

Table (1): Parameters of IKONOS; Spatial Resolution and Spectral Resolution.

Band	1-m PAN	4-m MS & 1-m PS
1 (Blue)	0.45–0.90 µm	0.445–0.516 µm
2 (Green)	*	0.506–0.595 µm
3 (Red)	*	0.632–0.698 µm
4 (Near IR)	*	0.757–0.853 µm

(Source: Space Imaging, Inc., 2003).

Figure (3): IKONOS Multispectral Relative Spectral Response.



(Source: Space Imaging, Inc., 2003).

Discussion:

Digital Image Processing:

Digital image processing techniques are used to enhance the image and make it more interpretable since it increases the discrimination level between the features within the image. It is used to enhance data as a premise to visual interpretation and enables to identify targets and extract information from an image. "Recognizing the visual elements of *tone, shape, size, pattern, texture, shadow, and association* are the key to interpretation and information extraction" (Jensen, J. R., 2007). The main digital enhancements used were False Color Composite; which helped in extracting information of valleys and shoua'ibs, road network and urban expansion. All urban features (land use/land cover) can be effectively discriminated by adding bands 4(0.757–0.853 μm), 3(0.632–0.698 μm) and 2(0.506–0.595 μm). There was no need for further spectral analysis since all required features are clear and discriminated.

Spatial GIS layers:

A GIS is a powerful tool and can provide better information to support many types of difficult decision-making (Fadda, E. H., 2011). Using the ESRI product (ArcGIS) software is possible to build and develop a complete flood database where every element on the map is related to its data in the attribute table. This will eventually support the decision-maker to make priority for managing flood risk. The extracted features from the IKONOS image have been quantified in the GIS database as GIS layers. Many more process, analysis and modelling will be applied; that including adding the attribute data and creating the (DTM). Mathematical operations using the Boolean logic method will be applied in order to model the produced GIS layers of the risk elements in the GIS environment. Where, all the produced GIS layers are corresponding with the IKONOS image projections.

Drainage basins layers:

The study area is covered by four drainage basins. The first one with a total area of 106.5Km ^{2} and represents 31.9% of the study area, its drainage is running to the south. The drain intensity of this basin is 193Km/km^2 and it is a basin of fifth grade according to Struller Measurement as shown in Figure (4)**.** The area of the second basin is 43.7 km^2 and represents 13.1% of the study area its drain intensity is 273Km/km^2 and runs towards the East and of fourth grade. The third basin occupies an area of 50.7 km^2 and represents 15.2% of the study area and flows towards King Khalid Airport with an intensity of 263Km/km^2 and of grade four. The fourth basin covers an area 99.5 km^2 with a 29.8% of the total study area; it flows towards Banban with intensity of 243Km/km^2 and of grade five.

Figure (4): Drainage Basins and Districts locations.

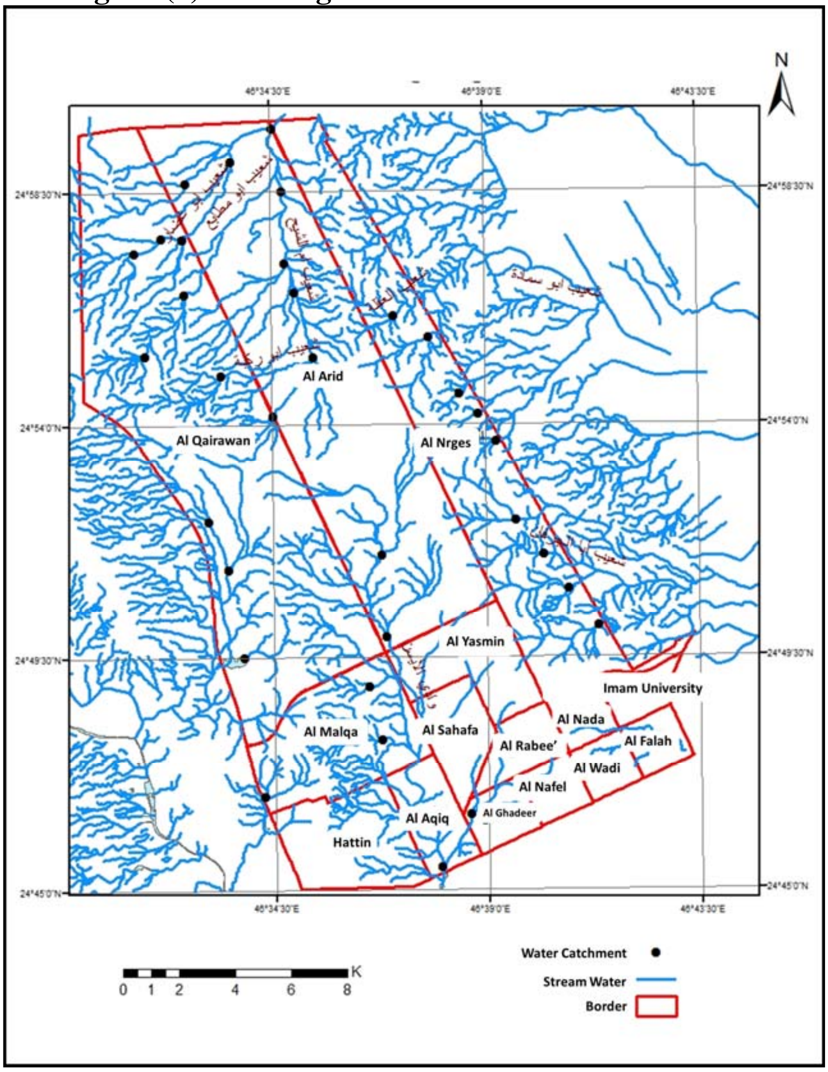
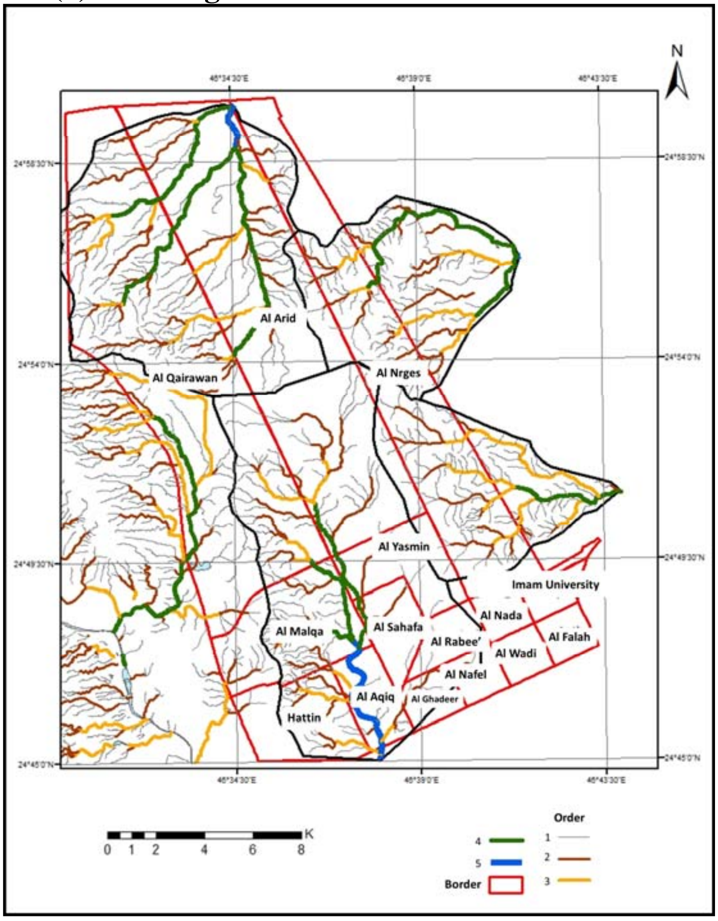


Figure (5): Drainage network ranks and basins boundaries.

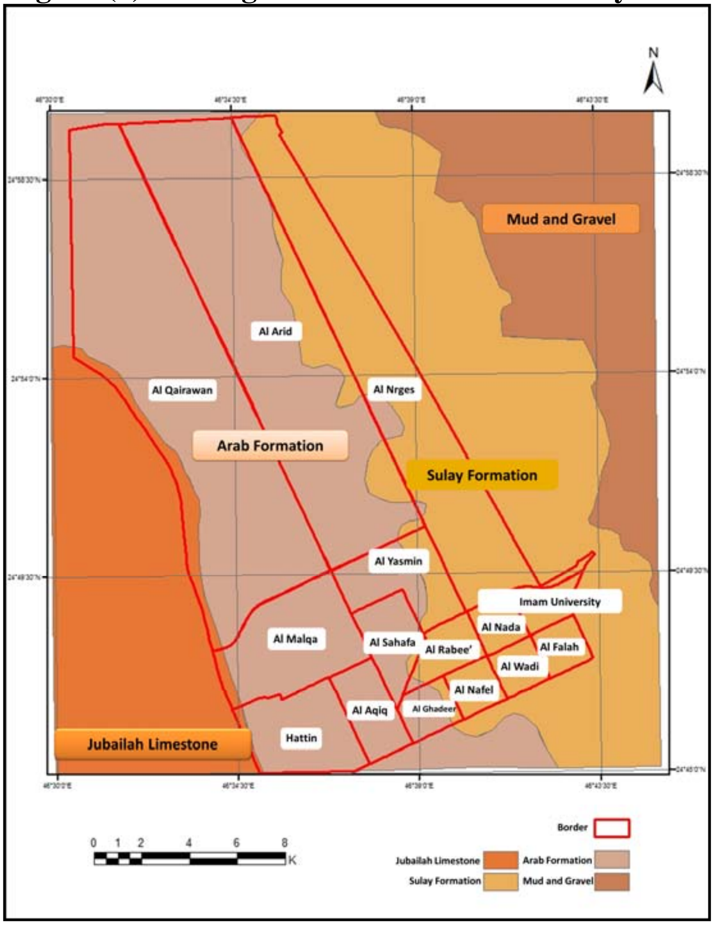


Geology Layer:

Sali formation covers Al Nafil, Al Falah, Al Nada, Al Rabee' and Imam Mohammad Bin Saud and small parts of Al Yasmin District. This formation is of Neocomian age and consists of coherent limestone of light brown color contains thin layers of coquina partially altered to dolomite in some places. Water infiltration in this formation is low. Arabic formation covers Hattin, Al Aqiq, Al Ghadeer, Al Sahafa, Malqa, Al Qairawan and a large part of Al Yasmin and Arid. This formation is brown and light brown limestone and dolomite in some places it converts into breccias as a result of water erosion.

Water infiltration in this formation is low. Silt and pebbles cover the airport area, and consist of unconsolidated superficial deposits which make infiltration of rain water very high. But due to the urban intensity and wide road networks increase the possibility of flooding as the construction prevent water infiltration into the ground.

Figure (6): Geological formations in the study area.



3.2.3 Road networks and water accumulation layer:

Many important roads are present in the study area (figure 7) like king Fahid which leads to Qaseem, the Eastern Ring Road which leads to

Mecca towards the west and to king Khalid Airport and Dammam towards the East, Salbokh road which leads to Der'eiyah and the Takhassosi road which cross the city of Riyadh from south to north. Many health care centers and shopping malls are on these roads. The total length of the roads in the study area is 7724 km. Thirty five (35) points were selected at the intersections of wadis and Shu'aybs which considered as dangerous locations due to the accumulation of surface running water. Many alternative solutions are available to prevent the flood damage and these include building concrete dams and drilling wells and pools to collect these waters. The drainage network covers intensively Al Qairawan, Al Nrges, Al Malqa, Hittein and Al Aqiq District s were the wadi intensity ranges between 1837 – 3178 Km/km^2, and therefore, these districts are the most vulnerable to flooding.

Spatial Analysis:

Cartographic modeling was significantly improved according to modern techniques in terms of accurate map production and map publishing. It offers an improved procedure for integrating map layers and designing analysis schema for spatial data. (Correia,F. N., et al., 1999). In this study a number of models were constructed; water flow direction, accumulated water flow and flood threatened areas especially north Riyadh as will revealed in the following sub-sections. Triangular Irregular Network (TIN) was also produced from the elevation data to show the elevation variations in the area.

Surface Analysis:

Digital elevation models (DEMs) provide a good way of driving landform attributes that may be used for prediction. (Musungu,k., et al, 2012). Highlands in the study area descend from the west to east at Al Aarid District then begin to rise until it reach Al Nrges area then descent again towards King Khalid airport in the direction of flooding. Another flood direction is from Al Aarid and Al Qairawan towards the north and south. The digital elevation model (DEM) that the highest elevation is 783m and the lowest is 634m in the airport area; Figure (9) shows the SPOT image drape over DEM of surface topography of the study area.

Figure (7): Road network in the study area.

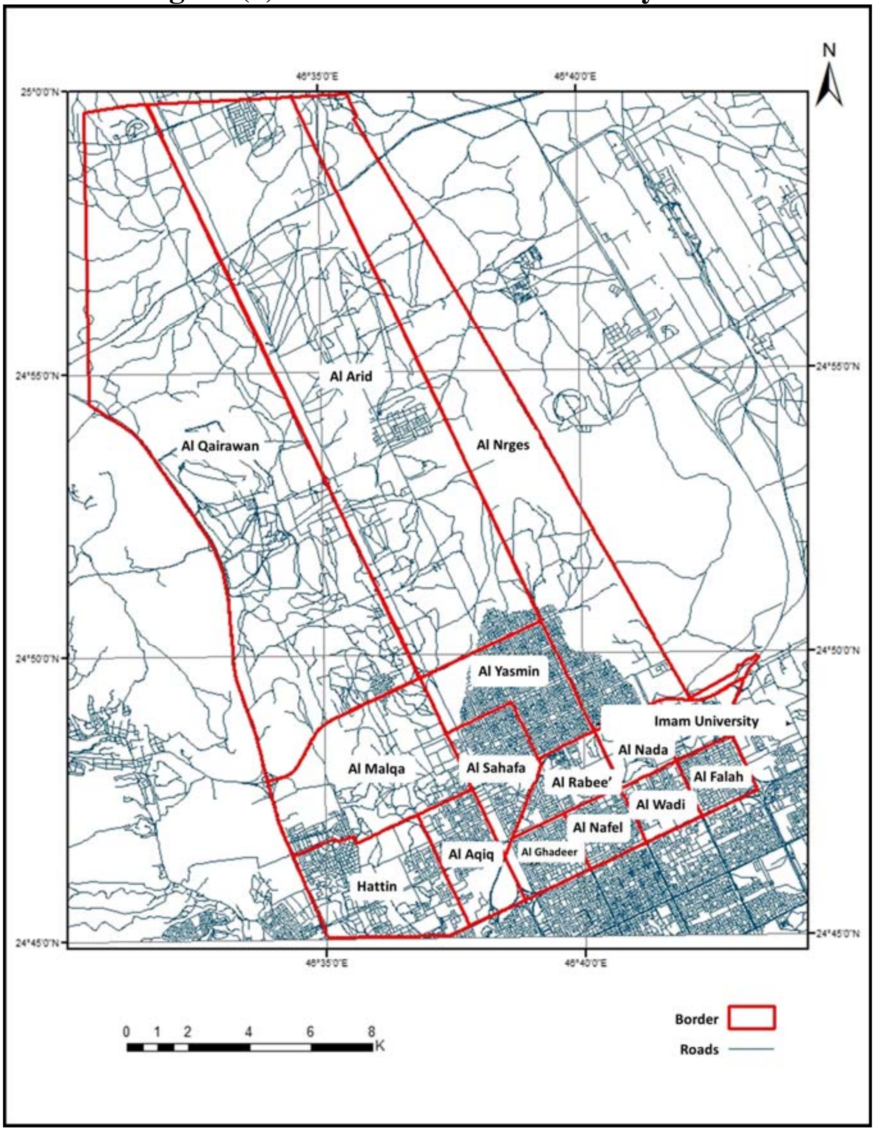


Figure (8): Water accumulation locations.

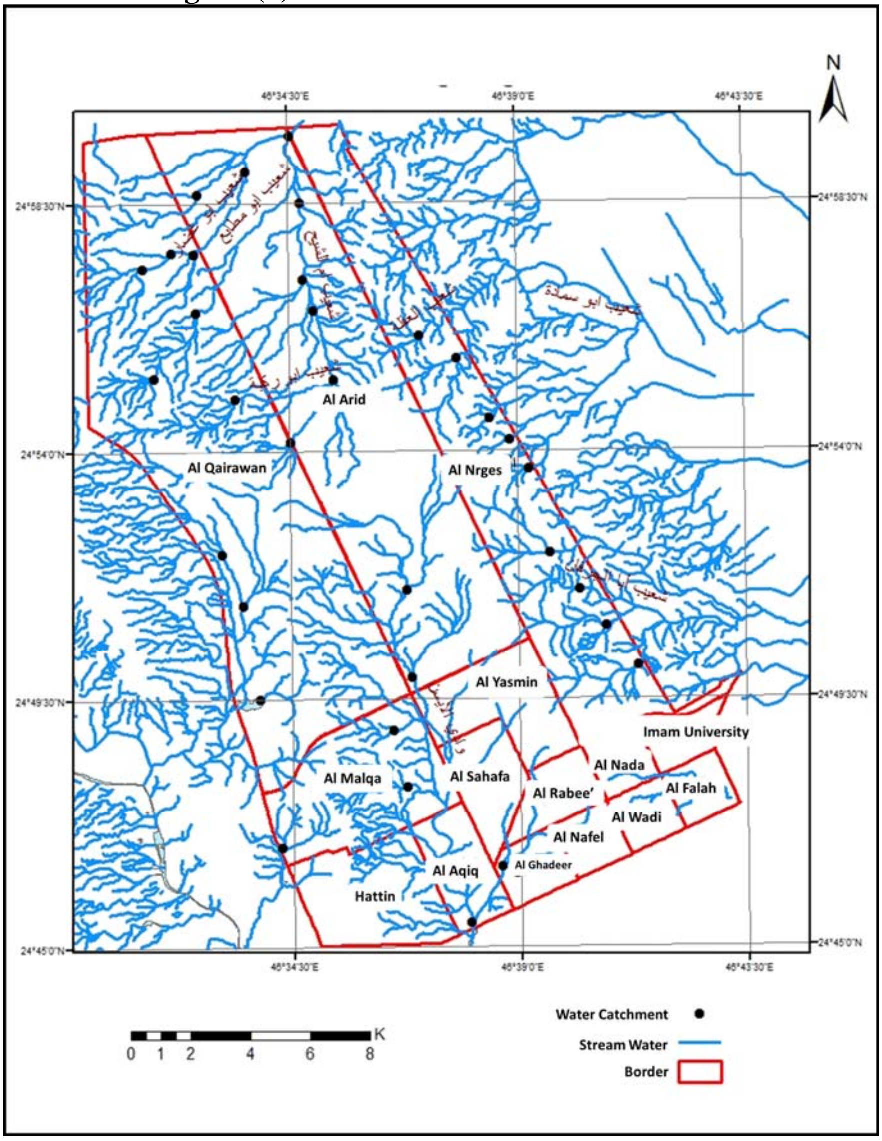


Figure (9): Three dimensional Satellite image of ICONOS drape over the DEM.

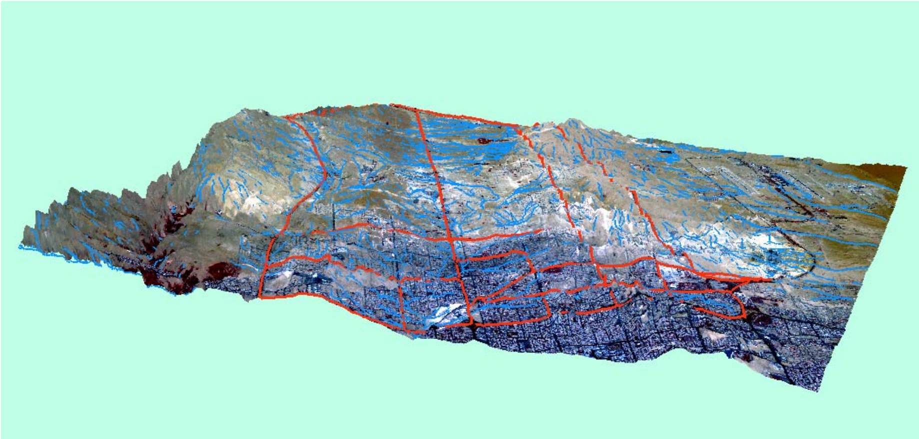


Table (2): Topography levels of the Districts included in the study area.

District	Lowest Level(m)	Highest Level(m)
Al Falah	640	670
Al Wadi	653	693
Al Nafel	651	678
Al Ghadeer	640	658
Al Aqiq	634	658
Hattin	637	694
Imam University	642	670
Al Nada	653	675
Al Rabee’	646	685
Al Sahafa	646	680
Al Malqa	647	702
Al Yasmin	652	696
Al Nrges	646	700
Al Arid	649	695
Al Qairawan	657	752

Slope Analysis:

Slope analysis is used to measure the change rate in earth surface levels. It is the rate of maximum change in z-value from each cell. The range of slope values in degrees is 0 to 90. (Sharaf, M. I., 2010). In the study area the highest slope percent is 38.75% with an angle of 21.18º.

Aspect Analysis:

Aspect analysis is one of the important standards that determine the horizontal direction to which a surface slope faces the aspect of a slope can make very significant influences on its local climate. If the value of the cell in the map is equivalent to 90 degrees, it means that the direction of the highest rate of declination is to the east. In case the surface is horizontal then there will be no declination direction and in this case the values of the cells in the network map value will be (-1) (Sharaf, M. I., 2010). Knowing the direction of the gradient will provide information about the direction of flooding, as shown in Figure (10). Table (3) shows the direction of the gradient at the values of grid cells where in the values of 0 to less than 22.5 the direction of the gradient is to the north, and from 22.5 to less than 67.5 the direction of the gradient North East.

Table (3): Slope direction according to cell values

Cell Value	Cell Direction
Less than 1	Plain
1 to < 22.5	North
22.5 to < 67.5	North East
67.5 to < 112.5	East
112.5to < 157.5	South East
157.5to < 202.5	South
202.5 to < 247.5	South West
247.5 to < 292.5	West
292.5 to < 337.5	North West
337.5 - 360	North

Flow direction analysis:

Flow direction analysis is one of hydrologic analysis that creates a raster of flow direction from each cell to its steepest down slope neighbor. One of the keys to deriving hydrologic characteristics of a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the *Flow direction tool.* (Zeiler, M.,1999). This tool takes a surface as input and outputs a raster showing the direction of flow out of each cell and output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells and is expressed in percentages. There are eight valid output directions relating to the eight adjacent cells into which flow could travel Figure (11). This approach is commonly referred to as an eight-direction (D8) flow model and follows an approach presented by Jenson, (1988). Figure (12) shows the surface flow map of the study area.

Figure (10): Slope direction in District layer in the study area.

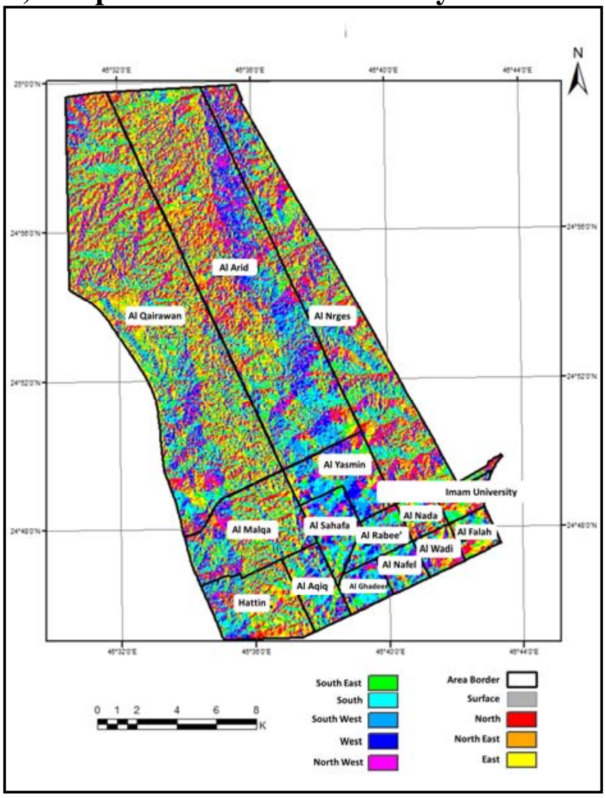


Figure (11): Defining values for surface flow direction.

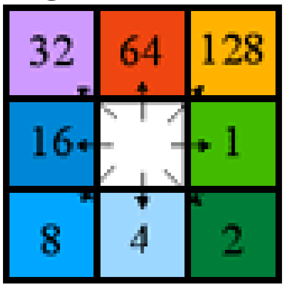
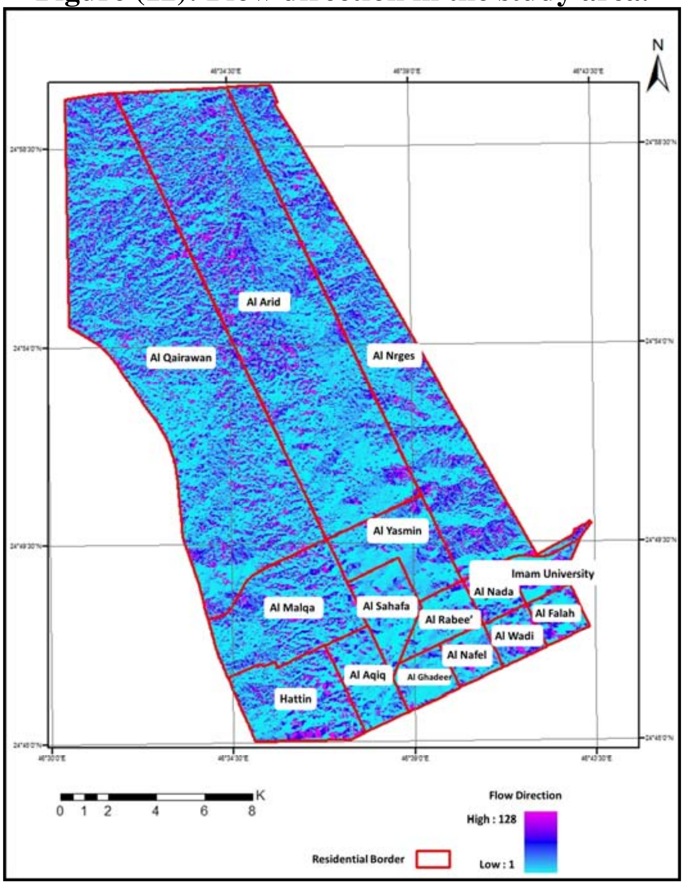


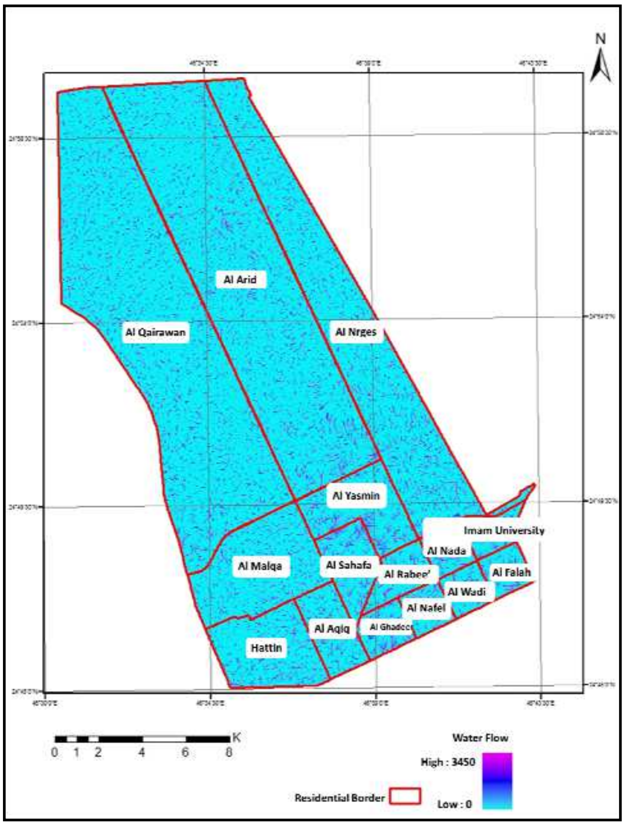
Figure (12): Flow direction in the study area.



Analysis of cumulative water flow:

A surface flow direction map determines the flow direction from one cell to another. In case that the water flow fall in the first cell in a certain direction and the second and third have also the same direction as the first this means that the third cell will receive an amount of water which accumulated from the first two cells. Cumulative flow analysis was conducted and the final result Figure (13) shows that each cell took its values from the number of cells flow into it and there was only one cell that fall in it 3450 cell.

Figure (13): Cumulative water flow in the study area.



Map overlay:

Map overlay is an important process utilized for the study of spatial relationships between different phenomena; it is the starting point for data analysis by GIS. It implies matching and collecting data from two or more maps in order to produce new data or new map to be the outcome of matching function or intersection of these phenomena. Analytical capacity is one of the most outstanding features of geographic information systems. Spatial Analysis is a process of representation, selection, testing and interpretation of the results of spatial models (Sharaf, M. I., 2010). In this study all data and information were used in the GIS environment for the analysis of floods in the north of Riyadh, and was linked to relevant data to be analyzed in order to locate areas of water flood risk. It was then produced in form of maps. Two maps were compared and matched, the first map is the drainage water basins, the second map is the residential area map this defined the residential area located within the drainage water basins as shown in Figure (14) and table (4) and how much area it occupies.

Figure (14): Residential areas over drainage layer.

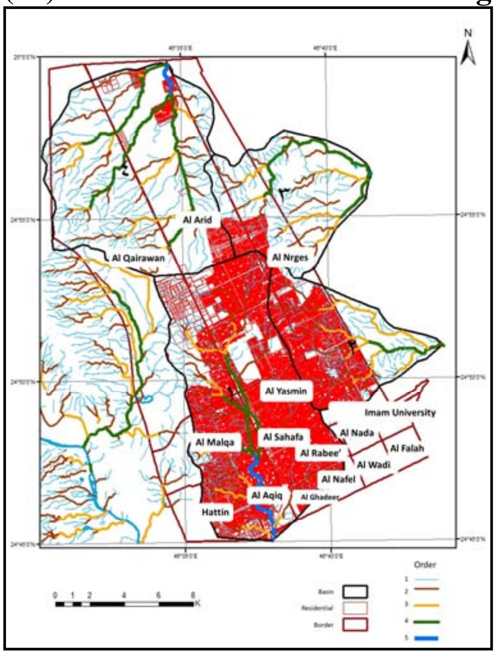


Table (4): Residential areas and road lengths compared to drainage basin area.

Drainage Basin	Drainage Basin area (km^2)	Residential area (km^2)	Road length (Km)
1	10.6.6	99.2	314.3
2	43.7	25.7	165.1
3	50.7	4.8	119.4
4	99.6	4.1	260.4

Data analysis shows that most district at risk of flooding in the event of rain and according to valleys intensity are respectively; Al Mlqa, Al Nrges, Al Qairawan, Hattin, Al Aqiq, the Arid, Al Falah, Al Ghadeer, Al Sahafa, Al Yasmin the Al Wadi, Al Rabee' then Al Nafel, and Al Nada. It was found that the District of Imam University does not have any valleys. As shown in the table (5).

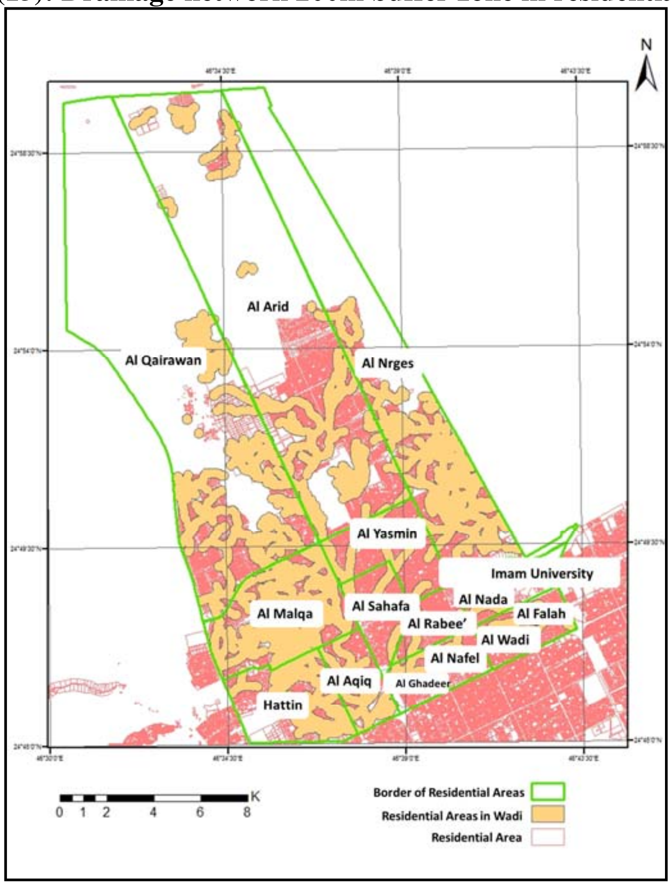
Table (5): Study area Districts and wadi length and intensity for each in ascending order.

District	Wadi Length (Km)	District Area (Km^2)	Wadi Intensity (Km/Km^2)
Imam University	0	4.1	0
Al Nada	1.7	4.0	0.3
Al Nafel	1.9	4.0	0.4
Al Rabee'	3.4	5.6	0.5
Al Wadi	2.6	3.9	0.6
AL Yasmin	9.0	112.7	0.7
Al Sahafa	7.4	7.8	0.8
Al Ghadeer	4.4	4.6	0.9
Al Falah	5.6	3.9	1.4
Al Arid	138.8	86.3	1.6
Al Aqiq	14.5	7.94	1.8
Hattin	28.6	15.1	1.9
Al Qairawan	238.2	96.9	2.4
Al Narges	138.2	54.8	2.5
Al Malqa	69.0	21.7	3.1

Buffer Analysis:

This process creates a new feature class of buffer polygons around specified Input features that can be polygons, lines, or points. Buffer operations of 200m zone, which increases the size of an object by extending its boundary for the most suitable size sufficient for the study. A 200m buffer zone was the most suitable, in which it has been chosen because the average width of the wadis in the study area is about 200m and by trial and error; was created around the water drainage network in residential areas Figure (15), non residential were excluded.

Figure (15): Drainage network 200m buffer zone in residential areas.



It was found that residential areas located in the valleys and streams threatened by floods and flash floods represent 80.96% in Al Mlqa District, 59.95% in Al Aqiq District, 56.70% in Hattin District, 50.54% Al Falah District, 37.58% Al Nrges District, 35.89% in Al Ghadeer District, 34.38% in Al Sahafa District, 32.99% in Al Yasmin District, 31.02% in Al Wadi District, 26.26% Al Rabee' District, 23.94% in the district of Al Qairawan, 22.6% in the District the Al Arid, 17.9% in Al Nada District, and 17.59% in Al Nafel District, as shown in Table (6).

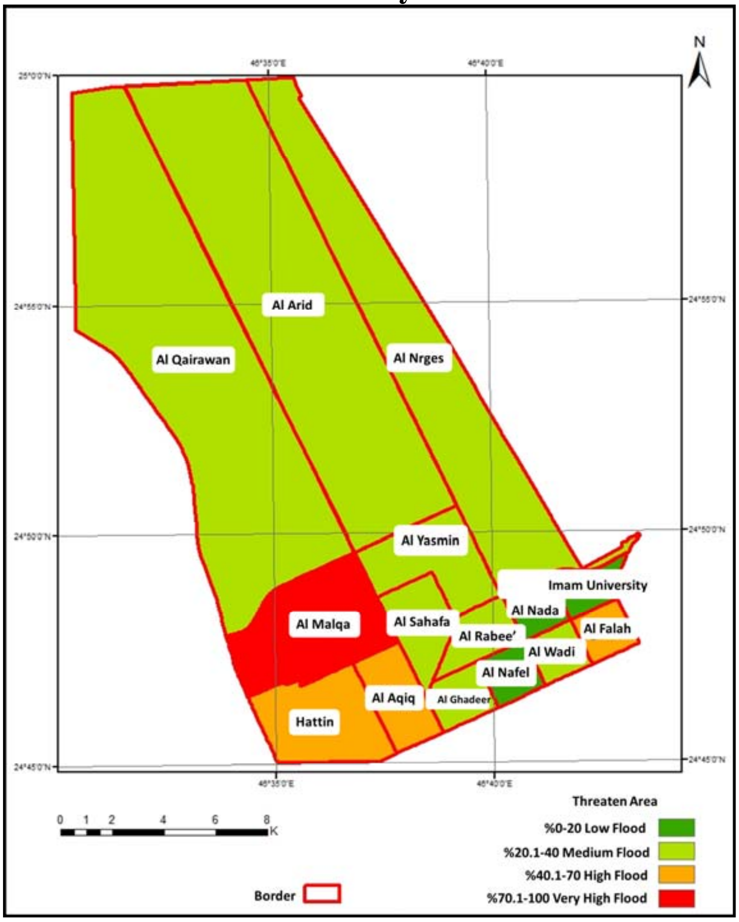
Table (6): Area and percentage of flood threatened Districts in ascending order.

Order	District	Area threatened (Km^2)	District Area (Km^2)	District Area threatened Percentage%
1	Imam University	0	4.1	0
2	Al Nafel	0.7	4.0	17.5
3	Al Nada	0.7	4.0	17.9
4	Al Arid	19.5	86.3	22.6
5	Al Qairawan	23.2	96.9	23.9
6	Al Rabee'	1.4	5.6	26.2
7	Al Wadi	1.2	3.9	31.0
8	Al Yasmin	4.2	12.7	32.9
9	Al Sahafa	2.7	7.8	34.3
10	Al Ghadeer	1.6	4.6	35.8
11	Al Nrges	20.6	54.8	37.5
12	Al Falah	1.9	3.9	50.5
13	Hattin	8.5	15.1	56.7
14	Al Aqiq	4.7	7.9	59.9
15	Al Malqa	17.5	21.7	80.9

Results and discussion:

It is noted that the change in District order in this analysis compared to the previous analysis because of the exclusion of water drainage network that do not intersect with the residential area. It is necessary to give these sites a priority in the implementation of drain network project. From table (6) a map was constructed showing the percentage of the districts areas threatened by the dangers of flash floods Figure (16).

Figure (16): Shading spatial map according to the area percentage threatened by floods.



The levels of vulnerability for each area can be identified in different ranges; but by considering the minimum and maximum percentage of flood threatened at each district as shown in table (6), which is 0%-80%. Thus, ranges of four classes (0-20%, 20.1-40%, 40.1-70%, 70.1-100%) are adequate, (any other split of the ranges can be done since the data is available in a form of GIS database).

According to the percent of threatened at each district as it appears in table (6) the following conclusion should be considered:

- Ranging from **0-20%** , then the District is exposed to a low level of flooding (Al Nada, Al Nafel, Imam University)
- Ranging from **20.1-40%** then the District is exposed to a medium level of flooding (Al Nrges, Al Arid, Al Qairawan, Al Yasmin , Al Sahafa, Al Rabee', Al Wadi and Al Ghadeer).
- Ranging from **40.1-70%**, the District is exposed to a high level of flooding. (Al Falah, Al Aqiq and Hattin)
- Ranging from **70.1-100%,** the District is exposed to an extremely high level of flooding (Al Maqa District).

A number of models were constructed in this study such as; water flow direction, accumulated water flow and flood threatened areas. Triangular Irregular Network (TIN) was also produced from the elevation data to show the elevation variations in the area. A GIS and remote sensing are substantial tools that can provide improved information to spatial analysts; it was possible to build and develop a complete flood database where every element on the map is related to its data in the attribute table.

Therefore, the following results should be taken in considerations:

- Water drainage network covers extensively the Districts of Al Qairawan, Al Nrges, Al Mlqa, Hattin and Al Aqiq valleys where ranging density in these Districts between 1837 and 3178 (km/km ^{2}) and therefore these neighborhoods most vulnerable to floods.
- Drainage Network covers in a moderate intensity Al Falah, Al Ghadeer, Al Sahafa and Al Arid wadis where density ranges in these districts between 946 and 1608 (km / km ^{2}).
- Drainage Network covers in a low-density the Wadi, Nafel, Imam University, Al Nada, Al Rabee' and Al Yasmin districts. Where density ranges between 0445 and 708 (km / km ^{2}).
- The spatial analysis showed that the highlands descend gradually from the west to the east until it reaches Al Arid

District and then begin to rise to Al Nrges District then begin to decline again towards King Khalid International Airport to the east. It is a threat to the airport, which turned out to be the effluent of the basin number (3).

- Highlands descend from the middle area of Al Qairawan and Al Arid Districts and headed to the north and south which is the direction of the floods in the event of rain.
- Basin No. (1) Contains the largest residential area that reaches to 99.2 km² of the total basin area and the largest road network, reaching to 314.3 km, followed by basin number (2) Where the residential area is 25.57 km ² and the length of the road network 165.1 km. While the lowest residential area is in basin number (3) which reaches 4.8 km² and the road network length is 4.1km.
- Demonstrated by the study, that Al Malqa district has the highest wadi density that reaches 3.18 Km/km², followed by Al Nrges 2.52 Km/Km² and Al Qairawan of 2.46 Km/km².

Through the comparison across different time periods the study found that there is an urban growth in the north direction. When these districts expand more, the valleys will be mediated the construction which will form a danger during rainfall. Above all, the impact of the flood on the affected areas (Al Falah, Al Aqiq, Hattin and Al Maqa District) based on the vulnerability level (low, medium, high and extremely high) will be of vast because several vital places, projects and many shopping malls are located in that Districts.

Recommendations and further research:

- The basin number (1) should be given a special attention since it contains most neighborhoods and give it priority in the provision of sewerage services and drainage.
- Implementation of drainage pipes and manholes to drain flooding water in densely populated areas and warn people of the dangers of floods and places of danger, and guiding them to safe places.

- It is important to have coordination between Riyadh municipalities and real estate developers when developing new schemes that take in to consideration solutions to storm water drainage and flooding.
- Taking into account the amount of flash floods and its pathways when implementing projects such as roads, tunnels and bridges, preventing these constructions of forming barriers against flood water.
- Carry out detailed studies for the disposal of flooding water in the drainage basins and catchment area covering the following neighborhoods: (Al Arid, Al Qairawan, Yasmin, Al Sahafa, Al Rabee', Al Ghadeer, Al Aqiq, Al Malqa, Hattin), which characterized by urban growing fast and where there is a high density of wadis present.
- Using the study's methodology in the analysis and positioning the flooding dangers in other cities in Saudi Arabia in order to minimize the effects of flooding risks.

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استخدام نظم المعلومات الجغرافية والاستشعار عن بعد لتحديد المناطق المعرضة لخطر الفيضان: حالة دراسة في شمال الرياض

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الملخص العربي:

تتعرض العديد من المناطق في مدينة الرياض لهطول الأمطار الغزيرة، مما يؤدي أحيانا إلى ارتفاع في منسوب المياه على الطرق واضطراب حركة المرور كما حدث في عام ١٩٩٥م وعام ٢٠١٠م. ومن المعروف جيدا أن الفيضانات لا يمكن الوقاية منها أو تجنبها، إنما من الممكن الحد من المخاطر الناجمة عنها أو التي يتعرض لها السكان وذلك من خلال اتخاذ تدابير للحد من أثارها المدمرة. وبناء عليه فإن بناء قاعدة بيانات وإنتاج خرائط بعد تحليل وتحديد عناصر الخطر في المنطقة اللازمة لبناء شبكات الرصد ونظم الإنذار المبكر. وقد أجريت هذه الدراسة من أجل تحديد أحواض الصرف الصحي ومجاري المياه في المناطق التي تعرضت للفيضان وتم تحديد اتجاهات النمو الحضري في شمال الرياض. وأجري التحليل المكاني لهذه الأحواض باستخدام الاستشعار عن بعد (RS) ونظام المعلومات الجغرافية (GIS) وذلك من اجل إنتاج خرائط موضوعية. كما تم بناء قاعدة بيانات مكانية إضافة إلى تحليل الانحدار باستخدام النماذج الرقمية للارتفاعات (DEM).

كلمات البحث: الفيضانات، الاستشعار عن بعد، نظم المعلومات الجغرافية، التحليل المكاني، والخرائط الموضوعية.

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