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Use of Remote Sensing and GIS to Analyze Drainage System in Flood Occurrence, Jeddah - Western Saudi Coast

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1. Introduction

Lately, natural hazards have been increased and occupied the attention at the regional and the global levels. Flood is one among the most severe aspects of these hazards, and more than one million people are killed each year in the low-income countries due to flooding as estimated by International Disaster Database (EM-DAT: The OFDA/CRED, 2010).

The Kingdom of Saudi Arabia, the major territory of the Arabian Peninsula, is located along an active tectonic zone of the Red Sea Rift System, which makes it unstable region, with complicated geology and geomorphology. Therefore, its territory is known by several natural disasters that occurred in different regions of the country over the past history, but they almost concentrated in the western coast, between the Arabian Shield and Red Sea, where the area of study is situated. Several aspects of natural hazards have been witnessed in this area, mainly floods, earthquakes and dust storms. These hazards are usually considered by inhabitants since they have a direct impact on their lifestyle, while the other aspects, such as soil and rock erosion, drought are not.

However, it has been longtime, this region haven't witnessed any remarkable catastrophic event, until the late 2009 when torrential rainfall existed in the city of Jeddah and the surroundings, and followed by damaging floods. This city is located on the middle of the western Saudi Arabia coast, is considered as the economic and touristic capital of the country with an increasing population of about 3.4 million people. It is also the main crossing point for pilgrims from different countries around the world.

The statistical overview introduced by the International Disaster Database (EM-DAT: The OFDA/CRED, 2010), shows that the number of people killed in Saudi Arabia in different natural disasters was 299 over 25 years ago (between 1982 and 2005). This in turn reveals the magnitude of impact the occurred flood disaster in 2009. This shows the magnitude of impact of the last occurred flood disaster. One year later, in January 2011, another flood event has taken place and covered larger geographic region. It also resulted damages and several people were killed, lost or injured.

Studies in this regard were rare and some of them focused only on technical issues, thus it is still difficult to figure out a clear understanding for the reasons behind these events and the mechanism of disaster action. Accordingly, implements for mitigation and risk reduction could not be properly applied in the lack of comprehensive studies, notably in analyzing the behavior and characteristics of the existing drainage system.

The study aims to analyze the topological elements of drainage systems and to induce their geomorphologic and hydrologic characteristics. It shows the geo-spatial data acquired from satellite images and the application of GIS. Digital Elevation Models (DEM) was also diagnosed to assess valuable elements for drainage analysis.

The area for study was selected through the correspondence between the limits of the existing water basins and the environs that are vulnerable to frequent floods according to floods of 2009 and 2011 (Figure 1). Thus, the resulting area totals about 1947km^2 and it extends from the coastline to the adjacent mountain chains. It lies between the following geographical coordinates: 39°32′ and 39°06′ E & 21°56′ and 21°1′9N.

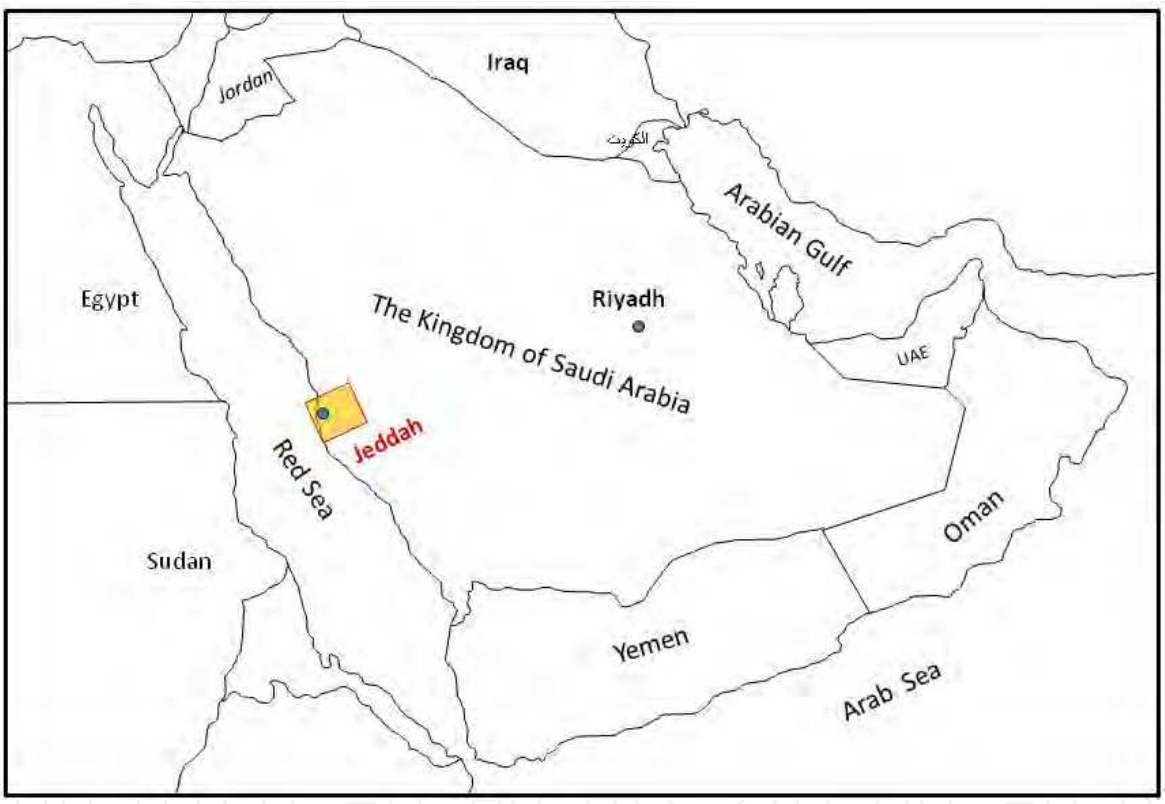

Fig. 1. Location maps of the Saudi Kingdom and Jeddah city.

2. Natural and anthropogenic characteristics

2.1 Drainage systems

Advanced techniques have been well demonstrated in illustrating streams and surface water basins. In this respect, DEM can be well utilized, and it can help inducing flow directions, and locating low-lands. However, erroneous results sometimes appear from DEM if the digital applications do not accurately obtain. Topographic maps are also used to delineate drainage systems. Therefore, streams are directly digitized in the GIS system, and thus catchment areas are extracted following geomorphologic and hydrological concepts.

In this study, topographic maps, of scale 1:50000 and contour interval 20m, were utilized and they were supported by the application of DEM in order to extract the related parameters for drainage systems, and they were directly digitized in the GIS system using *Arc-GIS 9.3* software. Consequently, streams were illustrated for each watershed and the watershed boundaries were identified. The area of study is about 1947km² (Figure 2 and Table 1).

Basin No.	**Basin**	**Area** (km²)	**Basin type**	**Basin No**	**Basin**	**Area** (km²)	**Basin type**
1	Ghouimer	319.7	Major	16	Selsli	13.7	Joining
2	Om El-Hableen	75.7	Major	17	Muwaieha	23.7	Minor
3	Basin # 3	6.5	Joining	18	Basin # 18	17.6	Joining
4	Daghbj	56.9	Major	19	Basin # 19	14.8	Minor
5	El Hatiel	59.6	Major	20	Basin # 20	21.6	Joining
6	Basin # 6	10.3	Joining	21	Abou Je'Alah	21.2	Minor
7	Basin # 7	25.8	Minor	22	Al A'ayah	14.7	Minor
8	El Assla	289.4	Major	23	Ed-Dowikhlah	17.1	Minor
9	Basin # 9	10.4	Joining	24	El-Baghdadi	29.6	Minor
10	Mreikh	46.7	Minor	25	Ketanah	34.7	Major
11	Kawes	70.1	Major	26	Basin # 26	13.0	Joining
12	Osheer	17.7	Minor	27	Esh-Shoabaa	40.5	Major
13	Basin # 13	12.5	Joining	28	Basin # 28	24.4	Joining
14	Methweb	54.2	Major	29	Da'af	37.9	Major
15	Ghlil	23.1	Minor				

Table 1. Watersheds in the area of study and their types.

Accordingly, the watersheds in the area of concern were divided into three types as follows:

1. Major basin: It encompasses principal hydrological characteristic, mainly funnel-like shape, where the difference between the numbers of branches is high in upstream and downstream areas, and it is characterized by uniform run-off. There are 10 major basins in the study area.
2. Minor basin: It is characterized by smaller areas than the major ones (usually less than 50km²), and it has almost a uniform run-off regime. They are 10 minor basins existing in the study area.
3. Joining basin: It is a geographic land extension between the major and minor basins. It is characterized by non-uniform run-off. There are 9 joining basins in the study area.

There are 29 watersheds in the area of study, 19 of them outlet towards Jeddah city at the coast, and totaling an area of about 1170 km², while the rest outlet into Wadi Fatima to the southern side of Jeddah city. The largest watersheds are Ghouimer (319.7km²) and El Assla (289.4 km²).

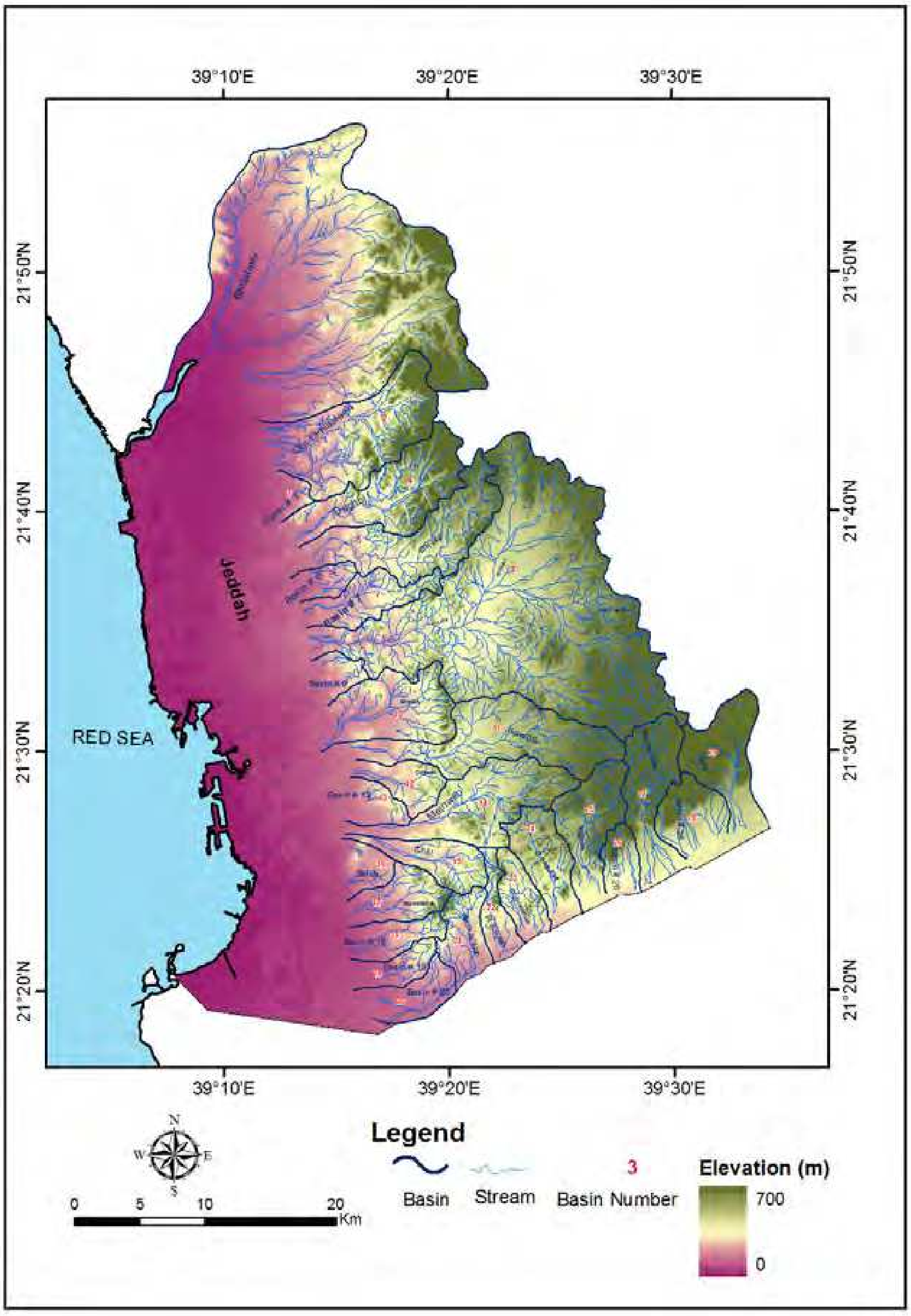

Fig. 2. Watersheds in the area of study.

2.2 Rainfall distribution

There is still undefined annual rainfall rate for Jeddah area. It was estimated at 350-400mm in the last few decades (Italconsult, 1967), while it has been recently estimated with less than 60mm, whereas, run-off is estimated between 5-6% according to Es-Saeed, et al. (2004). This decline in annual rainfall rate (i.e. about five times) is accompanied with a number of rainfall peaks, which is attributed mainly to the changing climatic conditions (IPCC, 2007).

Due to the lack of continuous and comprehensive climatic data, the remotely sensed data, which can be retrieved from satellite images, was used. Therefore, Tropical Rainfall Mapping Mission (TRMM) data was utilized in this study, and thus the geographic distribution, through maps, of rainfall in November 2009 and January 2011 were illustrated from TRMM data (Figure 3).

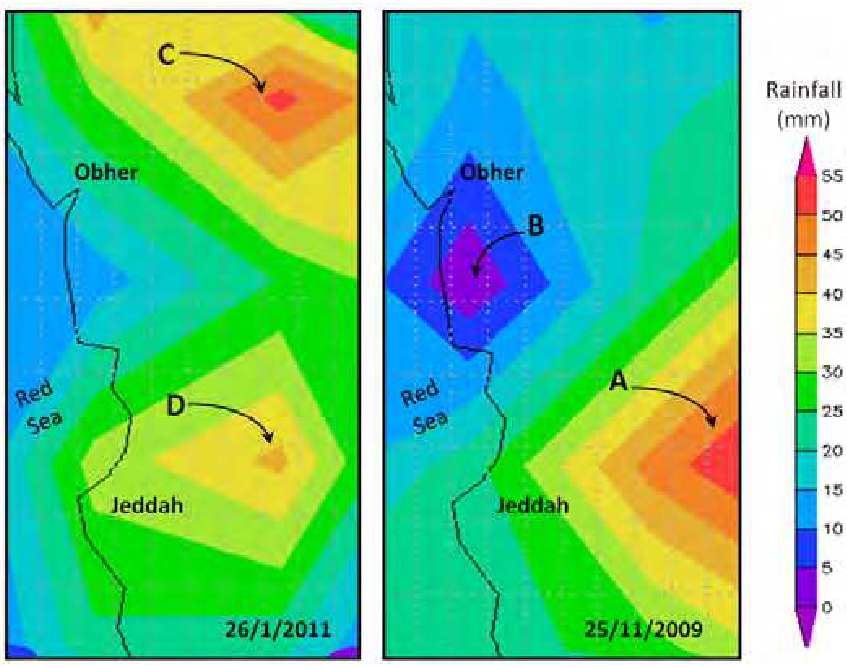

Fig. 3. Rainfall distribution in 2009 and 2011 according to TRMM data.

These maps could introduce essential tools to figure out the geographic distribution of rainfall in the two periods, which will be used consequently to compare it with the geographic distribution of damaged areas. Hence, it is clear that there is one dense cloudy domain in each event (2009 and 2011). These are A in 2009 and C in 2011, in addition to other less-dense ones. However, this was not very well realized previously. For the dense cloudy domain in 2009, it was estimated with a diameter of about 90km, whilst the other one of 2011, it was about 30km, and this reflects the degree of impact in the two periods. However the rainfall rate was estimated at about 95mm, and 120mm in 2009 and 2011; respectively; but this was attributed to a gauge point and not for the entire geographic distribution of rainfall.

2.3 Geomorphologic and geologic characteristics

Geomorphologic and geologic characteristics are of great importance in studying floods, since they govern the flow regime and many other related surficial processes (e.g.

infiltration rate, flow direction, water accumulation, etc). The area of study can be divided into three major zones according to their altitude and the existing rock bodies. These are:

1. Coastal area (10-20km width, 3m/km slope gradient).
2. Slopping lands (<5km width, 20m/km slope gradient).
3. Elevated areas (about 25km width, 6-7m/km slope gradient).

In addition, the study area includes large number of valleys, with diverse aspects. They are almost filled with sand and mixed sediments. These valleys are characterized by shallow depth (about 2-3m) and wide cross-section (500-700m), where the flood plains are often undefined or shallow enough to be identified.

According to the geology of the area, it is characterized by the interference of igneous and sedimentary rocks that interbedded in some instances with metamorphic rocks. Most of the exposed rocks are of the Precambrian age, whilst the coastal area is totally covered by sedimentary deposits, which are almost of looses. These rocks have tremendous deformation systems, including mainly fractures of different scale, joints and several folding aspects.

2.4 Urban expansion

The kingdom of Saudi Arabia occupies outstanding level in urban expansion, and this is well pronounced in Jeddah city where the population growth rate ranges between 20-28%, and thus the city is occupying now about 3.4 million people (3500 person/km^2). This is merely attributed to the number of foreign people attend during different periods for pilgrims and related religious tasks.

Lately, the geographic distribution of urban settlements has been extended towards the mountainous areas to the east. However, this distribution extends along the existing valleys from the elevated regions, which results obstacles in many valleys passageways. Accordingly, the interpretation of satellite images in combination with the analysis of old topographic maps show that urban expansion has been three times increased over 21 years (1975-1996), and thus it is followed by another increase of about 2.7 time in the last fifteen years (1996-2011), and this increase concentrates mainly along the eastern part of Jeddah city.

3. Materials and methods

There are many methods to study and assess floods and their controlling geomorphologic factors. They usually follow different approaches of analysis, and thus different results exist. This relies on the used tools; however, the utilization of new space techniques is utmost important in this respect, since they became of essential role for topological and drainage analysis. However, the use of such tools is still dependant on its availability. In addition, many studies focus on specific concept relates to floods and torrents, such as the analysis of hydrologic systems (Subyani, 2009), Digital Elevation Models (KACST, 2011), or the morphometric analysis for valleys (Yehia and El-Ater, 1997).

3.1 Used tools

3.1.1 Information and data

- Climate data from ground stations to induce the frequency of rainfall peaks by region.
- Climate data from space sources to cover the lack of ground data.

- General ground data (e.g. damaged areas, specifications of the channels, etc.).
- Supplementary information, including historical records of floods, urban expansion, etc

3.1.2 Maps

- Topographic maps of 1:50.000 scale, with contour interval 20 meters.
- Geological maps of 1:250.000 and 1:500.000 scale.

3.1.3 Satellite images

Satellite images of different optical and spectral specifications were used in this study. They have different characteristics, such as re-visit time, swath width, etc. there was a great concern to have these images in dates close to the disasters dates of disasters (Table 2).

Satellite	Spatial resolution	No. of bands	Acquiring date	Utility
Ikonos	1m	5	10/10/2009, 30/11/2009, 19/2/2010	Comparison before and after floods. Identification areas under flood damages (2009).
Worldview-1	0.5m	8	27/1/2011, 1/3/2011	Identification areas under flood damages (2011). Spatial data overlapping.
Worldview-2	0.5m	8	8/2/2011	
Quick Bird	0.5m	5	2/3/2011	High precision of comparative analysis for flooded areas.
Geo-eye 1	0.5m	5	2010	Establishing DEM
Aster	15m	14	2009	Identification of geological features.

Table 2. Used satellite images and their major specifications.

3.1.4 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) was analyzed in this study to induce empirical approaches for drainage analysis. This DEM data was supported by King Abdulaziz City for Science and Technology.

- Data for Digital Elevation Model (DEM), with 2 meters precision.
- Data for Digital Elevation Model (DEM), with 30 meters precision.

3.1.5 Software

- *ENVI-4.3* for satellite image processing, produced by *IBM*, Colorado, USA.
- *ERDAS Imagine 9.3* for satellite image processing, produced by *Leica*, Georgia, USA.
- *Arc-GIS 9.3* for GIS applications, produced by *ESRI*, Redlands, USA.

3.2 Methods of analysis

3.2.1 Images processing

Satellite images have become important tools of Earth observation since they can be used in several terrain applications and the processes occur. The science of remote sensing, in a broad sense, is represented by digital satellite images acquired in defined technical procedures. All selected digital satellite image data were primarily subjected to two principal stages: these are the: pre-processing and images processing procedures.

Pre-processing procedures are essential and diverse set of image preparation programs that act to offset problems. These processes are applied into the specialized software (e.g. *ERDAS Imagine, ENVI, etc.*) to increase the accuracy and interpretability of the digital data during the image processing phase. These commonly include: image sub-setting, atmospheric correction, geometric correction, image registration, geo-referencing and mosaicing.

Consequently, digital image processing can be applied to facilitate recognition of objects appear on terrain surface, and thus applying different analyses and measures required. For example, in *ERDAS Imagine* software, the most useful steps are: directional filtering, contrasting and sharpness. In addition, band combination is also applied, where single band and multi-band enhancement were carried out by interrelating each three bands as one set. These applications provided helped detecting color differentiation, pattern and tone, which would discriminate distinguished geomorphologic features. Moreover, thermal interpretation from thermal bands was applied. While *ENVI* software is also useful and can be friendly used for digital satellite images processing. The following digital applications were performed: Enhancement, Interactive stretching, Density slicing and coloring.

3.2.2 GIS applications

The capability of using GIS technology for earth surface based scientific investigation makes it more usable; especially for geographic applications when satellite images are not available. Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a computer-aided design and geo-referencing capabilities.

Arc GIS 9.3, which was used in this study, is a software program used to create, display and analyze geospatial data. It consists of three components: Arc Map, Arc Catalog and Arc Toolbox. Arc Map is used for visualizing spatial data, performing spatial analysis and creating maps to show the work results. While, Arc Catalog is used for browsing and exploring spatial data, as well as viewing a creating metadata and managing spatial data. Arc Toolbox is an interface for accessing the data conversion and analysis function the come from *Arc GIS*.

4. Data analysis and results

4.1 Three-dimensional models (DEM) production

Geographic information systems can be used also to build three-dimensional models for any geographical location on the surface of the Earth. The representation of terrain topography of any site needs data form three-dimensions (z, y, x), which is known as digital elevation model (DEM). Thus, the applications of DEM is well pronounced in several applications, and more certainly to induce many components, such as slope, sunlight exposure, drainage systems, low-lands, etc.

The concept behind establishing DEMs implies the treatment of elevation points whether from digital contour lines or from stereoscopic satellite images (e.g. SPOT images). Hence, triangulated irregulated network *(TIN)* must be primarily constructed, which represents digital data structure used in *GIS* of surface attributes of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (*X, Y* and *Z*) that are arranged in a network of non-overlapping triangles (Figure 4). *TIN*s are madefrom mass points, break-lines, and polygons. Mass points are height points; they become nodes in the network, thus they primary input into a *TIN* in order to determine the overall shape of the surface.

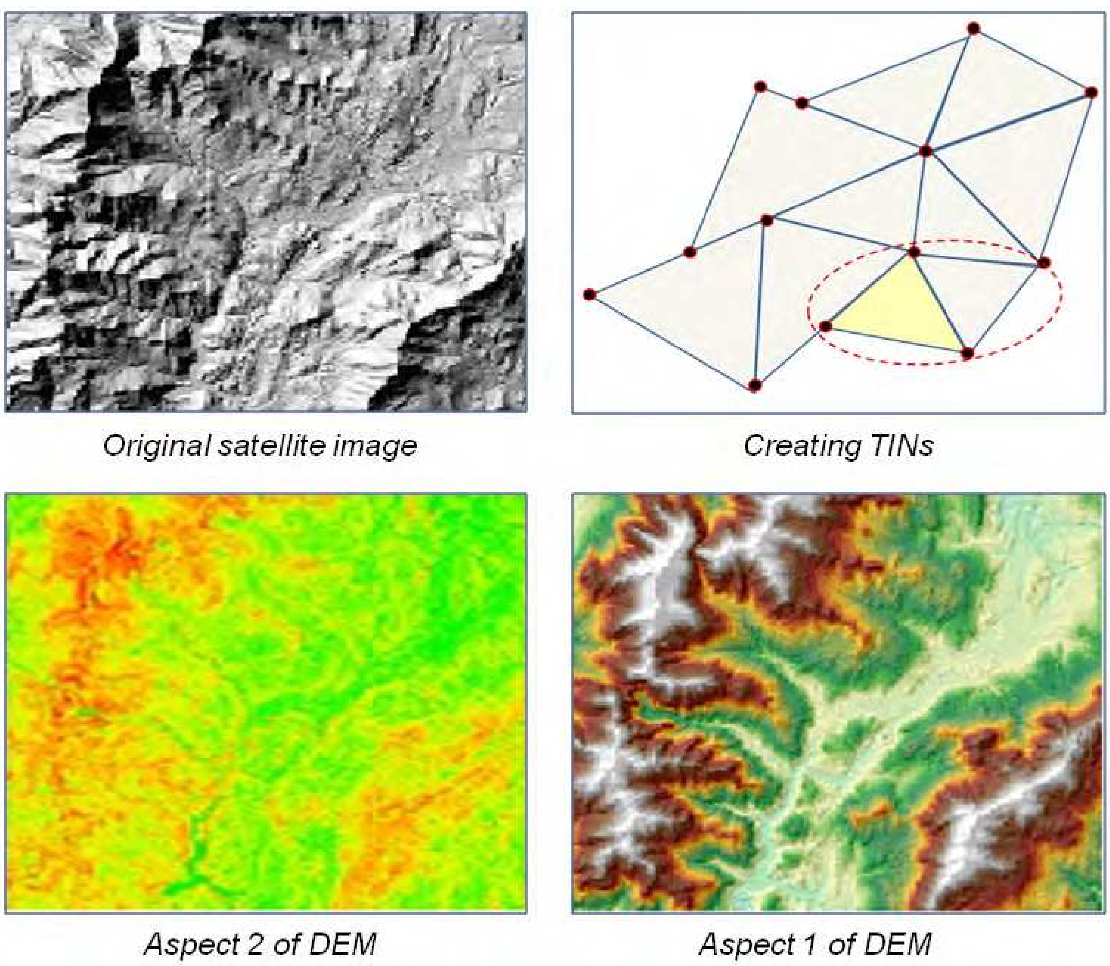

Fig. 4. Example showing the steps obtained to create DME aspects.

4.2 Analyzing digital elevation mode

Currently, the use of Digital Elevation Models (DEM) has found widespread applications in several geomorphologic and hydrological purposes; especially that this technique allows the extraction of topographic features of the earth surface making possible the display of all natural features for the both vertical and horizontal resolutions. However, DEM extraction requires elevation data for topographic features with geographic coordinates of each elevation. Therefore, topographic maps with contour lines are electronically digitized in specialized GIS software. In case these maps weren't available at a digital format, satellite images with stereoscopic characteristics can be used. In this study, Geo-eye-1 satellite images, with 2m precision were used.

In this study, after establishing the DEM, the resulting data was analyzed to recognize slope gradient, cross-sections, channel slopes and depressions. Hence, the three first factors interact together to form water flow network from drainage system thresholds to the valleys outlet.

4.2.1 Terrain slope

Terrain slope is considered as an important factor in identifying the flood regime. In this study, terrain slopes are considered rather than the valley slopes. Naturally flood risk increases with terrain slope gradient (angle of inclination with the horizontal) due to the increasing energy of run-off resulted from the surrounded surfaces to the adjacent valleys. It is viewed from the capacity of valleys receiving water bulk and bed loads from these surfaces, which may result flooding.

In order to evaluate these geometric variables from DEM, every surface must be taken independently (i.e. terrain surface in certain exposure), and since these variables will be used in studying the overland flow, it was necessary to analyze the variation required for every water basin separately in the area of study. Since water basins consist of a set of surfaces expanding toward valleys; however, it can be dividing each basin into zones with a specified surfaces slopes and defined area for each surface. It makes it possible to evaluate the total slope effectiveness in every basin in the study area. This can be done by creating DEM in GIS; and more specifically in Arc-GIS software (example in Figure 5).

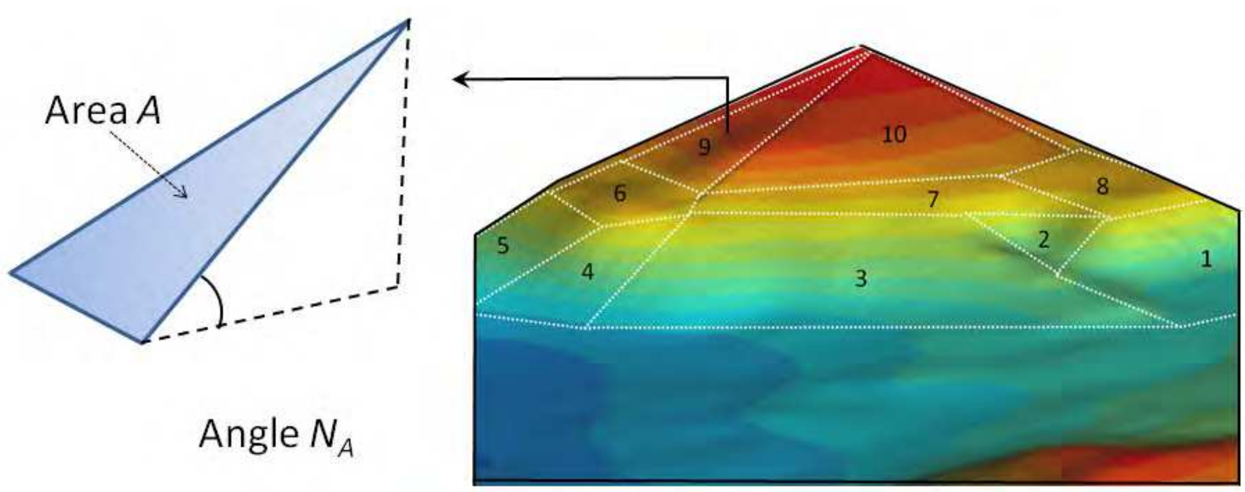

Fig. 5. Classifying terrain surfaces according their slopes for each surface.

Nevertheless, slope gradient of the surface is taken from a linear approach where it is described as the length slope (Ls) according to several studies (Khosrowpanah, et al., 2007), and the total surface of the area is not considered.

In order to evaluate the effectiveness of the total slope in the surface water flow energy, the area (basin) must be divided into a number of surfaces, where each surface is characterized by a defined slope angle (level of inclination) (N_a). Therefore, the areas of these surfaces (A) with their angles will be calculated.

Thus, the exponential interaction of to surface inclination with its area (multiplication calculation), can induce the effectiveness (St) of water volume loaded towards valleys. It can be calculated to every surface then the sum can be calculated by dividing the resulted values on the number of surfaces (Ns) as follows:

$$St = \frac{(A_1 \times N_{a1}) + (A_2 \times N_{a2}) + (A_3 \times N_{a3}) + \ldots}{N_s}$$

In this study, the surface slope angles were classified into nine intervals ranging between 0º-10º for the very low slope effectiveness to 80º -90º for the very high slope effectiveness. Thus, slope effectiveness values were calculated for the 29 basins exist in the area of study (Table 3).

Basin No.	**Basin name**	**(N_a)**	**(A)** Km²	**Average slope effectiveness** (º)	**Total effectiveness** (St)
1	Ghouimer	23	12.5	°8	Medium
2	Om El-Hableen	16	0.84	10°	Medium
3	Basin # 3	2	0.48	3°	Low
4	Daghbj	20	1.02	15°	High
5	El Hatiel	17	0.96	11°	High
6	Basin # 6	3	0.65	4°	Low
7	Basin # 7	5	2.74	12°	High
8	El Assla	32	5.72	7°	Medium
9	Basin # 9	3	1.43	4°	Low
10	Mreikh	9	1.88	7°	Medium
11	Kawes	18	2.12	9°	Medium
12	Osheer	5	0.98	5°	Low
13	Basin # 13	2	1.97	4°	Low
14	Methweb	13	2.05	11°	High
15	Ghlil	7	0.78	4°	Low
16	Selsli	2	0.27	1°	Low
17	Muwaieha	5	1.57	8°	Medium
18	Basin # 18	4	1.18	6°	Medium
19	Basin # 19	3	0.87	2°	Low
20	Basin # 20	1	0.58	1°	Low
21	Abou Je'Alah	5	1.08	9°	Medium
22	Al A'ayah	4	1.49	7°	Medium
23	Ed-Dowikhlah	8	0.97	5°	Low
24	El-Baghdadi	17	1.07	12°	High
25	Ketanah	19	1.24	14°	High
26	Basin # 26	7	0.58	15°	High
27	Esh-Shoabaa	19	1.22	17°	High
28	Basin # 28	9	1.13	13°	High
29	Da'af	14	1.76	15°	High

Table 3. Slope effectiveness in water basins after calculating values from DEM.

4.2.2 Cross sections

Cross sections of valleys are commonly used in many geomorphologic and hydrologic studies that rely on evaluating tributaries and the mechanism of run-off of water and the bed load, whether for run-off rate or erosion and sedimentation. It is well known that the characteristics of cross-section of tributaries separately have no impact on the hydrological system for flood assessment, but it needs an interaction with other hydrological and geomorphologic characteristics.

Cross section variables to any water course comprise the width, depth and the length of the primary stream, but in the case of wide flood plain, with shallow depth (as in the study area); however, width and depth of these plains will be included too. In the case of wide and shallow flood plains, run-off water can easily overflow into these plains when water level increases in the primary watercourse even with a small amount because the difference in depth, of the primary watercourse and flood plains, is relatively negligible (Figure 6).

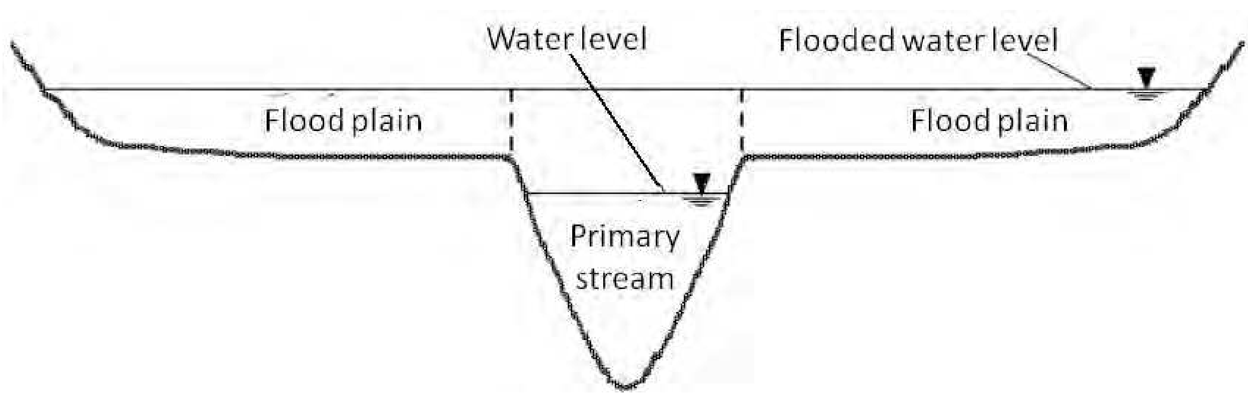

Fig. 6. Schematic cross-section showing major dimensions of a valley.

Normally, the width and depth of water channel are not constant, and they vary with valley length. Therefore, in calculating the capacity of each channel, it must be divided into different channel segments each with specific depth, width and length. Where the length is determined according to channel diversions (i.e. a section is attributed to each stream segment with specific direction). When the three geometric variables (length, width and depth) are determined, with those variables of the flood plain, thus the total section area of each segment can be calculated and the sum of the resulted values will extend the total cross-section area of the valley (Xt). It can be calculated as follows:

$$X_t = \frac{\{\left[(W_{m1} x\, D_{m1}) + (W_{f1} x\, D_{f1}) \right] x\, L_1\} + \{\left[(W_{m2} x\, D_{m2}) + (W_{f2} x\, D_{f2}) \right] x\, L_2\} + \ldots}{N_{sg}}$$

Where:

- W_{m1} is the width of the main valley, No. 1.
- D_{m1} is the depth of the main valley, No. 1,
- W_{f1} is the width of flood plains No.1,
- D_{f1} is the depth of flood plain No.1,

- L_1 is the segment length,
- N_{sg} is the number of segments.

It is possible to calculate geometric variables using DEM if it is characterized with high resolution that fits with the width and depth of cross-sections. The analysis is done by dividing the sections into different segments. Thus, Arc-GIS software is used to calculate the variables to each segment (Table 4).

Basin No.	**Basin name**	**No. of Channels**	(Xt) Km^2	(St)
1	Ghouimer	4	0.126	Medium
2	Om El-Hableen	2	0.215	High
3	Basin # 3	1	0.095	Low
4	Daghbj	2	0.128	Medium
5	El Hatiel	2	0.075	Low
6	Basin # 6	1	0.102	Medium
7	Basin # 7	1	0.087	Low
8	El Assla	8	0.121	Medium
9	Basin # 9	1	0.230	High
10	Mreikh	1	0.183	High
11	Kawes	4	0.182	High
12	Osheer	1	0.105	Medium
13	Basin # 13	1	0.021	Low
14	Methweb	1	0.099	Low
15	Ghlil	1	0.258	High
16	Selsli	1	0.177	High
17	Muwaieha	1	0.183	Low
18	Basin # 18	1	0.172	High
19	Basin # 19	1	0.114	Medium
20	Basin # 20	1	0.247	High
21	Abou Je'Alah	1	0.084	Low
22	Al A'ayah	1	0.097	Low
23	Ed-Dowikhlah	1	0.073	Low
24	El-Baghdadi	1	0.035	Low
25	Ketanah	1	0.045	Low
26	Basin # 26	1	0.046	Low
27	Esh-Shoabaa	1	0.076	Low
28	Basin # 28	1	0.104	Medium
29	Da'af	1	0.062	Low

Table 4. Cross-section areas of primary valleys as calculated from DEM.

4.2.3 Channel slope

In addition to terrain surface slope that adjacent to valleys; yet the slope gradient (degree of inclination) of the valley channel itself is an important geometric element that must be considered in assessing floods and torrents. Hence, flow rate increases with the degree of inclination of the valley channel. In this respect, flow rate plays a major role in accelerating the process of channel discharge, which is also accompanied with high rate erosion process. Whilst, slow flow rate decreases the discharge rate and consequently influences flood occurrence.

The channel slope can be calculated using the following simplified equation:

$$\frac{L \ = \ \text{Lenghth of the channel}}{\Delta h = \ \text{Difference in elevation}}$$

However it is obvious that stream channels are characterized by different elevations along each valley, and they are not similar. For this reason, sometime it is referred to the following equation introduced by Morisawa (1976).

$$= (E\ 0.85\ L) - (E\ 0.10L) /\ E\ 0.75L$$

Where:

E is the elevation,
L is a lenght point along the channel,

As for example, (E 0.85 L) means the elevation at 85% distance from the upstream.

The availability of DEM easily enables calculating the channel slope with considerable precision, where the slope gradient is calculated on several defined parts along the valley with more accuracy then using the mathematical equation mentioned above.

Accordingly, in this study, this method was followed and the results are as shown in Table 5. Results show the channel slopes of primary valleys. Thus, having the three main variables (terrain slope, cross sections and their slopes) enables assessing the flow capacity of these valleys, which together influence flood occurrence. Therefore, it is obvious that there are basins more prone to floods and torrents (such as Om El-Hableen and Daghbj basins) than other basins in the area (such as basins no. 1 and 6).

4.2.4 Depressions

Depressions are considered as one the most important terrain features in floods and torrents occurrence. They play a double role in surface water flow and surface water storage, since depressions are naturally retarding water flow and store almost capture water within the terrain surface. As well as, depressions may accumulate water directly from rainfall. Therefore, they are considered as flooded areas, but with least damage.

Hence, identifying depressions directly from satellite images in dry seasons is not an easy task, unless they filled with water for better observations. However, DEM can help identifying depression in any condition, since it relies on elevation differentiation (e.g. 2 meters accuracy). Therefore, depressions characterize terrain surface and enable to cartography the water accumulation from torrential rainfall.

In this study, a new concept was followed in using DEM manipulation to localize depressions.. This concept relies on creating reference lines to the earth surface at defined

Basin No.	Basin name	Number of terrain surfaces	Channels No.	General slope Average	(St)
1	Ghouimer	23	4	16	Medium
2	Om El-Hableen	16	2	18	Medium
3	Basin # 3	2	1	23	High
4	Daghbj	20	2	28	High
5	El Hatiel	17	2	19	Medium
6	Basin # 6	3	1	7	Low
7	Basin # 7	5	1	13	Medium
8	El Assla	32	8	16	Medium
9	Basin # 9	3	1	6	Low
10	Mreikh	9	1	13	Medium
11	Kawes	18	4	19	Medium
12	Osheer	5	1	11	Medium
13	Basin # 13	2	1	8	Low
14	Methweb	13	1	16	Medium
15	Ghlil	7	1	14	Medium
16	Selsli	2	1	4	Low
17	Muwaieha	5	1	7	Low
18	Basin # 18	4	1	10	Low
19	Basin # 19	3	1	9	Low
20	Basin # 20	1	1	6	Low
21	Abou Je'Alah	5	1	17	Medium
22	Al A’ayah	4	1	19	Medium
23	Ed-Dowikhlah	8	1	18	Medium
24	El-Baghdadi	17	1	27	High
25	Ketanah	19	1	34	High
26	Basin # 26	7	1	33	High
27	Esh-Shoabaa	19	1	36	High
28	Basin # 28	9	1	18	Medium
29	Da’af	14	1	29	High

Table 5. Valleys’ slope and their water-bearing capacity.

elevations according to the terrain characteristics. Hence, any elevation below will be considered as a zone with depression.

Table 6 shows the total area of depression among each water basin. But it must be taken into account that these depressions are not only natural ones, since a large part of the study area is occupied by low-lands that collect water due to excavation and construction (planned zones, roadsides, etc.). In this respect, the integration of satellite images taken after the occurrence of torrential rainfall in the 25th of November 2009 and the 26th of January 2011, with DEM can help in identifying natural depressions from man-made ones.

Basin No.	Basin name	Total depressions area (km^2)	Basin No.	Basin name	Total depressions area (km^2)
1	Ghouimer	6.52	16	Selsli	0.35
2	Om El-Hableen	2.13	17	Muwaieha	1.81
3	Basin # 3	0.35	18	Basin # 18	0.73
4	Daghbj	1.86	19	Basin # 19	0.53
5	El Hatiel	2.14	20	Basin # 20	1.04
6	Basin # 6	0.12	21	Abou Je'Alah	1.54
7	Basin # 7	1.05	22	Al A'ayah	0.88
8	El Assla	11.24	23	Ed-Dowikhlah	1.17
9	Basin # 9	0.83	24	El-Baghdadi	0.46
10	Mreikh	2.19	25	Ketanah	0.37
11	Kawes	2.88	26	Basin # 26	0.24
12	Osheer	1.22	27	Esh-Shoabaa	0.87
13	Basin # 13	0.24	28	Basin # 28	1.43
14	Methweb	3.05	29	Da'af	0.34
15	Ghlil	1.34			

Table 6. Areas of depressions in different watersheds.

4.3 Geometric analysis of watersheds

Geometric shaping of water basins is considered as a one of the key factors that control the mechanism of geographic distribution of water on the surface of the earth. In this study, geometric standards are considered for water basin perimeter without taking into account morphometric standards located within this basin. Thus, the shape of the water basin, as well as the elongation rate and rotation rate are the most important standards.

4.3.1 Shape

There are several patterns that characterize the outer shape of water basin, each of them play a role in run-off from the upstream to downstream. The basins shape control the branching process of tributaries and thus the flow regime (Black, 1991). For example, basinswith circular shape has regular water discharge from all available tributaries and consequently water can reach the outlet at the same time. But this is not the case in basin with oval-like shape basins where there are differences in the discharge process according to the timing and therefore is considered as less prone to floods. There are several characteristics for specifying the shape of water basins, and the most important are as follow:

4.3.1.1 Length/Width ration

The ratio between the basin length and width (LW) is an indicator of surface flow effectiveness, and consequently an increase in the ratio of the width compared to the length make longer the flow duration and vice versa. Where the average value of this ratio in regular basins is 0.5, which means that the basin length is equal to the twice of its width. This is defined by the following simplified equation:

$$\text{Length / Width ratio} = \frac{\text{L = length of the basin}}{\text{W = Width of the basin}}$$

4.3.1.2 Shape factor (S_f)

The controlling factor in shaping water basin is determined according to the central length (L_{ca}), which is the length of the main channel (Figure 7). It largely represents the basin orientation, and has an integral role in the flow mechanism from different tributaries to the major outlet. It also contributes to infiltration rate and time duration of run-ff to be joined from different existing branches with different dimensions. Thus, the following equation is used to elaborate this factor.

$$S_f = (LL_{ca})^{0.3}$$

Where L is the maximum length of water basin
L_{ca} is the distance from the center of the basin circle to the outlet.

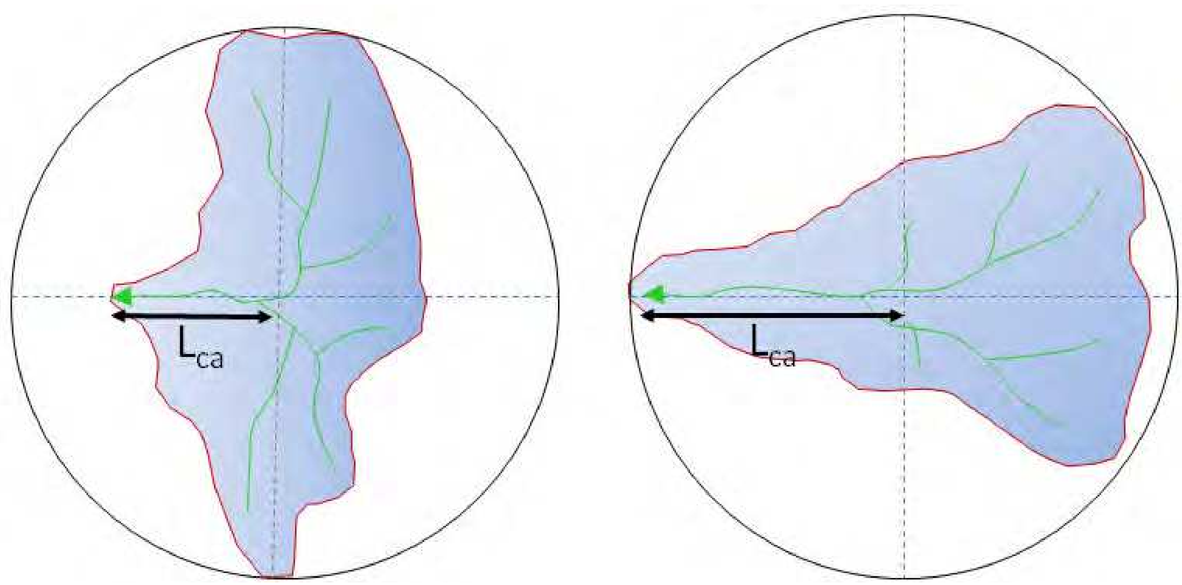

Fig. 7. Representation showing the shape factor in surface water flow regime.

4.3.1.3 Width/outlet width ration

Width/outlet width ration is the ration between the basin width to the outlet width. If the basin width from the upstream is bigger enough than the outlet width, flood occurrence is more probable (Al Saud, 2010a a, b), as shown in Figure 8. This can be attributed to the inadequate drainage capacity of water derived from upstream; and therefore made impossible the regular drainage mechanism through the outlet.

The width/outlet width ration is almost consistent with the characteristics that can be extracted from the DEM, as mentioned previously. However, in this case we treat the basin outer limits and not with the terrain features inside. It can be simply represented as:

$$\frac{W_b = \text{Basin width}}{W_d = \text{Outlet width}}$$

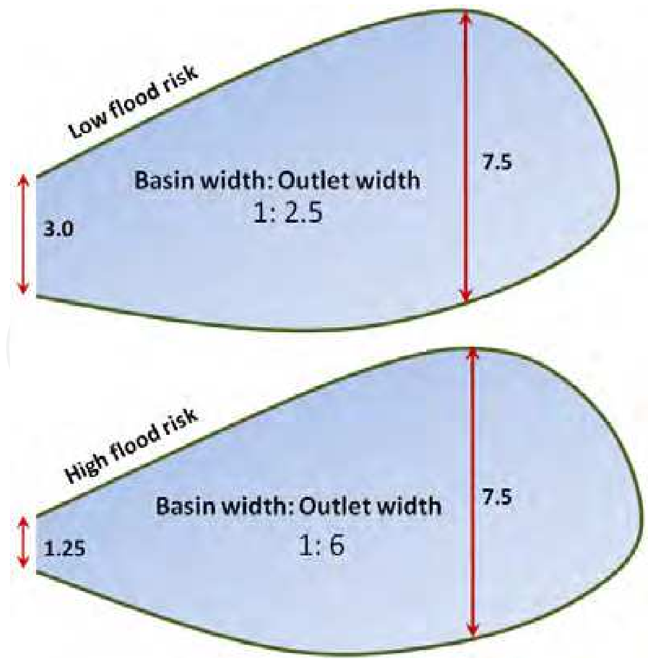

Fig. 8. Representative figure showing the widths of upstream and out let.

4.3.1.4 Elongation ration

It also essential to characterize the basin elongation, or one-direction stretching, according to its area. It equals 1 for the intake circle, whilst, it is zero for the straight line. According to Schumm (1956), the elongation ration equals:

$$R_e = 2/L_m\,(A/\pi)^{0.5}$$

where L_m is the basin length parallel to the primary watercourse, and A is the basin area, as shown in Figure 9. Therefore elongation ration governs the flow regime at the outlet.

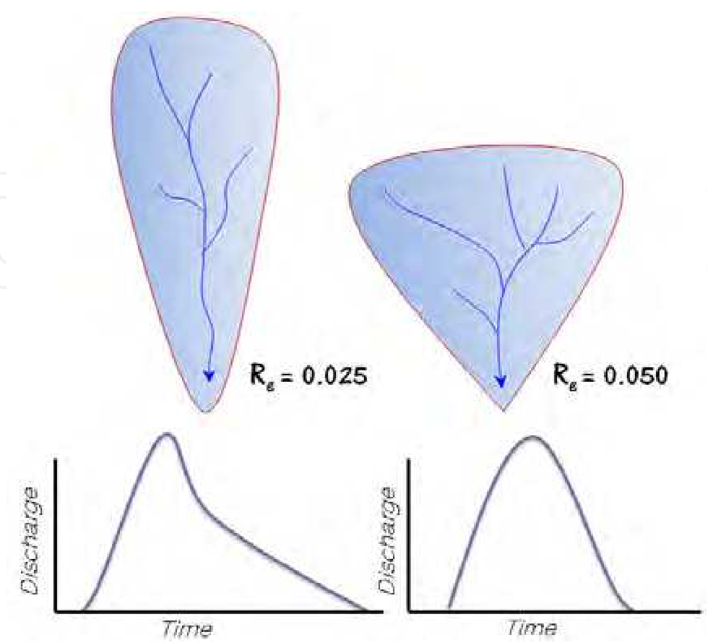

Fig. 9. Representation for two basins with different elongation ratio.

4.3.1.5 Circularity ration

Circularity ration (Rc) represents the uniformity between the external perimeter of the water basin comparing to its circular form (Miller, 1953).

$$Rc= A/A0$$

Where A_0 is the perimeter of the circle, A area of the basin

The analysis of principal geometric characteristics was applied on the main water basins in the area of study with the exception to none completed basins (joining basins) as shown in Table 7. It is shown some basins are characterized by normal effectiveness with respect to this type of natural disasters.

Basin No.	**Basin name**	**Length/width ratio** (Lw)	**Shape factor** (S_f)	**Width/outlet width** (W_b/W_d)	**Elongation ration** (R_e)	**Circularity ration** (Rc)
1	Ghouimer	1:0.87	5.83	1:2.5	0.82	3.30
2	Om El-Hableen	1:2	3.88	1:1.8	0.68	1.39
4	Daghbj	1:3	4.42	1:2	0.51	1.03
5	El Hatiel	1:4.3	4.72	1:3	0.44	0.96
7	Basin # 7	1:3	3.22	1:2	0.53	0.60
8	El Assla	1:1.2	6.77	1:8.5	0.58	2.36
10	Mreikh	1:1.75	3.64	1:1.3	0.78	1.08
11	Kawes	1:3.8	5.99	1:2.57	0.38	0.85
12	Osheer	1:1.6	2.81	1:3	0.58	0.62
14	Methweb	1:2.2	5.26	1:5	0.43	0.82
15	Ghlil	1:2.15	3.45	1:2.3	0.47	0.57
17	Muwaieha	1:1.55	3.05	1:1.6	0.63	0.72
21	Abou Je'Alah	1:1.5	2.57	1:1.7	0.91	0.80
22	Al A'ayah	1:2	3.25	1:1	0.45	0.48
23	Ed-Dowikhlah	1:1.6	2.92	1:1.55	0.61	0.58
24	El-Baghdadi	1:2.2	3.34	1:1.4	0.59	0.91
25	Ketanah	1:1.7	3.78	1:2.3	0.56	0.80
27	Esh-Shoabaa	1:2.5	4.16	1:1.5	0.49	0.80
29	Da'af	1:1.75	3.58	1:1.45	0.62	0.93

Table 7. Shape characteristics in water basins as shown from DEM.

4.4 Morphometric analysis of drainage systems

4.4.1 Drainage density

Water channels take several geometric patterns, and compose a collection of natural networks. However, the most important in drainage distributions is the density of tributaries among the basin. For example, we can find areas with high drainage density faced with areas with a lower density. This is primarily due factors related to the terrain characteristics. Also, drainage density can be calculated using the following equation:

$$\frac{\sum L}{A} = \frac{\text{Total length of tributaries in a particular area}}{\text{Surface of the area}}$$

Table 8 shows the resulting values of drainage density in each basin.

Basin No.	Basin name	Density (Km/Km²)	Basin No.	Basin name	Density (Km/Km²)
1	Ghouimer	0.98	16	Selsli	0.53
2	Om El-Hableen	1.12	17	Muwaieha	1.02
3	Basin # 3	0.28	18	Basin # 18	1.13
4	Daghbj	0.96	19	Basin # 19	0.97
5	El Hatiel	1.36	20	Basin # 20	1.20
6	Basin # 6	041	21	Abou Je'Alah	1.53
7	Basin # 7	1.15	22	Al A'ayah	1.27
8	El Assla	1.77	23	Ed-Dowikhlah	1.24
9	Basin # 9	0.61	24	El-Baghdadi	1.14
10	Mreikh	1.76	25	Ketanah	1.25
11	Kawes	1.37	26	Basin # 26	1.23
12	Osheer	0.54	27	Esh-Shoabaa	2.20
13	Basin # 13	0.35	28	Basin # 28	1.15
14	Methweb	1.33	29	Da'af	0.95
15	Ghlil	0.85			

Table 8. Drainage density in the water basins.

4.4.2 Stream order

Usually, the biggest fraction of the surface runoff occur in the channel and its different tributaries to form a water network starting from reaches from the highest elevations to reach at the end the outlet. From this point, the relation between different stream orders is seen. Small streams that starts from the top of the mountains and that are connected from one side are given the 1st order appellation. The 2nd stream order is created by the junction of two or more 1st –order streams, and so on.

Hence the process of identifying different stream orders is not the purpose of this study, but it is a kind of tools that help us in analyzing the relation between the number of these streams and more certainly the bifurcation ratio which is calculated from the following equation:

$$B_r = N_r/N_{r+1}$$

Where "N_r "is the number of streams for the order "r", and "N_{r+1}" is the number of streams for a higher order.

In this study, the Arc-GIS 9.3 software was used to classify streams in their specific orders (Figure 10), followed by calculating the morphometric variables needed where all streams and their tributaries are numbered, making the calculations easier (Table 9).

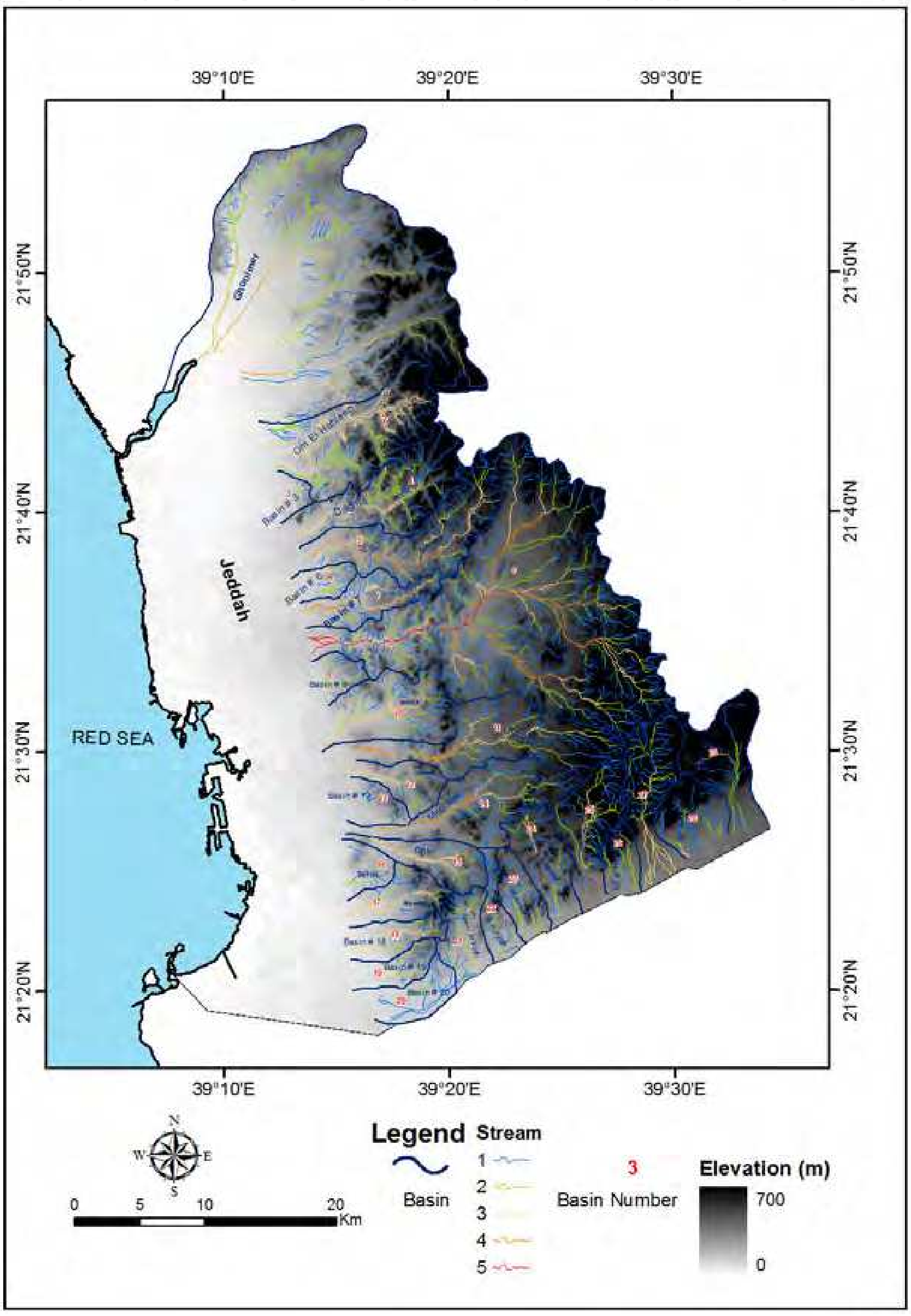

Fig. 10. Stream orders in the basins of the area of study.

Basin No.	Basin name	Number of stream orders					Total length (km)	Bifurcation ratio (B_r)
		1	2	3	4	5		
1	Ghouimer	107	68	15	8	-	342.7	2.64
2	Om El-Hableen	45	24	26	-	-	148.9	1.39
4	Daghbj	37	24	14	-	-	101.7	1.62
5	El Hatiel	73	24	16	8	-	117.5	2.18
6	Basin # 6	14	5	3	-	-	16.2	2.23
7	Basin # 7	30	10	7	3	-	51.9	2.25
8	El Assla	351	135	54	38	14	589.4	2.30
9	Basin # 9	7	7	-	-	-	12.8	1.00
10	Mreikh	31	23	14	2	-	74.9	3.33
11	Kawes	52	24	12	7	-	117.3	1.96
12	Osheer	7	7	5	-	-	20.2	1.20
14	Methweb	56	16	6	7	-	87.3	2.34
15	Ghlil	17	3	7	-	-	37.8	2.41
17	Muwaieha	17	9	13	1	-	37.9	5.19
21	Abou Je'Alah	30	11	5	-	-	45.8	2.46
22	Al A'ayah	13	6	-	-	-	25.6	2.16
23	Ed-Dowikhlah	18	10	-	-	-	29.6	1.80
24	El-Baghdadi	31	14	5	-	-	41.4	2.50
25	Ketanah	48	26	8	2	-	74.7	3.03
27	Esh-Shoabaa	55	20	25	-	-	88.1	1.77
29	Da'af	18	12	-	-	-	41.3	1.50

Table 9. Major variable for stream orders in the area basins.

4.4.3 Meandering ration

A stream channel takes many meandering aspects along the channel length, where several flow characteristics occur on each meander. This depends on many geomorphologic and hydrological characteristics such as slope gradient, rock types, geological formations and many others. And it is found that the meandering ratio play a role in water floods, since the increase in the meandering ratio decrease the flow energy and increase the stream load capacity due to erosion mechanism on the meandering sites. The meandering ratio is calculated according to the following equation, and the results are shown in Table 10.

$$\frac{\text{Primary stream length }(\text{curved}) = L_{\text{m}}}{\text{Primary stream }(\text{straight}) = L_s}$$

Basin No.	**Basin name**	**Meandering ratio** (M_r)	**Intersection Ratio** (I_r) Km²
1	Ghouimer	1.05	3.2
2	Om El-Hableen	1.35	6.3
3	Basin # 3	1.18	70
4	Daghbj	1.31	6.1
5	El Hatiel	1.02	5.5
6	Basin # 6	1.01	0.8
7	Basin # 7	1.04	1.2
8	El Assla	1.27	7.6
9	Basin # 9	1.10	2.4
10	Mreikh	1.23	2.6
11	Kawes	1.28	3.1
12	Osheer	1.19	0.53
13	Basin # 13	1.03	0.26
14	Methweb	1.17	3.4
15	Ghlil	1.14	1.9
16	Selsli	1.01	0.34
17	Muwaieha	1.12	2.4
18	Basin 18	1.12	1.61
19	Basin 19	1.05	1.15
20	Basin 20	1.12	1.04
21	Abou Je'Alah	1.19	4.6
22	Al A'ayah	1.17	2.04
23	Ed-Dowikhlah	1.20	1.92
24	El-Baghdadi	1.14	1.80
25	Ketanah	1.23	3.61
26	Basin # 26	1.12	2.03
27	Esh-Shoabaa	1.27	5.8
28	Basin # 28	1.17	1.17
29	Da'af	1.20	2.11

Table 10. Meandering and intersection ratio for the basins in the study area.

4.4.4 Intersection ration

Usually in studying morphometric characteristics of drainage systems, many formulas and concepts interfere from analysis. However, some characteristics are found with a great importance but less concern. Among these characteristics, is the intersection ratio that can be obtained through identifying the intersection nodes (i.e. confluences and diversions) of different channels and branches (Al Saud, 2009).

The number of intersection nodes reflects higher drainage density and thus uniform flow. They are usually measured as the number of nodes within a specified area. Results of insertion ratio are plotted in Table 10.

5. Conclusion and discussion

Flood, as a hydrologic process with catastrophic impact, is mainly governed by the geomorphologic characteristics of the terrain where it exists. Therefore, it is a common criterion to assess the terrain behavior and its respond to receive rainfall water and how it drains water. In this concern, all required geomorphologic elements must be primarily considered, taking into account the entire drainage system, including the catchment area and the existing streams characteristics among the catchment. However, in the lack of adequate data and information on the drainage system for any area, often alternative tools for analysis are used, and more certainly the remotely sensed (i, e. many satellite images) and GIS tools have become of great role in this respect. In this study, these advance tools were utilized using specified software types for data manipulation and analysis, plus a series of satellite images and thematic maps that can fulfill the subject matter.

Accordingly, three major parameters were analyzed and then they were correlated to their response to water flow regime and thus floods. This was applied to Jeddah city, which has witnessed to severe flood events, and the hydrologic and geomorphologic measures are still unclear. These parameters include: the geometric analysis for digital elevation models (DEM), geometry of basins and drainage morphometry of streams. This will enable assessment the vulnerability of the basins in the study area to floods, as well as these parameter can be well utilized in applying flood control management approaches.

Based on the analyzed geometric measures; however, there are a number of basins exist with relatively large values, such as Ghouimer with respect to the shape factor, elongation and circularity ratio. Also Al-Assla basin has an obvious respond to flood due to its width/length ration, which reaches 8.5:1. However, there are a number of basins with less responding to floods such as Abou Je'Alah basin.

The morphometry of streams among these basins is also of utmost importance in controlling the flooding process. This is well pronounced on the sites where streams are connected, notably those streams with thick sediment sequences, as those exist in several valleys in the study area. Moreover, the area of concern was found to be characterized by dense drainage systems unlike the rest coastal zones in the western Saudi Arabia, which in turn reflects a unique surface water flow among channels due to the large number of connected streams.

In addition, the expansion of urban settlements within the valleys courses interrupts the majority of the analyzed parameters. Thus, several basins are being closed at their outlets due to the existing human settlements. As well as these settlements, with the tremendous excavation processes and engineering particles motivated the release of sediments, which in turn move easily with water and thus increase the bed load of the flooded water.

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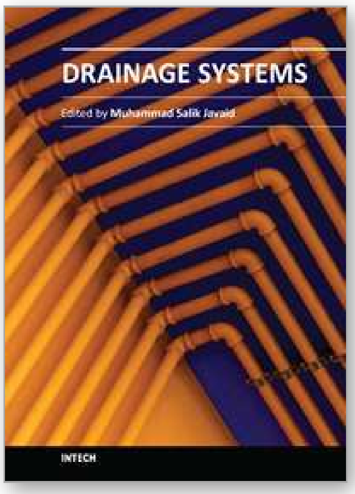

Drainage Systems

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