

Chapter 2

Methodology and Tools of Analysis

Abstract Several methods are used for flood risk assessment. These differ between regions and even between investigators depending on the tools that are available for data analysis. Recently, remotely sensed data have become a useful source of information with regard to terrain characteristics and water flow regime. The use of different spatial and temporal resolution satellite images and digital elevation models (DEMs) is essential for data manipulation in the GIS system, with a special emphasis on flood risk assessment and mapping of the flood-prone area.

2.1 Methodology

Several methodologies are applied to the study and assessment of floods and torrents, which usually produce diverse results according to the procedures of analysis that are applied to identify areas at risk from natural hazards. However, new advanced techniques have a major role to play in this respect, since these techniques have become a useful tool for monitoring and identification purposes, as well as for damage assessment.

Some established procedures are applied directly in the field (i.e. *in-situ* measurement) and others observe the surface of the terrain from space. The use of new techniques is mainly dependent on their availability as investigative tools. Due to the fact that flood water follows spatial distribution on the terrain surface, maps and satellite images are useful tools for analysis.

In order to achieve an optimal study with creditable results, it is first necessary to identify the major objective of the study. This is because the study of floods and torrents may have different purposes in different regions; consequently, tools and procedures may differ also. In addition, some studies focus on only one theme related to floods, such as analyzing the geomorphologic aspects (Subyani 2009); or establishing digital models (KACST 2011), or drainage morphometric analysis (Yehia and El-Ater 1997), while other studies treat all concepts related to the flood process (Al Saud 2010).

Table 2.1 Used satellite images in this study and their major specifications

Satellite	Spatial resolution (m)	No. of bands	Acquiring date	Utility
<i>Ikonos</i>	1	5	10/10/2009, 30/11/2009, 19/2/2010	Comparison before and after floods Identifying damaged areas by flood (2009)
<i>Worldview-1</i>	0.5	8	27/1/2011, 1/3/2011	Identifying damaged areas by flood (2011)
<i>Worldview-2</i>	0.5	8	8/2/2011	Overlapping spatial data
<i>Quick Bird</i>	0.5	5	2/3/2011	High precision comparative analysis for recognized small-scale flooded areas
<i>Geo-eye 1</i>	0.5	5	2010	Establishing DEM aspects
<i>Aster</i>	15	14	2009	Identification of geological features

The major areas of investigation in studying floods and torrents can be summarized as follows:

1. Mapping flood-prone areas.
2. Identifying factors that influence floods and torrents.
3. Assessing the damage caused to areas by floods and torrents.
4. Studying and proposing flood controls for better flood mitigation.

Bearing in mind these areas of investigation, the appropriate methodology can be decided upon, and after identifying the physical and anthropogenic factors that are at work, flood controls can be proposed based on scientific understanding. The listed areas of investigation that comprise the basis of the study may be compared with the studies that have been undertaken on floods in Saudi Arabia. However, there is no similarity between the two, except the studies done by the author, as revealed in Table 2.1. The present study will integrate the listed areas of investigation within a comprehensive theme of analysis. In addition, the natural factors which exist in the study area and the assessment of the two flood events that occurred in 2009 and 2011 will be examined. This study was completed in two phases and over approximately 2 years (Fig. 2.1). The first phase was started directly after the catastrophic flood event of November 2009, which resulted in severe damage to the east and south-east of Jeddah City over an area totaling about 688 km². A comprehensive assessment was carried out, after which the acting factors were identified. For this, satellite images were used, which were analyzed in accordance with different thematic maps.

After the flood event which occurred in January 2011, and which mainly affected the north-east and northern areas of Jeddah City, as well as extending to some southern regions, the second phase of study was started, and it had a larger spatial coverage. The geography of the new area (of the second phase) was increased to about 1947 km².

The methodology followed in this study was achieved by an ordering scheme, and consisted of a number of practical tasks. This methodology depends, in a broad

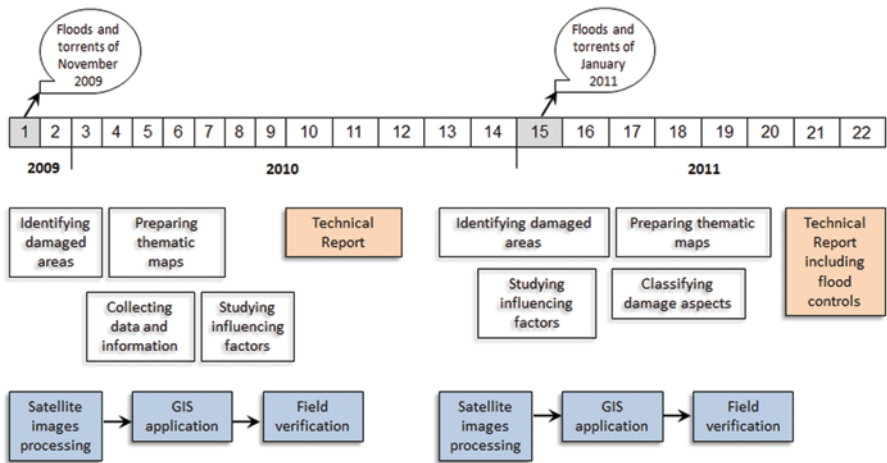


Fig. 2.1 Flow chart of the major phases of the study

sense, on preparing data and information on the area of concern, and then correlating these data and information with other analyses of floods and torrents which have focused on different aspects. Hence, these two components will help in identifying the factors governing floods and torrents in Jeddah and its surroundings. Based on the results, flood controls can be proposed to mitigate the impact of these catastrophic events. Also, determining the influencing factors helped in selecting the proper methodologies for this study, which enabled decision makers to take appropriate action.

2.2 Tools for Analysis

It is necessary to have all tools for analysis prepared before starting such a study, since the proposed methodologies in many studies fundamentally depend on the availability of the tools that are required. Normally, different tools and applications are used even for one theme. They can include desk study documentation and laboratory investigation, while other applications require field surveillance and *in-situ* measuring. All of these aspects depend on the topic to be investigated and its objectives.

Floods and torrents are studied from different spatial aspects. This can be mainly achieved by studying their geographic distribution and monitoring the water flow regime, as well as by identifying the physical and anthropogenic factors that influence them and other related elements. This enables the coverage of large geographic areas of surface terrain. Hence, it is of the utmost importance to focus on the use of spatial tools for analysis. These are mainly represented by maps, aerial photos and satellite images, in addition to other supplementary tools, such as time series records, data and other related research aspects.

The sections below show the principal data and tools used in this study.

2.2.1 Data and Supplementary Information

- Climatic records from ground stations to investigate rainfall peaks by region.
- Climatic records from remotely sensed data to cover the lack of ground data.
- Terrestrial thematic measures (e.g. damaged areas, channel characteristics, lake capacity, existing flood controls, etc.).
- Supplementary information, including historical flood events, urban expansion and instigated protection.

2.2.2 Maps

- Topographic maps (1:50.000 scale & 20 m contour interval)
- Geological maps (1:250.000 scale & 1:500.000)

2.2.3 Digital Elevation Models (DEMs)

- Digital Elevation Model, DEM of 2 m accuracy¹.
- Digital Elevation Model, DEM of 30 m accuracy.

2.2.4 Satellite Images

In this study, satellite images with different optical and spectral characteristics were processed. They encompass various technical specifications, such as images of the scene area (i.e. swath width), re-visit time, number of bands, etc. In addition, these images were acquired close to the date of flood occurrence (Table 2.1).

2.2.5 Software

- ENVI-4.3 for satellite image processing (produced by: IBM, Colorado, USA).
- ERDAS Imagine-9.3 for satellite image processing (produced by: Lucia, Georgia, USA).
- Arc-GIS-9.3 for Geographic Information System applications (produced by: ESRI, Redlands, USA).

¹ Space Research Institute, King Abdulaziz City for Science, Saudi Arabia.

2.3 Satellite Image Processing

Space science has become an extremely useful tool for analysis in many geo-spatial applications, notably in those related to the study of surface terrain and the processes that take place on it. Space science is mainly comprised of the study of digital satellite images. These images enable the identification of terrain features which are associated with natural hazards. The efficiency of these satellite images has been clearly demonstrated, especially in the assessment and study of floods and torrents, which are characterized by different optical and spectral specifications that enable the identification of flood processes. Satellite images have a miscellany of properties, and it is essential to consider these when selecting the type of satellite image to be analyzed. For instance, it is important to consider the “Spatial Resolution” of the image, which reflects its capacity to identify terrain features from space. For example, from space, Ikonos images can recognize objects on the Earth’s surface of approximately $1\text{ m} \times 1\text{ m}$ area. This is virtually equal to an observation from space of about 100 m altitude; whilst MODIS images cannot discriminate objects on the Earth’s surface with an area less than $250\text{ m} \times 250\text{ m}$. In addition, there is another property which must be considered when selecting a satellite image: the “Re-visit time”, which represents the time that a satellite needs to return to the same location above the Earth’s surface. For example, the Landsat satellite takes 16 days to complete one orbit around the Earth, while the SPOT satellite takes 26 days.

Moreover, satellite images of various types have many electronic properties, such as the number of bands and their wavelength and spectrum ranges (e.g. thermal band, optical band, etc). After considering these properties, a number of satellite images were selected for this study. The Space Research Institute at King Abdulaziz City for Science and Technology (KACST), in Riyadh played a major role in providing many of these images. Thereafter, six different satellite images were processed using the above ENVI-4.3 and ERDAS Imagine-9.3 software (Table 2.1 and Fig. 2.2). These images were acquired at different dates, and they cover different terrain localities within the area of study.

One of the great advantages of the selected satellite images is the dates on which they were acquired; some of them were retrieved before the date of the two flood events, and some others directly after these events. In addition, each of these images was composed of a number of scenes in order to cover the largest spatial area of the damaged terrain. Overlapping between different satellite images was applied to cover the entire region of Jeddah City and its surroundings (Fig. 2.2).

Usually, a variety of spectral analysis approaches for digital image processing is applied to facilitate the recognition of objects that appear on the terrain surface, and then different analyses and measures are required. For example, in ERSAD Imagine software, the most useful applied digital steps are directional filtering, in addition to contrasting and sharpness. Band combination is also applied, where single band and multi band enhancement are carried out by interrelating each three bands as

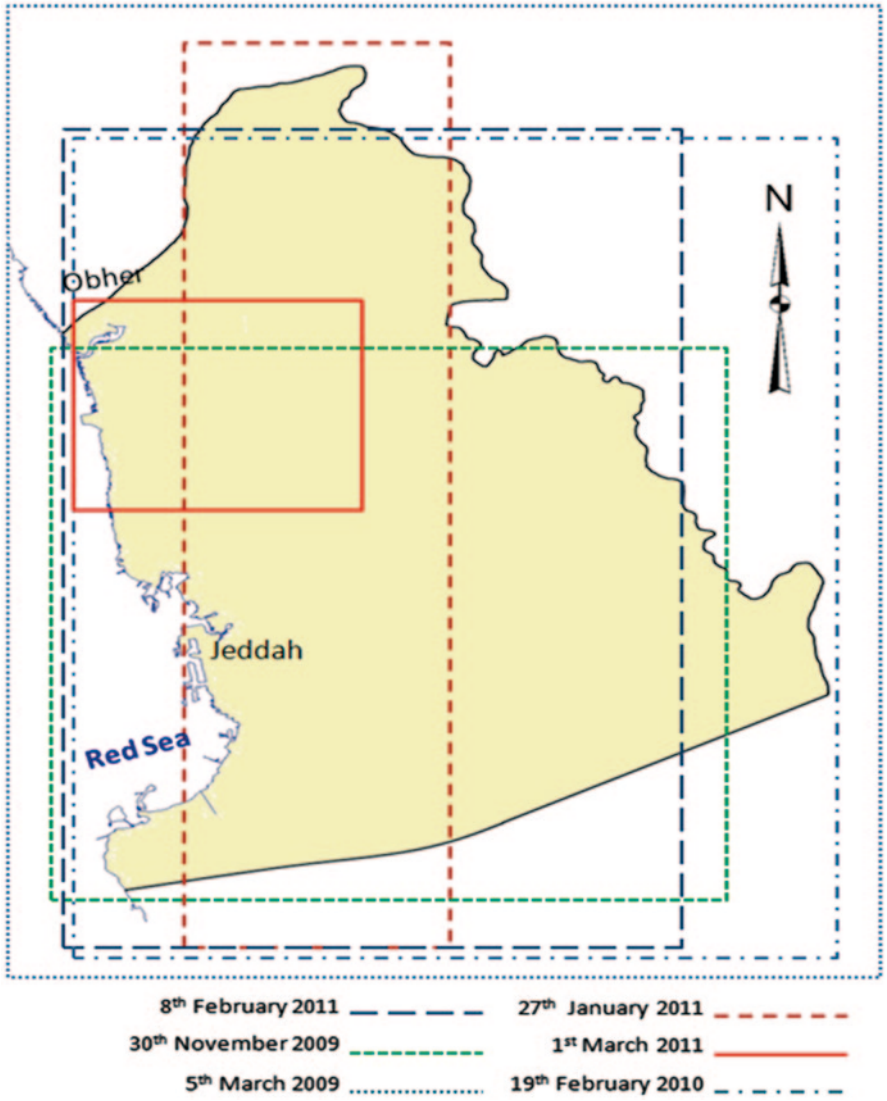


Fig. 2.2 Satellite images used in the study

one set. These applications are helpful in detecting color differentiation, as well as pattern and tone, which facilitates the recognition of terrain features. Moreover, the recognition of temperature difference for various objects from thermal bands is a very useful application. ENVI-4.3 software is also good for processing digital satellite images. It includes the following digital applications: enhancement, interactive stretching, density slicing, coloring and spectral analysis (Fig. 2.3).

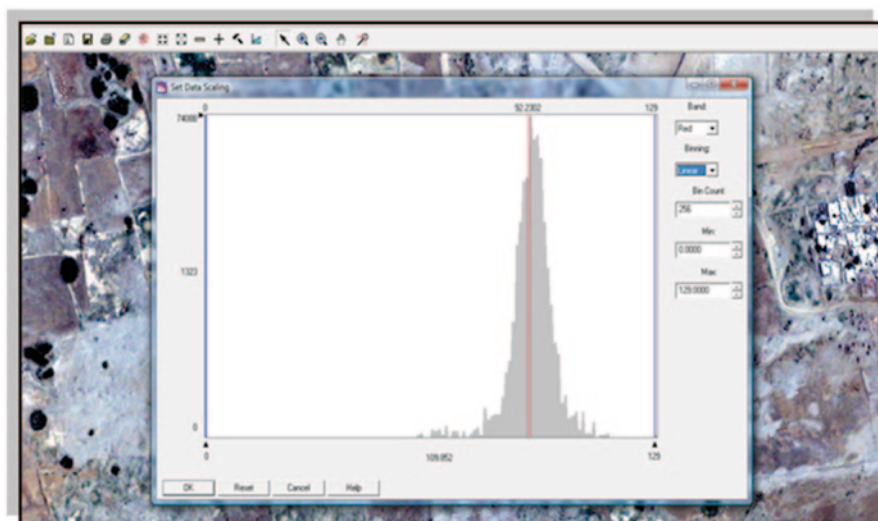


Fig. 2.3 Example of spectral analysis application on image processing

2.4 Geographic Information System (GIS)

The applications of GIS are different from those in image processing. GIS serves in data analysis and modeling, as well as in data storage and manipulation, while image processing of satellite images is used as a tool to extract geo-spatial data observed on the terrain surface. Thus, the use of GIS in studying natural hazards implies a systematic integration with space science. The application of GIS also involves mapping approaches, which are digitally implemented, in addition to data harmonization for further manipulation between different sets of databases, and this facilitates the reading of geo-spatial information.

In the assessment of floods and torrents, GIS is integrally supported by the geomorphologic and hydrological information that has been extracted. Therefore, different variables and statistics can be measured and analyzed, notably when it is applied to diagnosing drainage systems, whether for the geometry of the basin or the streams within each basin. This is essential for identifying the mechanism of the flood process, in terms of the running water or water accumulation on the terrain surface.

Arc-GIS software is able to generate all thematic information together and reveal the required database and maps on the same board. Therefore, data integration can be applied in systematic selection built on digital approaches whenever it is needed (Fig. 2.4). This helps in identifying geographic zones which require further investigation and consequently calculating different measures and dimensions.

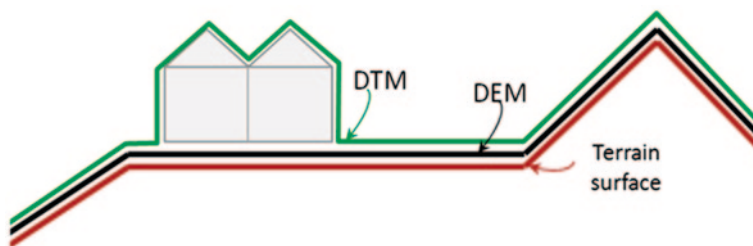


Fig. 2.6 Example showing DEM and DTM

system of surface attributes for the physical characteristics of land surface, made up of irregularly distributed nodes and lines with three dimensional coordinates that are arranged in a network of non-overlapping triangles. DEM extraction can also be obtained from digital data for elevation attributes. Therefore, digital contour lines on digital topographic maps are useful for establishing DEMs.

Three-Dimensional (3-D) models differ according to the purpose of the study. They can be Digital Elevation Model (DEM) or Digital Terrain Model (DTM). In the first, the 3-D shows only the elevations of terrain surface level, while DTM shows all elevations on the terrain surface including human settlements and construction sites (Fig. 2.6).

In this study, two approaches to build DEMs were followed. The first was from digital topographic maps with a contour interval of 20 m, after applying a systematic digitizing procedure for these contours. The second approach uses the Geo-eye-1 satellite with a 2 m contour interval, which was provided by the Space Research Institute at King Abdulaziz City for Science, in Riyadh. These images are characterized by stereoscopic viewing (acquiring visualization from two facing sides on the satellite). This visualization enables the extraction of the elevation in digital forms, and thus it is used in constructing DEMs for further hydrologic and geomorphologic analysis, which was applied to draw watersheds in Jeddah and the surrounding area.

2.6 Field Verification

Field verification includes carrying out a survey of the terrain in order to confirm the reliability of information and data extracted from satellite images, as well as to assess the accuracy of information derived from the obtained thematic maps, which were resulted from the integration of different digital geo-spatial themes. Field verification was carried out in phases, notably after the flooding events in 2009 and 2011.

Topographic maps (scale 1:50.000) and satellite images with several optical and spectral characteristics, notably high-resolution ones, were used in the field verification. Field notes, modifications and corrections, as well as other related

information were reported for each site after measuring the geographic coordinates using the Global Positioning System (GPS).

The main objective of field verification is the assessment of the geographic distribution of flood zones, and thus these zones were measured in terms of water depth and erosion rate, for example. In addition, different aspects of the damage were investigated, including its dimensions and spatial distribution. In this way, field verification enables the identification of all physical and anthropogenic factors that influence floods and torrents. It also helped in recognizing the historical and socio-economical aspects that affect floods and torrents, as they were declared by the inhabitants, and facilitated recognition of the small-scale flood controls that were put into place by the inhabitants of the area.

In addition, a detailed field reconnaissance was carried out in the localities where flood controls exist, such as water channels, tunnels, bridges, as well as the old and new reservoirs, i.e. El-Mesek Lake (formerly named), the Precautionary Dam, Es-Samer Dam and Omm El-Kheir Dam. Other protective measures that were carried out after the floods and torrents of 2009 and 2011 were also investigated. Based on field verification, new flood controls were proposed by the study.

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