Chapter

# Flood Risk and Vulnerability of Jeddah City, Saudi Arabia

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## Abstract

Coastal cities are often vulnerable and subject to the risks associated with floods, hence the need to sensitize decision-makers on the threats posed by climate hazards and uncontrolled urbanization. This study is part of this logic and aims to identify and map the flood zones of the city of Jeddah in order to reduce their vulnerability and to integrate them into the strategies of prevention and fight against the risks of flooding. The recent floods in 2009 and 2011 have caused heavy human and material losses that will permanently mark the collective memory of the inhabitants of the city. The multisource and diachronic data used as well as the methodology adopted made it possible to perform a multi-criteria spatial analysis by combining optical satellite imagery and radar DEM, topographic and geological maps, rainfall records, and available statistical data. Thus, risk factors have been identified and combined to understand and appreciate the gravity of recent disasters and provide planners and decision-makers with tools to assist in the effective and adequate management of the ever-changing urban space, in a context of climate change and increased anthropogenic pressure on coastal cities.


**Keywords:** naturals hazards, flooding, multisource data, urban extension, Jeddah, Saudi Arabia

## 1. Introduction

Given the changing climate, rapid demographic growth, and significant urbanization, the risks of natural hazards have increased. Many regions of the world have seen devastating floods in recent years, as in the case of Saudi Arabia, which is part of the dry climate region. The city of Jeddah, located on the eastern coast of the Red Sea in the western region of the Kingdom, was hit by earthquakes in the southeast of the city, causing damage to life and property, which had social, psychological, economic, health, and environmental effects.

The urban explosion and the rapid growth of coastal cities mean that coastal cities are highly vulnerable to climatic hazards, which increase the risk of natural disasters [1]. In recent years, several regions of the world have experienced severe flood problems. This is the case of Saudi Arabia, a country characterized by arid climatic conditions, but which has, in recent years, faced severe flooding, particularly in the urban centers which are experiencing a strong expansion. Among these is the city of Jeddah, a cosmopolitan metropolis bordered by the Red Sea and Saudi Arabia's second largest city after the capital Riyadh in terms of population and economic development [2]. Its area was multiplied by 10 between 1972 and 2010. It is considered the door of the Muslims to the two holy places: Mecca and Medina. In 2009 and 2011, the city experienced floods (**Figure 1**) causing death and serious damage at the social, psychological, economic, health, and environmental levels [3]. The roads where turned into torrents and saw dozens of cars washed away. The present work illustrates a spatial analysis of flood risk based on multisource data (satellite, DEM, cartographic and statistical) and aims to identify flood-prone areas to determine the vulnerability of the Jeddah area so as to avoid urban extension in risk areas and to develop adequate management of the environment.


**Figure 1.**
*Floods in 2009 and 2011. Source: Internet.*

## 2. Study area

A cosmopolitan city, a major nerve center of the Red Sea and a dynamic port city, Jeddah is located in the Alhijaz region, on the Red Sea coast, developed on Tihamah coastal plain. It is the main urban center of the West (**Figure 2**). Its


**Figure 2.**
*Study area.*

geographical location on the ancient trade routes and its status as a seaport and airport through which the vast majority of pilgrims travel to the two holy cities Mecca and Medina have made it the most cosmopolitan city in all of Saudi Arabia. While the population was estimated at nearly 1 million in the late 1970s, it rose to 1.4 million in 1986, exceeding 3 million in 2010 [4]. It now stands at nearly 3.5 million, with a rate of 3.5% according to the municipality of Jeddah, which represents 14% of the population of Saudi Arabia.

## 3. Geological and geomorphological framework



According to Monnier and Guilcher, the morphological setting is characterized by the Tihamah littoral plain with a maximum width of 40 km, located at the foot of the highly dissected Precambrian granitic mountains of Alhijaz whose peaks reach several hundred meters. The plain is surmounted by a crest of basalts forming part of a set of castings called harrats (lava flows today in inversion of relief), coming from mouths located at a hundred kilometers inside and going back to the old Pleistocene based on their stratigraphic relations [5] in [6]. The existence of geomorphological phenomena related to the eustatic variations of the Red Sea during the Pleistocene is noted. The stability (or geological instability) of the coastal plain is related to the earthquakes associated with the formation of the Red Sea. Most faults, diaclases, and cracks take parallel and orthogonal directions to the Red Sea. Hydrologically, there are 24 watersheds in the context of the flooded area. Sixteen watersheds are directed toward the city of Jeddah to the west, and the rest flows in a southwesterly direction toward the great valley of *Wadi* Fatimah [7].

The study area is composed of Precambrian-Cambrian formations, overlain by a succession of Cretaceous-Tertiary sedimentary rocks and Tertiary-Quaternary basaltic lava flows and Quaternary-to-recent alluvial deposits (**Figure 3**).

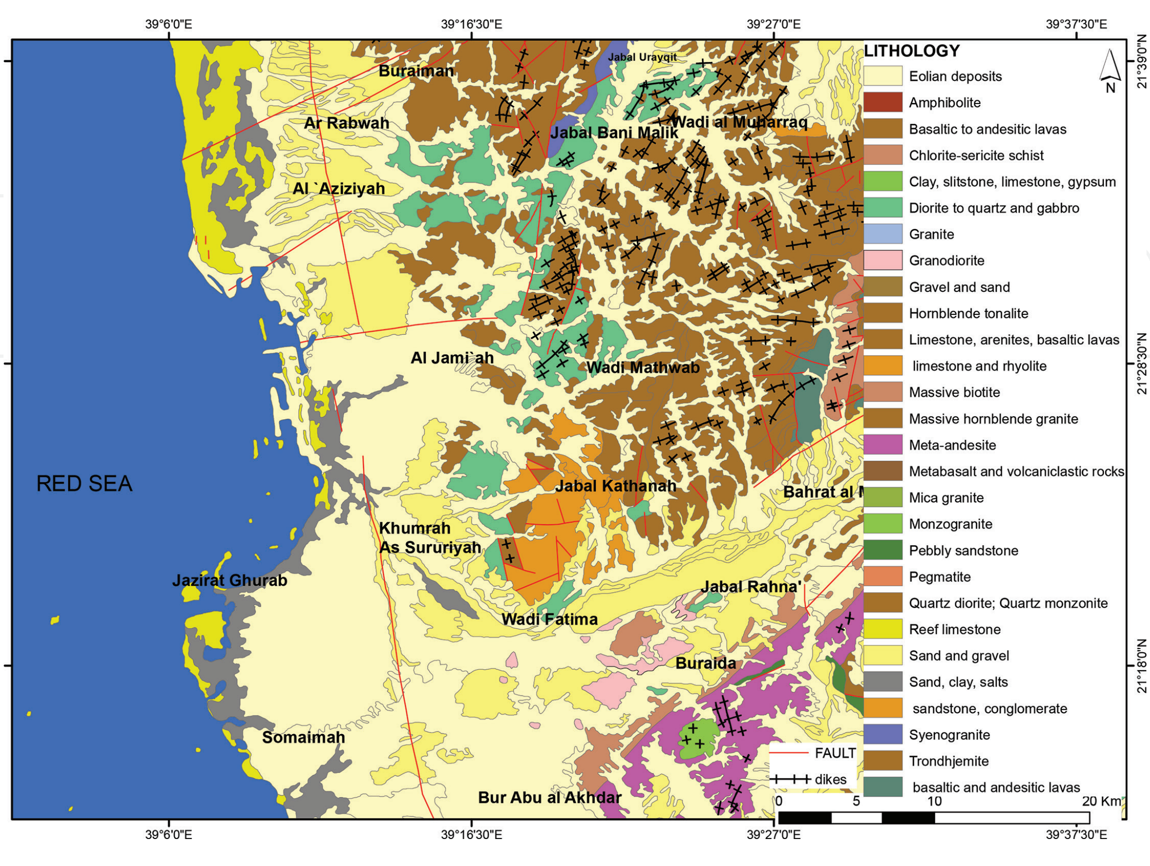


**Figure 3.**
*Geological map of Jeddah city.*

Volcanic lava tongues are associated with lineaments and ancient valleys. These lava formations follow the tracks of the paleovalleys and the direction of the movement of the water. The presence of volcanic languages and Quaternary sediments plays an important role in locating the population and human activities following the presence of springs and loose and fertile soil. The deltas of coastal *wadis* are affected by agricultural activities along the Red Sea coastal plain. **Figure 4** shows the geomorphological and topographic contexts of the city of Jeddah. This figure shows that the city extends on the outlet of several *wadis*, which in spite of the urbanization take back their old courses during strong and intense precipitations. Jeddah has developed all over the coastal plain and beyond, disrupting the normal flow of water.

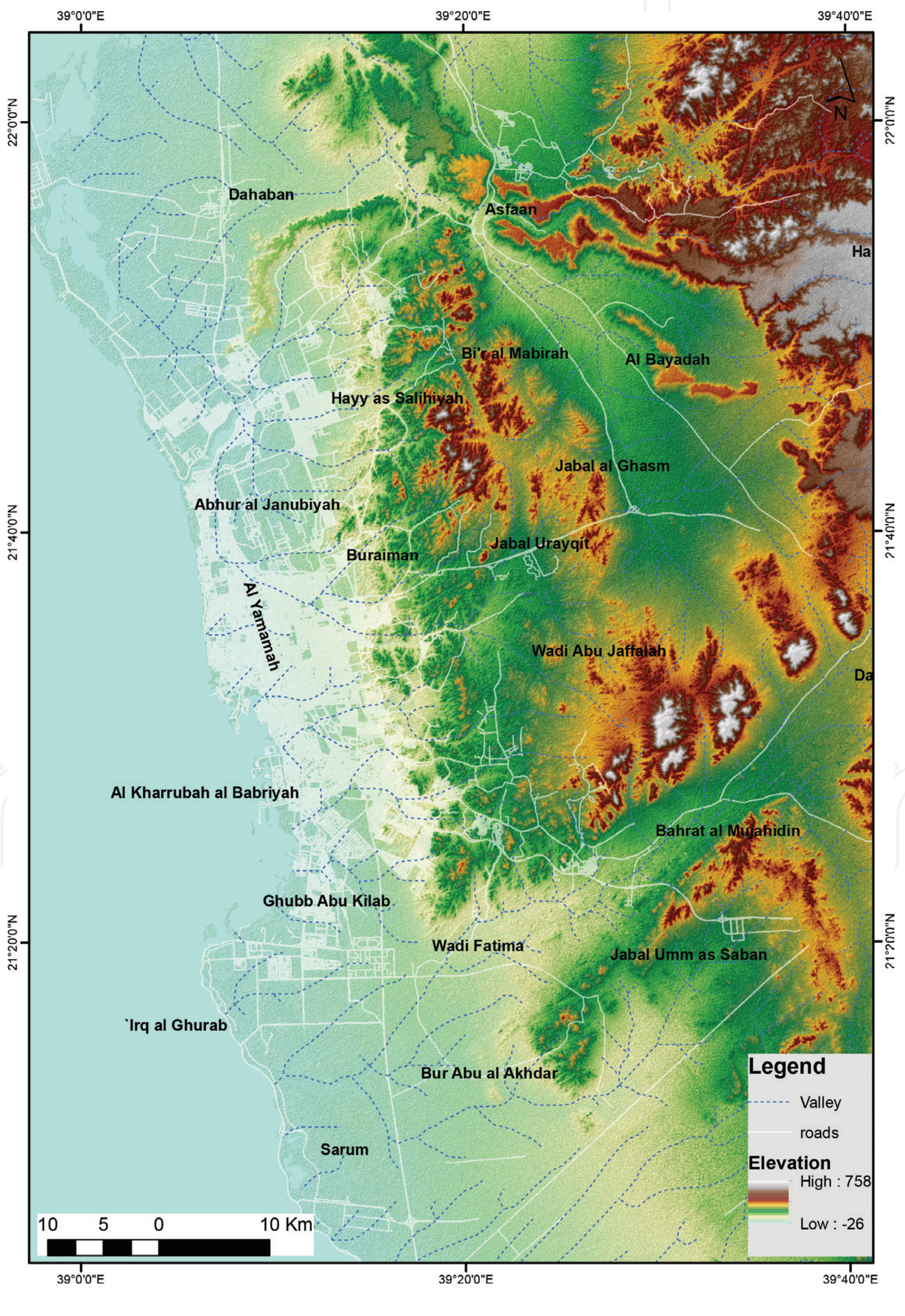


**Figure 4.**
*Geomorphological and topographic contexts of Jeddah city.*

## 4. Materials and methods

Remote sensing is a crucial tool for researching submersion areas and for assessing natural hazards. The present study is based on the processing of multisource and multidate satellite data, supplemented by cartographic documents and field observations. These different data were integrated in the same mapping projection system before proceeding to a series of digital treatments: digitalization, color composition, improvement, combined classifications using image texture, and fusion. **Figure 5** shows the different stages of treatment. Rainfall statistics were also used.

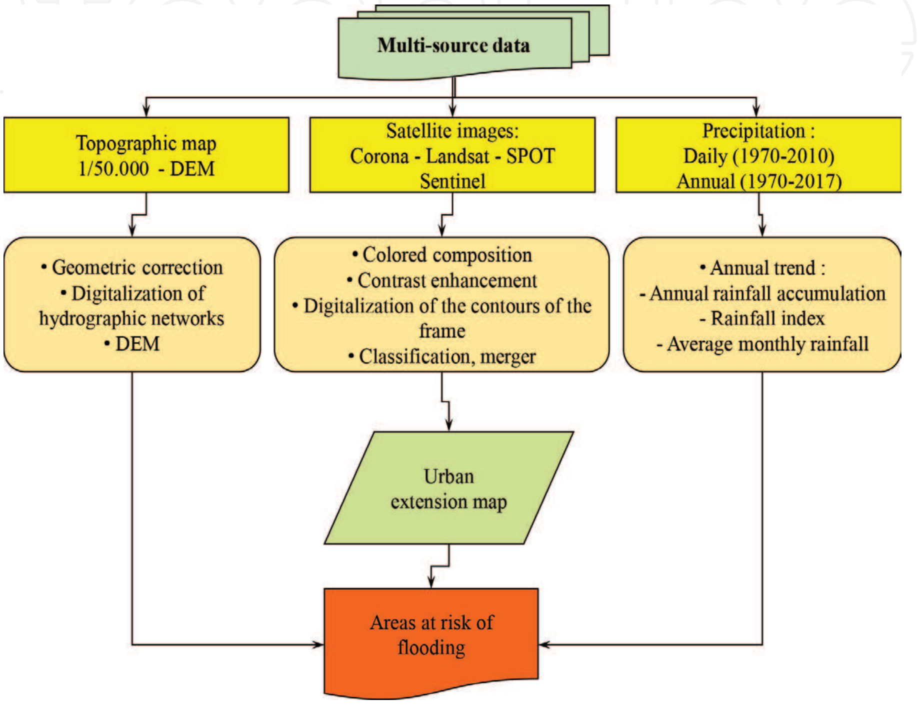


**Figure 5.**
*Methodology of the study—Different stages of treatment.*

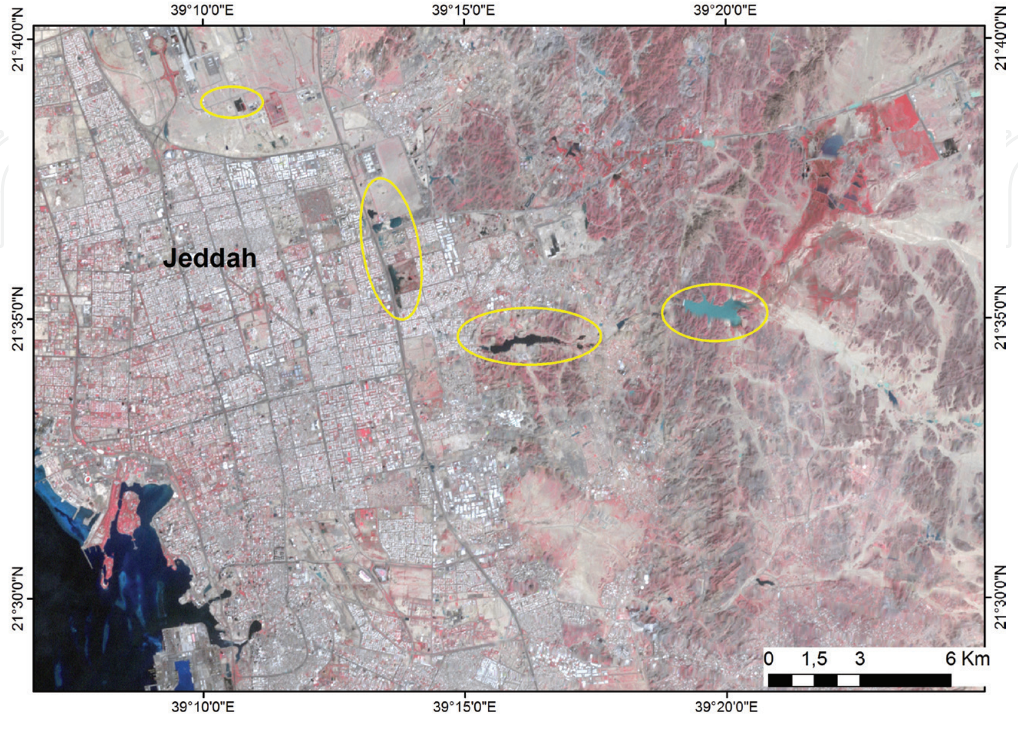


**Figure 6.**
*Extract from Landsat ETM+ of February 1, 2011. There are only a few small water bodies (circled in yellow).*

It should be noted, however, that the data used do not allow for immediate monitoring of the catastrophic floods that occurred in 2009 and 2011. The lack of information on the intensity and duration of rainfall data that caused the floods does not allow for a detailed analysis of rainfall conditions. For this reason, we will limit ourselves to a general descriptive analysis of the 1970-2017 rainfall data sets for the Jeddah station. At the level of remote sensing data, we did not find SPOT or Landsat images within 3 days after the floods, whereas beyond this period the traces of flood are no longer visible on the satellite imagery, as shown in **Figure 6**. We note that phenomena are as violent as ephemeral. The only image in our possession that is close to the January 27 flood is a Landsat ETM+ acquired on February 1, 2011 (**Figure 6**). The data at our disposal nevertheless allow the monitoring and mapping of the most vulnerable areas.

## 5. Research findings and discussion

### 5.1 Variable and torrential rainfall

It can be seen from **Figures 7** and **8** that the rainfall pattern of the Jeddah area is characterized by a great interannual variability marked by the alternation between wet years (as in 1996, when 284 mm was recorded) and completely dry years, as in 1986 (where no raindrop was reported according to the data processed). As for the seasonality of the rains, it is observed that the precipitation is winter (they begin in October and end in April, **Figure 8**) [8]. These are the typical characteristics of the temperate and Mediterranean climate. This is not the monsoon regime that is generally active in July and September. We can also say that it is the month of November which records the maximum of precipitations and for which the services of civil protection must be more vigilant to envisage periods of water levels in *wadis* and floods. Analysis of daily rainfall (even if the latter do not cover the whole period) is revealing. It shows that the daily rainfall during the 2009 flood (70 mm) "Flash flood or crue eclair" are the largest in 24 hours since 1979. This extreme event combined with the urban growth experienced in the city in this period explains the severity and magnitude of the disasters recorded. The 1970s did not experience major floods, despite large amounts of precipitation falling (1972, 1973, 1978, and 1979); this is due to the absence of urban expansion in this period in risk areas (*wadi* beds). The year 1996 had an exceptional year-to-date, but did not do any damage because the rains fell over several days [9, 10].

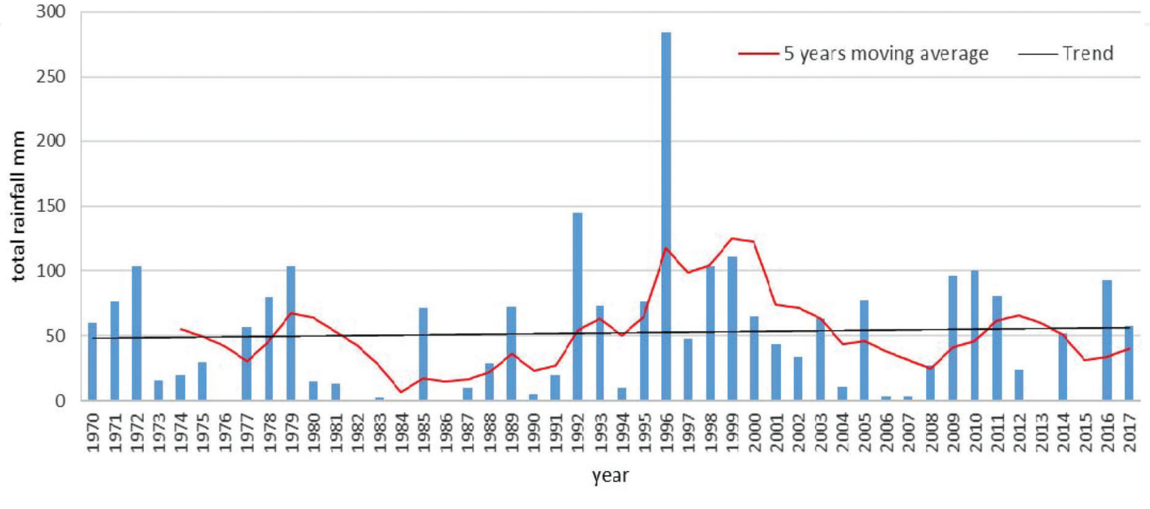


**Figure 7.**
*Annual total rainfall in Jeddah 1970–2017.*

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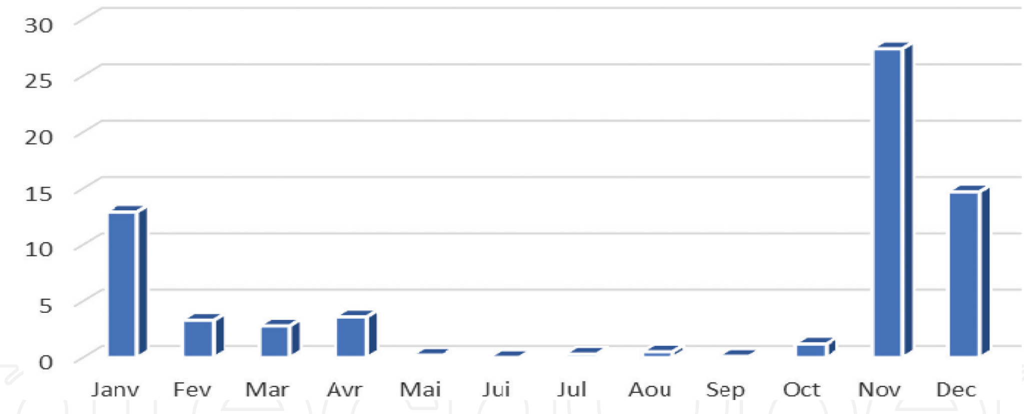


**Figure 8.**
*Average monthly rainfall in Jeddah 1970–2014.*

It has become clear that Saudi Arabia is located in new climatic trends, represented mainly by torrential rains. This was obviously marked by events of frequent natural disasters and especially intense rainfall in different parts of the territory [4]. Disasters recorded in 2009 and 2011 are caused by problems of urbanization combined with the frequency of precipitation that was recorded in less than 2 hours. The city of Jeddah does not have a truly effective system of sanitation and drainage, especially the southern part of the city where the houses are located in *wadi* beds and poorly built because they do not conform to technical standards. Significant rainfall events recorded in recent years and widely reported in the media are those of January 2011 "75.9 mm"; December, 2010 "65.6 mm"; and November, 2009 "70 mm" (**Figure 9**).

We put emphasis on the fact that anthropogenic pressure has aggravated the extent and scope of flooding, in particular the phenomenon of urban extension along the rivers in their lower reaches, as is the case, for example, in "*wadi* Assir, *wadi* Al Asla" (**Figure 10**) where homes were recently built without taking into account any assessment of natural disaster risks. A recommendation is made to apply similar studies for flood risk assessment in Saudi Arabia using the same method applied in this research.

Constructions in littoral zones result in a destruction of the environment. The sea is a space that is subject to planning and development for leisure activities. The population has no sense of the littoral environment; thus, it takes an education policy, aiming to enhance the image of the environment and to demonstrate the factors that could effectively contribute to stopping the destruction of nature [6]. The impact of urbanization and the delimitation of its extension is one of the

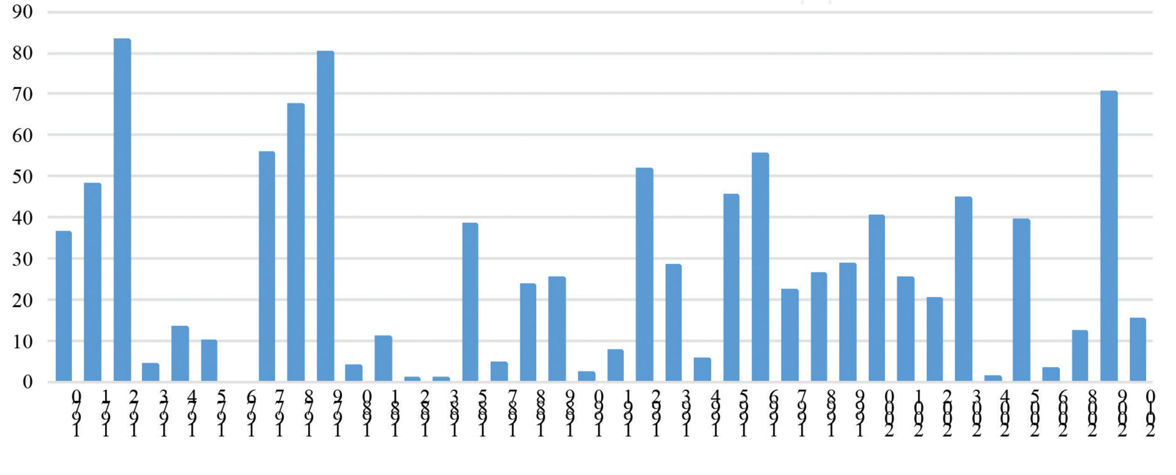


**Figure 9.**
*Total daily maximum rainfall in Jeddah (1970–2010).*

**Figure 10.**
*Urban extension along the wadis beds, flood 2009 (IKONOS image, after [7]).*

fundamental concerns of the management and planning of space. The urban perimeter is an essential data in an analysis for the determination of the peripheral growth of large cities and to highlight the choice of the location of new constructions [11] in [12]. Beginning around 1980, an accelerated impact of construction of buildings, roads, port facilities, and recreational areas has affected the urban area of Jeddah. The area of the city increased from 6200 ha in 1966 to 9500 ha in 1972 and 68,500 ha in 1986; it reached 110,000 ha in 2018 (**Figure 11**).

The growth of the city is mainly toward the north along the plain of Tihamah. The urban expansion that started out in anarchy is nowadays planned. The first steps to be adopted were legislative, beginning with the regulation of the private and public uses of space and activities.

The demarcation of risk areas was established by spatial analysis. The map was made by combining the layers of urban extension zones and the hydrographic network (**Figure 12**). The approach to identifying flooded areas from satellite images was mainly applied using direct visual interpretation and field verification.

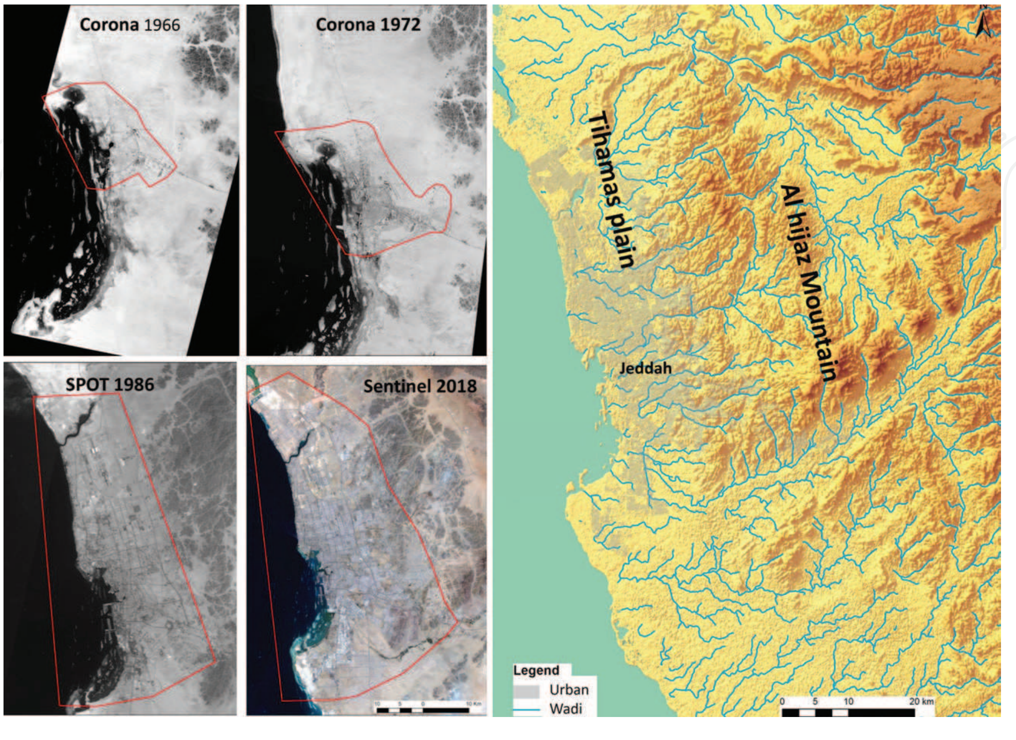


**Figure 11.**
*Urban extension of Jeddah city between 1966 and 2018 and its topographic context (from remote sensed data).*

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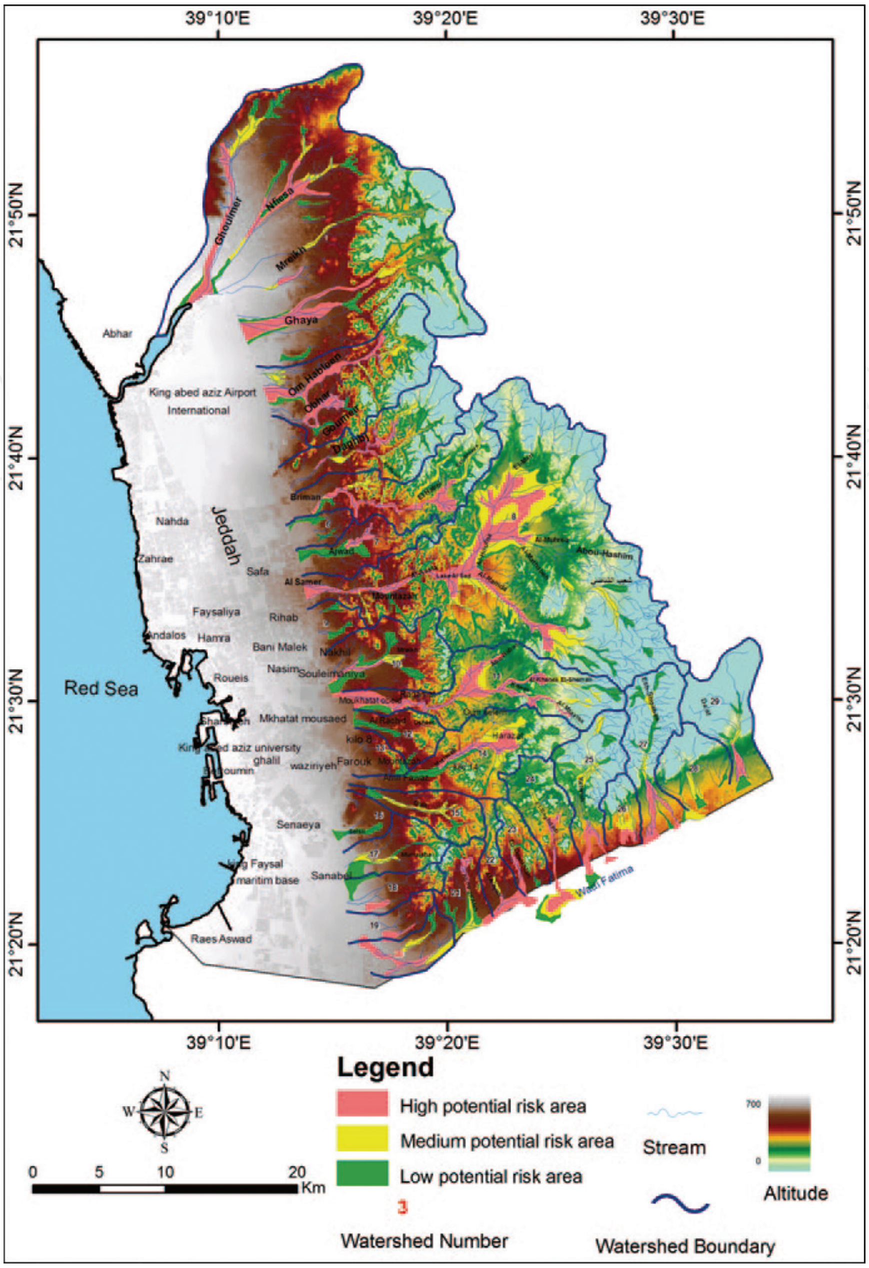


**Figure 12.**
*Natural flood and torrent risk map (after Al Saud M [14]).*

As a result, a map showing risk areas with different levels of damage was produced. For this purpose, we have identified three flood risk zones: the first zone, representing the very high risk, refers to the direct contact strip between the *wadis* and the urban fabric. The second zone presents a high risk, which groups the zones next to the first, at the level of the third zone, which, with moderate risk, is located in the sectors bordering on the second zone. The proposed map is the result of a synthesis that should be completed and validated to adjust and take into account other risk factors. This research could therefore serve as a decision-making tool and constitute a discussion paper for a rigorous spatial planning of the city of Jeddah. Strengthening the legislative framework is necessary at the present time for appropriate management of natural risks [13].

### 5.2 Environmental impact assessment of floods

The rainfall that fell over certain areas of the study area was concentrated, but many of the natural-like areas of the affected area are still at risk if the same phenomenon is repeated at a high rainfall and exceeds the 5-year moving average. Damage includes the destruction of thousands of cars, the displacement of hundreds of families, the evacuation of homes in the affected areas and the nearby neighborhoods during the crisis, in order to avoid possible future rains, the destruction of farms, and the emergence of mental disorders of people who lived the disaster. Losses were estimated at $ 3 billion, resulting in damages of $ 5.1 billion [3]. In this context, it was necessary to address the environmental impact assessment of the floods, to determine the size of the disaster and its geographic distribution, and thus to identify the factors and dynamics of the flow of water and drifting load, so that the appropriate solutions can be conceived and the right decision can be taken. The study is subject to global climate changes and specifically with the expectation of increased rainfall and simultaneous rainfall frequency in the coming years in extreme quantities [15].

The concept of environmental impact assessment emerged at the beginning of the 1960s and included all studies on the direct or indirect impact of any intervention on the environment based on a vision that includes planning and forecasting. The environmental assessment study of a project examines the potential or resulting environmental impacts, identifies appropriate actions to address adverse impacts and minimizes them, and achieves positive returns to the environment in line with existing standards. The environmental assessment process requires identifying all elements that can be classified, its structure in terms of basic data organization, prediction of impacts and changes, and providing solutions and recommendations [16].

The evaluation process has two main aspects: the first aspect is the interactive planning of a purely technical and administrative nature, while the second is participatory planning involving a technical and administrative part. The technical aspect includes study, interpretation, and prediction of the project. The management aspect focuses on the sound decision-making process, with ongoing field monitoring of the environmental impact of the project. The impact study is based on three methods: identifying impacts, developing strategies, and evaluating variables. The effects are identified using several methods, including ad hoc methods, checklist impacts, matrices, networks, overlays, and models.

#### *5.2.1 Multiple standards to support decision-making*

The environmental impact assessment process is based on several criteria—which allow for the appropriate decision of environmental solutions at four levels:

- The subject matter of the decision and the activities involved in the original problem.
- Analysis of results and preparation of standards.
- Decision modeling and operational methods.
- Procedures for investigation and preparation of diagnosis.

This typology can help to make decisions at four levels:

- Choose the best procedures.
- Sort them according to their own values.
- Sort by relevance.
- Describe and present results systematically and formally.

Decision-making is based on a multidisciplinary team comprising a reporter, a facilitator, a decision-maker, and an effective intermediary. On the other hand, it depends on the modeling of variables including business objectives, organizational variables, field information, and basic factors in the study. The decision is preceded by the so-called negotiation process between a multidisciplinary team on environmental impact assessment studies. The process goes through several stages: consultation, negotiation, confrontation, agreement, dialog, and discussion.

#### *5.2.2 Disaster variables*

The flow of floods in deserts and arid regions is a product of the interaction of a number of factors and physical and human variables that overlap and affect each other at different degrees. In this context, the cause of the disaster floods in the city of Jeddah is due to a range of variables, including those listed below.

The high density of the hydrographic network and the absence of widening of the sewage for the flow quantities with the intensity of the descent of the springs; the intensity and the high rates of precipitation in short periods, which were in the form of convective and frontal storms and the absence of channels and waterways suitable to absorb the flowing quantities, in addition to the urban expansion of the city on the valleys; and the lack of a strong infrastructure to contain the rapid population growth. Moreover, these variables include the rise of the water table due to the leakage of sewage, irrigation, and rainwater with the high level of seawater.

#### *5.2.3 Modeling the probability of occurrence of the hazard*

This process, carried out immediately after the floods, includes:

- A statistical report on the flow of floods (water height, speed, duration of flood, speed of water level rise, and flow times) from knowledge of the risks associated with the natural phenomenon, which depends on the combination of risks and the likelihood of occurrence, exceeding its natural limits.

- Hydrodynamic modeling of floods by choosing the appropriate method due to the multiplicity of models in this area. It is one-dimensional and multidimensional.

#### *5.2.4 Modeling exposure to risk*

This type of modeling as summarized in **Figure 13** includes the following elements:

##### *5.2.4.1 Identification at risk*

This consists of identifying all at-risk elements by integrating accurate and correct multisource databases and mapping them according to the scale of the methodology of the study, followed by field outputs to complete some of the data deficiencies and to verify the completed cartographic documents.

##### *5.2.4.2 Social effects*

The social effects of the city's population, their family composition, their indigenous culture, and their psychological effects are based on three main factors that should be taken into account: the indicators of flood (FI), people at risk, and their

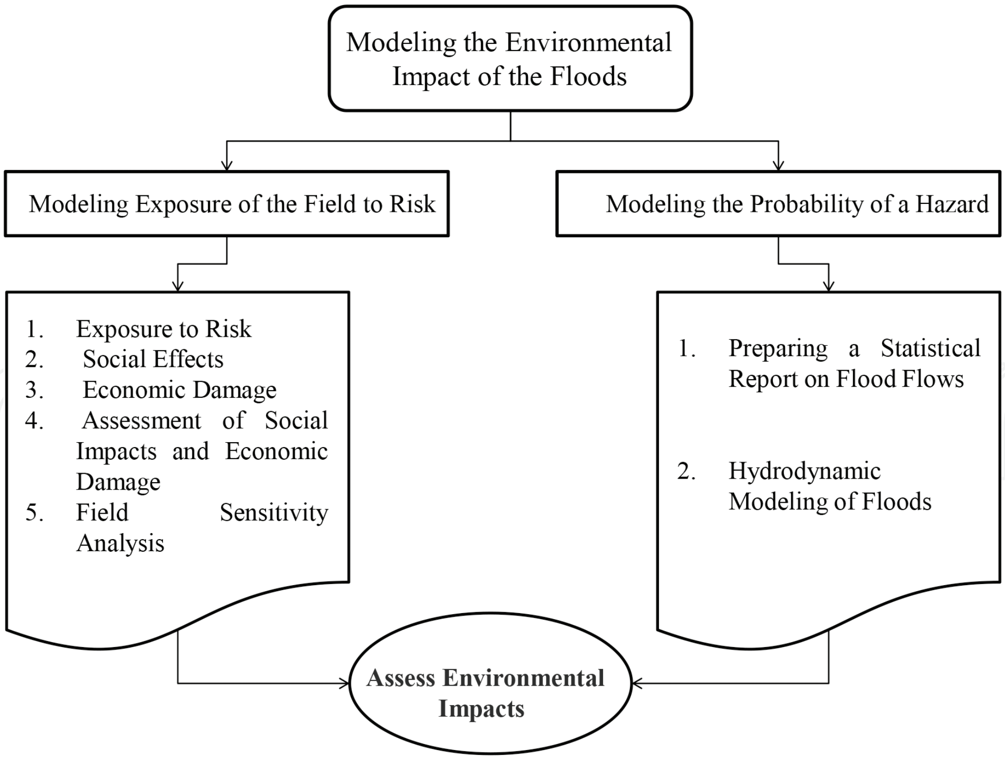


**Figure 13.**
*Modeling the environmental impact of the floods.*

vulnerability (AC). These three factors are combined in the following mathematical equation:

$$SI = 0.5FI + 0.25\,V + 0.25\,AC \tag{1}$$

This process aims to assess the social impact index (SI) at various levels: "high, medium, and low" [17].

*5.2.4.3 Economic damage*

The assessment of economic damage depends on the knowledge of the relationship between the losses caused by a particular type of property due to floods and flood indicators, especially the depth of water, its speed, duration, and pollution according to the basic spatial unit adopted in the research scale.

*5.2.4.4 Evaluation of social and economic impacts*

The assessment of social and economic impacts requires the use of complementary data sources that allow for the identification of new characteristics identified in the presentation analysis of the estimated cost of property, the number of people living in the property, the sensitivity and social vulnerability, and the adaptive capacity of the affected society.

*5.2.4.5 Sensitivity analysis*

In this context, a very important variable is needed, which affects the modeling of flood risk and the emergence of some uncertainty in the digital process of assessing the impact of floods on the environment, namely knowledge of the water level, which is due mainly to the lack of data needed for careful study of such topics.

### 5.3 Toward a future vision for assessing environmental impact

In this context, the following points can be formulated:

- Raise awareness of environmental issues, establish a sense of individual and collective responsibility for maintaining and improving them, and encourage national voluntary efforts in this area.

- Make environmental planning an integral part of comprehensive planning for development in all industrial, agricultural, urban, and other fields.

- Adhere to the General Regulations of the Environment and the Implementing Regulations issued by the General Presidency of Meteorology and Environmental Protection in Saudi Arabia.

- Form a national emergency management body responsible for preparing for natural disasters, developing ready-made rescue programs, and taking precautions to deal with risks before and after they occur.

- Develop an early warning system based on modern technology, which is linked with relevant departments, such as traffic, civil defense, the secretariat, the governorate, the Ministry of Meteorology, and government and private hospitals, and inform the population in all available ways and means, including the use of mobile phones.

- Establish cooperation between officials and decision-makers to enhance preparedness and response, in order to deal with natural disasters.

- Develop awareness programs among the different segments of society, and activate its role to learn how to deal with disaster at the time of its occurrence.

- Implement periodic and continuous reviews of all systems and plans related to natural disaster management.

- Set up training courses for constituents and other community groups.

- Review and study all systems related to regional planning, especially with regard to the determination of the urban scope of each city to identify the lack of plans and their applications.

- Take advantage of the experiences of countries that are at risk, and cooperate with them when necessary.

- Activate the role of maintenance of equipment and rain streams in the seasons of precipitation.

- Give attention to the preparation of hydrological studies and the exploitation of their results in the completion of various development projects.

- Adopt some measures for existing buildings to reduce their risk of flooding [18]:
    - Ensuring the security of persons by establishing an area of refuge, facilitating the passage of the interests of rescue and debris, preventing the floating of waste on water, and checking the location of swimming pools and water basins.

- ○ Sealing water leaks in buildings by installing water leakage barriers, processing sandbags, cracking, network packaging (electricity, gas, telephone, and water), closing ventilation outlets under flood levels, and using internal pumps to pump water.
- ○ Facilitating the return to normal mode by creating the surroundings of the buildings, using thermal insulation of water, placing the electrical panels outside the water level, establishing a separation network for the flooded places, and completing a peripheral drainage.

- Application of environmental assessment methods including checklists, matrices, networks, GIS, and expert systems.

### 5.4 Measures taken in previous periods to address the problem of floods

#### *5.4.1 Completion of floodwater channels*

- The northern channel of the direction of sailing for the drainage of the Valley of El Assla and Mreikh (**Figure 14**).
- The central channel for the drainage of the valleys of Karaa, Mreikh, Ghia, Om Hableen, Daghbj, and Bariman.
- The southern channel of the drainage of the valleys of Kawes, Osheer, Methweb, Ghlil, and Khumra.

#### *5.4.2 Construction of medium and trench dams*

#### *5.4.3 Dam Lake which was previously used in sewage*

It was found that most of them obstructed the movement of water and were exposed to the intensity of evaporation and high temperature in the region, with a decrease in the level of water in general in the area surrounding the body of the dam, and desertification of most of the land in front of it. This is due to the increased risk of floods caused by the phenomenon of sedimentation behind dams. The lack of access to the sea has led to the deterioration of the marine environment, where many marine organisms, including benthic fish and crustaceans that feed on the sediment, have been affected [19] (**Figure 15**).

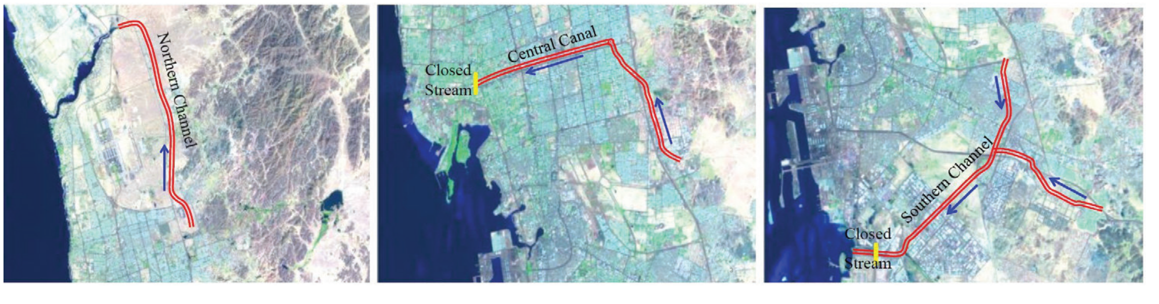


**Figure 14.**
*Floodwater channels.*


**Figure 15.**
*Dam Lake for sanitation.*

### 5.5 Some ways to reduce the risk of floods

The valleys have devastating effects on urban facilities:

- Establishment of dams of various types and forms (surface and subsurface) on the main valleys or on the tributaries, especially in the places of danger revealed by hydrological studies, to reduce the runoff in the valleys and the use of water in times of extreme necessity.

- Rationalization of the construction of protection dams in major cities, which lack rainwater drainage channels and floods to regulate flow.

- Establishment of industrial channels to transfer runoff from hazardous areas to places where runoff water can be exploited.

- Cladding process using appropriate materials on the sides of roads or barriers to be provided around residential areas, farms, and installations.

- Geomorphological maps that illustrate the locations of risk and safety places on which any plan is developed.

- Treatment of the source of the problem of sedimentation in dams.

- Creation of different land use schemes away from hazardous areas, based on prior scientific studies.

- Benefit from this study in applying its proposals to similar areas in Saudi Arabia.

- Application of warning methods, including:
  - Using flash flood warning systems for sudden flooding by connecting rain and runway monitoring stations with automatic telephones and light signals to warn residents and road users.
  - Employing remote sensing and radar data to monitor the weather situation and identifying hazard areas.
  - Organizing awareness sessions and workshops, using awareness leaflets and warning plates, with guides and maps for road users, and methods to be used to avoid danger.
  - Making use of studies of the expected periods of flow, the expected volume of the flood, thereby informing the inhabitants of these areas in advance, in addition to the precautions to be taken by the citizens and the authorities responsible for them.

## 6. Conclusion

This study looked at the vulnerability of the city of Jeddah to floods. Several risk zones have been identified. Spatial analysis of flood risk has led to the establishment of a two-dimensional, natural, and societal hazard profile. It has produced several valuable pieces of information that can be used as part of a geographical information system for monitoring the natural risks of the city of Jeddah. The vulnerability of the study area to the risk of flooding seems to have increased sharply following the uncontrolled and very rapid extension of the urban fabric but also to the irregularity of the annual precipitations. Regarding the state of flood risk in Jeddah, the study showed that by combining multisource and multi-species data, it is possible to obtain a good estimate of areas vulnerable to flood risk, monitored and validated by reliable fieldwork. It would also be necessary to establish risk levels for any new housing area and redevelop very-high-risk sites to avoid future disasters, taking into account climate change. This chapter also allows for the establishment of solid foundations for the study of environmental impact assessment, according to a methodology that takes into account all the variables and criteria that must be met in such studies, in order to model them and provide possible solutions to protect the danger zone and predict future exposure. This is not excluded in light of climate change and global warming, which cause catastrophic floods in most regions of the world.

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## References


[1] Niang AJ. La résilience aux changements climatiques: Cas de la ville de Nouakchott. (Resilience against climate change: Case of Nouakchott City). Geo-Eco-Trop. 2014;**38**:155-168

[2] Al SM. La transformation socio-spatiale à Djeddah (Arabie saoudite). Thèse de doctorat en Géographie. France: Université Paris IV - Sorbonne; 2010. p. 563

[3] Momani N, Fadil A. Changing public policy due to Saudi City of Jeddah flood disaster. Journal of Social Sciences. 2010;**6**:424-428

[4] Ewea HA. Hydrological analysis of flooding wastewater Lake in Jeddah, Saudi Arabia. JKAU: Meteorology, Environment & Arid Land Agriculture Science. 2010;**21**:125-144

[5] Hacker P, Hötzl H, Moser H, Rauert W, Ranner F, Zötl JG. Region around Jeddah and its hinterland: Geology, geomorphology and climate. In: Jadd, Zötl JG, editors. Quaternary Period in Saudi Arabia. Vol. 2. Vienne-New York: Springer; 1984. pp. 107-122

[6] Monnier O, Guilcher A. Le Sharm Abhur, ria récifale du Hedjaz, mer Rouge: Géomorphologie et impact de l'urbanisation. Annales de Géographie. 1993;**102**(569):1-16

[7] Al Saud M. Assessment of flood hazard of Jeddah area 2009, Saudi Arabia. Journal of Water Resource and Protection. 2010;**2**:839-847

[8] Subyani AM, Hajjar AF. Rainfall analysis in the contest of climate change for Jeddah area, Western Saudi Arabia. Arabian Journal of Geosciences. 2016;**9**:122. DOI: 10.1007/s12517-015-2102-2

[9] Almathlouthi S. Fortes pluies dans la ville de Jeddah en Arabie Saoudite, causes et conséquences. Revue de L'association des Géographes Tunisiens. 2005;**17**:7-18. (in Arabic)

[10] Yesubabu V, Srinivas CV, Langodan S, Hoteit I. Predicting extreme rainfall events over Jeddah, Saudi Arabia: Impact of data assimilation with conventional and satellite observations. Quarterly Journal of the Royal Meteorological Society. 2016;**142**:327-348. DOI: 10.1002/qj.2654

[11] Tonye E, Akono A, Ndi Nyounguy A, Assako Assako RJ. Utilisation des données ERS1 et SPOT pour le suivi de la croissance périphérique de la ville de Yaoundé (Cameroun). In: Bannari A, editer. Laboratoire de Télédétection et de Géomatique de l'Environnement, Département de géographie, Université d'Ottawa, Actes du Colloque international, Université d'Ottawa, Ottawa 10 au 12 mai. 1999. pp. 83-98

[12] Ould Sidi Cheikh MA, Ozer P, Ozer A. Risques d'inondations dans la ville de Nouakchott (Mauritanie). Géo-Eco-Trop. 2007;**31**:19-42

[13] Daoudi M. Risque d'inondation et vulnérabilité de la ville de Jeddah, Arabie saoudite. Geo-Eco-Trop. 2014;**38**(2):259-270

[14] Al SM. Flood control management for the city and surroundings of Jeddah, Saudi Arabia. In: Springer Natural Hazards. 2015. p. 169. DOI: 10.1007/978-94-017-9661-3_12

[15] IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp

[16] Poutrel JM, Wasserman F. Comité scientifique Espace et cadre de vie France, Société d'études pour le développement économique et social. Prise en compte de l'environnement dans les procédures d'aménagement: Essai Méthodologique sur les Études d'impact. Collection Recherche Environnement, Broché, Diffusion la Documentation Française. 1977. p. 183

[17] Dewals BJ, Detrembleur S, Archambeau P, Erpicum S, Ernst J, Pirotton M. Caractérisation micro-échelle du risque d'inondation : Modélisation hydraulique détaillée et quantification des impacts socio-économique. La Houille Blanche. 2011;**2**:28-34

[18] SPW. Inondations: Réduire la vulnérabilité des constructions existantes, Une publication du Service public de Wallonie, Belgique. 2014

[19] Daoudi M. A systematic approach to assess the impact on the environment: Flood risk model. Egyptian Journal of Environmental Change. 2015;**7**(2): 43-52. (in Arabic)