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Utilizing GIS in Flash Flooding Risk Assessment in Urban Environment with Reference to Yanbu and Rabigh Cities, Western Saudi Arabia

Ahmad A. Al-Modayan

Geography Department, King Abdulaziz University,
P.O. Box 80258, Jeddah 21589, Saudi Arabia

amodayan@gmail.com

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Abstract. The Western part of Saudi Arabia is characterized by aridity, and extreme spatial and temporal variability of rainfall. Flash floods occur immediately after heavy, short rainstorms and destroy human lives and properties. As this part of Saudi Arabia contained many major cities of economic importance that located along the eastern coastal part of the Red Sea, the study attempts to locate and categorize the areas of Yanbu and Rabigh cities vulnerable to flash flooding through the usage of GIS techniques. Hazard zones were drawn and a classification of risk assessment was made. The risk class was linked to the land cover and land use in the area through which it was found that the risk to man-made environment in Yanbu and Rabigh cities was mainly medium risk. The risk stems from the fact that most of the land use and roads are located in the vicinity of the main Wadi's channels and main streams specially north and east of Rabigh city and the central and southern part of Yanbu city. These areas are found to be subject to the risk of flooding, especially after heavy local storms.

*Keywords***:** Flood, risk analysis, GIS, urban environment, Rabigh, Yanbu, Saudi Arabia

Introduction

Flash floods are among the most catastrophic hydrological phenomena in arid regions. They are rare but common in arid regions and may result in the occurrence of irregular and extreme events, and present a potential

threat to both lives and property. Man-made structures such as dams, bridges, culverts, wells, roads and highways along and across wadi courses are highly at risk from flash floods. Flash floods form rapidly and they flow down over extremely dry or nearly dry watercourses involving intense rainfall of short duration (Subyani *et al.,* 2009). In addition, the difficulty of data collection, due to the low population density and inaccessibility of these areas limits the reliability of the data recorded for such environments. Extreme climatic variations from year to year, and variation in rainfall increase the problems of constructing probabilistic rainfall-runoff models. As a result, flood prediction for wadi channels is plagued with both risks and uncertainties, and requires complex techniques for successful achievement (Yair and Lavee, 1985; and Tingsanchali and Karim, 2005).

In semi-arid and arid regions, rainfall has a high variation in space as well as in time. In Saudi Arabia, rainfall can be described as being little and unpredictable as well as irregular, but very extensive during local storms. The western region of Saudi Arabia receives a moderate amount of rainfall compared with the other regions, because of its mountainous nature and location within the subtropical zone. In general, rainfall in this area occurs in winter and spring seasons due to the African-Mediterranean interaction (Şen, 1983; Alyamani and Şen, 1992; and Subyani, 1999, 2004).

The western region of Saudi Arabia is characterized by low altitude-flat coastal plain bounded from the east with a chain of high rugged mountains of the Arabian Shield oriented North-Northwest to South-Southeast. Most of the wadis draining from these mountains toward the west passing through the coastal plain to the Red Sea. Many of the major cities and villages along the coastal plain are situated along or at the mouth of these wadis. Due to the aridity of the area and lack of long-term strategic planning, most of the population tend to settle along wadi courses and sides. Flash floods along these wadis caused severe damages to lives and properties in the past (Subyani *et al.,* 2009).

In Saudi Arabia, storm water and flood management have been applied and developed in some research projects since the late 1980's. Ishaq (1985) identifies a proper model for the management of storm water in the cities of the Kingdom of Saudi Arabia.

Nouh and Al-Laithy (1988) examined the construction damages due to the floods. They set up guidelines for adequate bridge design in the southwest region of Saudi Arabia to avoid the destructive effects of flash floods on highway structures. Abdurazzak *et al.,* (1995) present suitable methodologies that can be used to evaluate flood magnitudes and their frequencies, design hydrograph and protection measures.

The main purpose of this study is to compile all related data, spatial and non spatial, into a GIS system in order to develop a geospatial database to assess the flood hazard maps in Rabigh and Yanbu areas, located in Western Saudi Arabia. This will help in the mitigation of flooding hazard risk. In addition, these techniques will help to develop flood-hazards zonation maps. From these maps we can identify urbanized and industrial areas affected by such hazards.

Geographical Setting of the Study Area

Wadi Rabigh

Wadi Rabigh is one of the most important resources for agriculture and water in Rabigh area. It is bounded by Lat. 22° 30' and 23° 30' N and Long. 39° 00' and 40° 00' E. Some villages are located in this basin such as Akhal in the upstream and Haqqaq in the downstream, in addition to some small villages which are distributed around Rabigh city (Fig. 1). It is an important industrial city which will hold huge petrochemicals projects in the future as King Abdullah Economic city. The new industrial city will house an international airport as well as a harbour which will be among the largest in the region.

Wadi Rabigh is mainly made up of three main streams which are Wadi Nuwaybah, Wadi Nada and Wadi Al-Akhal. All these three wadis form the Wadi Rabigh basin and the outlet goes through a flat area into Rabigh city (Fig. 2a). Wadi Nuwaybah is located in the downstream of Rabigh basin and originates from the basement complex rocks, Haqqaq spring is located in this area (Fig. 2b). Wadi Nada is located in the southern part of Rabigh basin and originates from Harrat Rahat and confluences with Wadi Al-Akhal (Fig. 2c). Two kilometers after Al-Akhal-Nada confluence, a huge concrete gravity dam is being constructed with more than 200 million m^3 storage volume of water (Fig. 2d).

Wadi Fara'a

Wadi Fara'a is one of the biggest and most important agriculture and water supplies for Yanbu area. It is located in the far north of the study area and bounded by Lat. 24° 00' and 25° 00' N and Long. 38° 00' and 39° 00' E. Many major villages such as Faqali, Suwayq and Sudayrah, are located within the catchment area of Wadi Fara'a. In addition, the main road of Jeddah-Yanbu crosses the delta of Fara'a basin as it flows towards the Red Sea. The wadis that originate in the mountains are deep and narrow, and enclosed by steep, rocky slopes. Their valley bed contains boulders, cobbles, gravel and sand periodically scoured by flash floods. Three main streams are forming Fara'a basin, which are Wadi Rakho, Wadi Kubar and Wadi Nakhli (Fig. 3). The wadi catchment has many small tributaries, which are typical in the basement complex rocks, and their longitudinal profiles follow NW-SE directions indicating that they are most probably controlled by major structures of the red sea rift. These three major wadis meet near Suwayq town and form one main channel as it drains towards the Red Sea coastal plain (Fig. 4a).

Wadi Fara'a drains the basement complex rocks and due to lack of rainfall, drought occurs in the downstream of the wadi (Fig. 4b). In the upstream, native trees such as Acacia are abundant in Wadi Rakho (Fig. 4c). In addition, date and palm tree farms as well as grazing lands are irregularly distributed in the area (Fig. 4d).

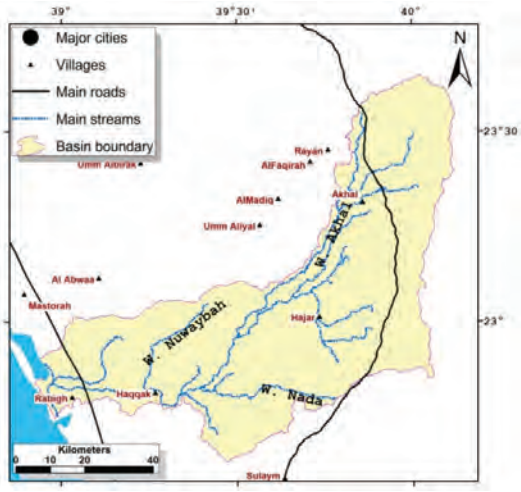
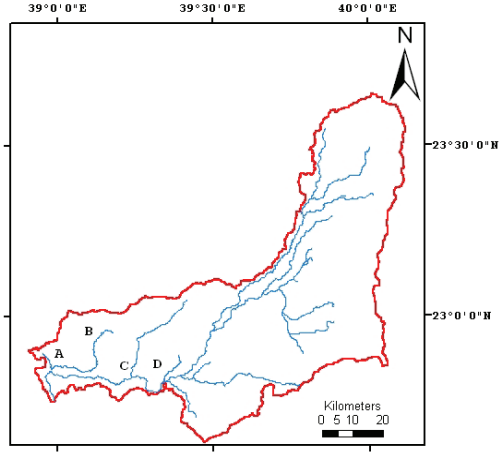


Fig. 1. Wadi Rabigh main physiographic features.

(a). Wadi Rabigh outlet.

(b). Ain Haqqaq in Wadi Rabigh.



(c). Wadi Rabigh-Al-Akhal confluence.

(d). Wadi Rabigh Dam site.

Fig. 2. (a, b, c, & d) Physiographic features of wadi Rabigh.

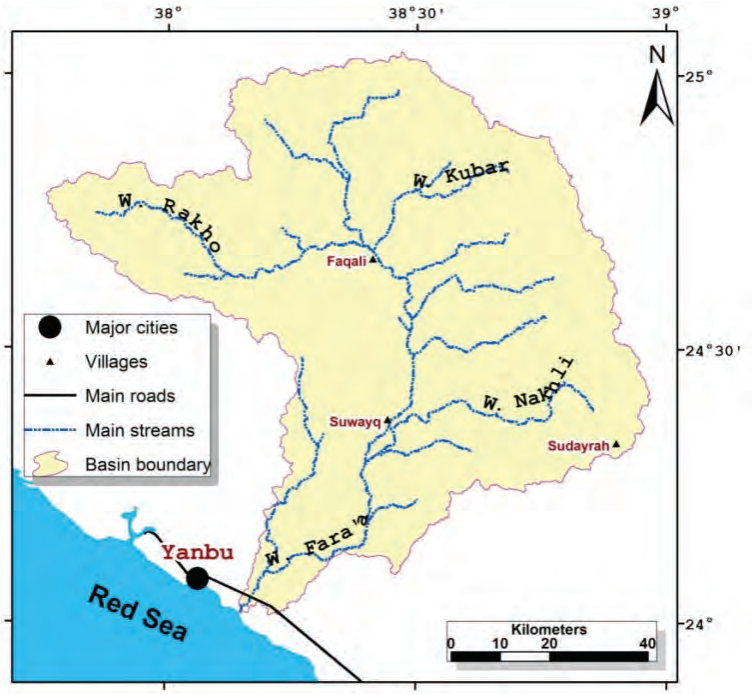


Fig. 3. Wadi Fara'a main physiographic features.

Results and Discussion

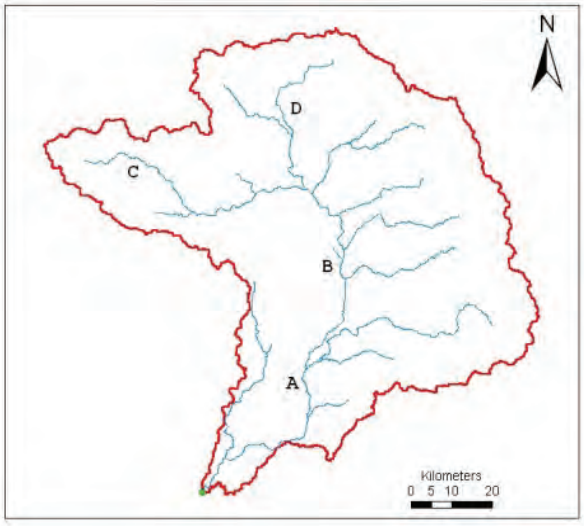
Rabigh Area

Figure 5 shows the land use of Rabigh city. The city is divided into six main districts: Industrial Zone, Port zone, Residential Areas, Sea Resort, Educational Zone, and a Central Business District (CBD) which includes the Financial Island.

The Industrial Zone is estimated to cover 63 million m², which will be dedicated to industrial and light manufacturing facilities identified as key growth drivers of the Saudi economy. With an estimated area of 13.8 million square meters the Sea Port will be the largest in the region. The port will have facilities to handle cargo and dry bulk. The residential area will be divided into smaller residential, commercial, and recreational areas. The educational zone is planned to consist of a university campus flanked by two research and development parks. CBD is planned to offer 3.8 million m² of office space, hotels and mixed-use commercial space.

(a). A well along Wadi Fara'a Downstream.

(b).Signs of drought in Wadi Fara'a.



(c). Wadi Rakho upstream and native trees.

(d). Farms in Wadi Kubar.

Fig. 4. Physiographic features of wadi Fara'a.

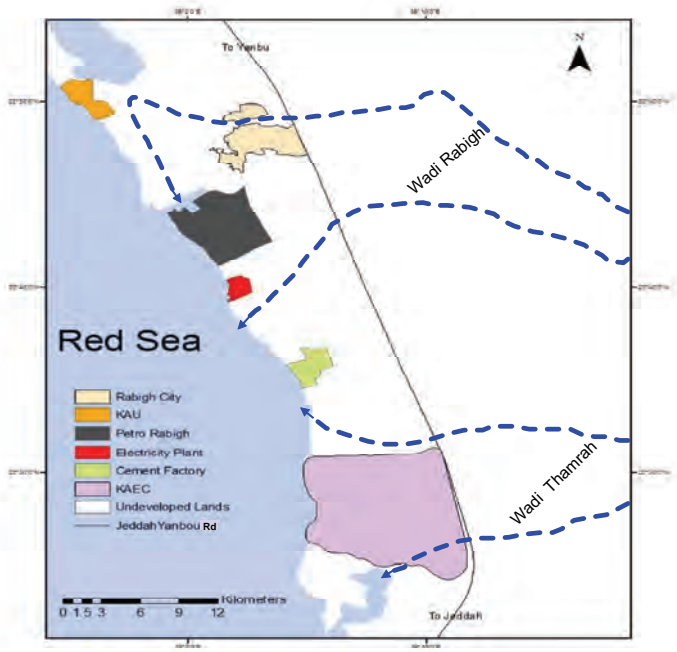


Fig. 5. Land use map of Rabigh city.

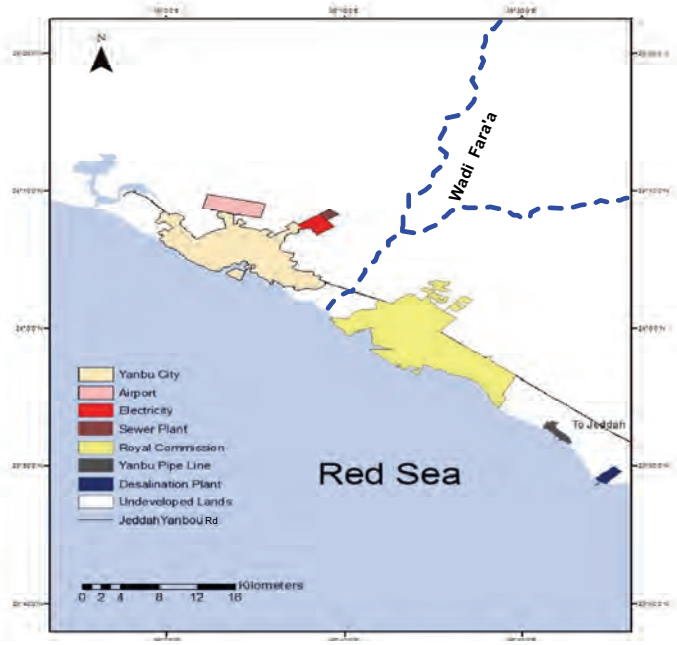


Fig. 6. Land use map of Yanbu city.

Yanbu Area

The Yanbu economy was traditionally dependent on the pilgrim trade and the export of agricultural products, especially dates. Its harbor is being enlarged and improved to ease the pressure on Jeddah. The city has pipelines built in the 1980s for the delivery of petroleum and petroleum products to a major petrochemical complex at Yanbu. The town has a small airfield that connects the city to the rest of the country. The new Industrial City of Yanbu was planned as the spearhead for the modernization of the whole of Saudi Arabia's rural northwestern coastal region. It would also provide a new strategic outlet on Red Sea shipping lanes, to handle most of the Kingdom's sea-borne trade.

The industrial city of Yanbu functions not only as a prominent port on the Red Sea and as an industrial city but also as a home and community for the inhabitants of the city. The City has one of the main petrochemical industries and desalination plants in the Kingdom. Figure 6 shows the different land uses in the city of Yanbu.

Risk Analysis

Slope Risk

The Slope factor is one of the major hydromorphometric parameters needed for flood risk assessment. However, the aspect of the slope is the direction that runoff would take under the influence of gravity and resembles the angle of the maximum slope. In Wadi Rabigh, Figure 7 shows the mean slope produced from DEMs using GIS software. Main streams start from deep valleys in the lava Harrats in the east and high slope mountains in the middle of the basin. In the downstream, where Rabigh city situated, factories and highways are located, they are subject to flood risk in the flat coastal area. However, the threat of flood comes from the runoff accumulations in the main channel downstream as it reaches the coastal plain causing flooding to villages and farms such as Haqqaq agricultural area and Rabigh city.

In Wadi Fara'a, Figure 8 shows the mean slope produced from DEMs using GIS software. It shows that high mountains cover most of the basin, with severe to very severe slopes. In downstream, the slope is categorized as slight to very slight as the wadi goes into the coastal plain area. Although the Wadi Fara'a basin is relatively large it is characterized

by low population and human settlements with limited numbers of villages due to the high relief and the ruggedness of the mountainous in the eastern part of the basin and also due to low rainfall density. The wadi's tributaries converge in an area between the mountains with low slopes before it reaches the coastal plain causing a decrease of the runoff velocity and thus causing low flood risk to coastal villages and the city of Yanbu.

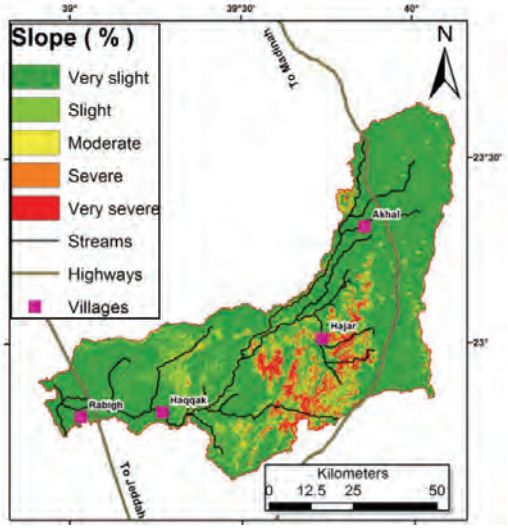


Fig. 7. Slope classes of wadi Rabigh.

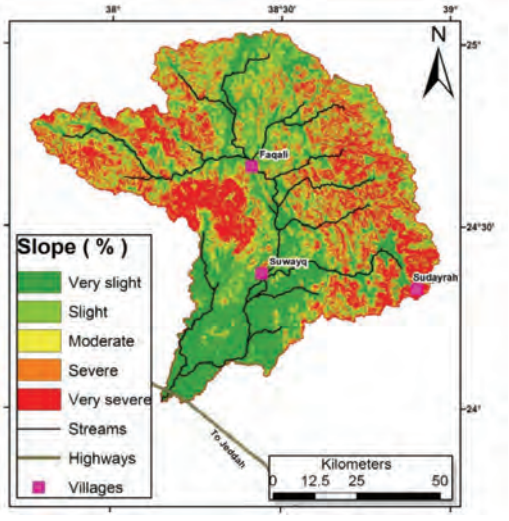


Fig. 8. Slope classes of wadi Fara'a.

Hydrological Risk

The hydrological hazard maps are essentially based on the characteristics of the floodplain. It involves data collection and preparation, model creation and execution, and mapping. A floodplain analysis requires stream channel cross-section, discharge rates in specific storm of interest, loss coefficients and hydraulic boundary conditions.

In the present study, these areas are classified into three risk categories according to the hydrologic situation (high, medium and low risk). These categories are dependent on buffer zones of risk assessment for cities, roads and villages that are situated mostly in the downstream areas of the basins (Fischer and Fischenich, 2000).

Figures 9 and 10 show the hydrological risk buffer zones for the delta of Wadi Rabigh and Wadi Fara'a, respectively. Most of the land use and roads in the vicinity of this area are located within the buffer zone of the main Wadi's channels. Streams specially North and East of Rabigh city, and Jeddah-Madinah expressway, Wadi Fara'a would also have the same level of risk to Jeddah-Madinah expressway , plus the risk to the central and southern part of Yanbu city.These areas are found to be subject to high flooding risk, especially during the local heavy annual storms (which occurred usually in October and November). Flat areas in both cities are subject to the accumulation and formation of water ponds and lakes, which increases environmental and health risks. In the mountains areas the slope factor has the advantage of driving storm water into streams and channels, but it is considered medium flood risk to available human structures and activities.

Land Use\ Land Cover Risk

Land use and land cover are dynamic entities, which vary both spatially and temporally, especially in agricultural areas where the crop rotation patterns, crop type, and total acreages planted in crops vary from year to year. Risk assessment of land use is classified into two main categories, high risk and medium risk. The high risk category includes valuable infrastructure which can be the subject of floods. Medium risk is designated for areas with low population and seasonal agriculture lands that are located in flood zones. There are no areas of low risk to man-made environment, and these two risk zones have no impact on the reduction of the quality of life. Figures 11-12 show the productive and important areas that are subjected to flooding with the proposed classification degree of hazards.

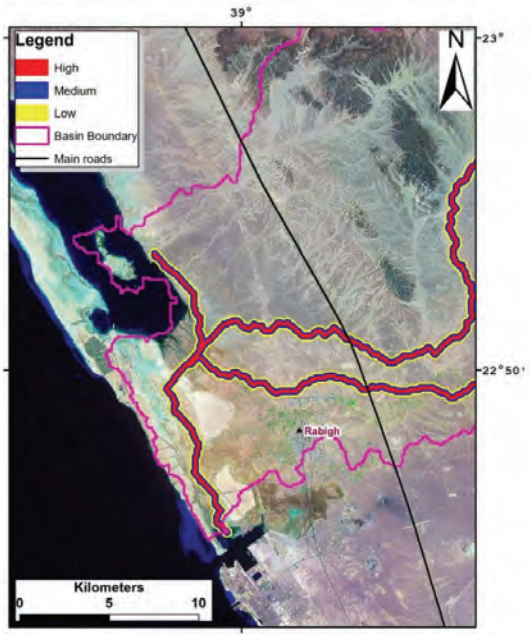


Fig. 9. Flood risk zonation map at the delta of Wadi Rabigh.

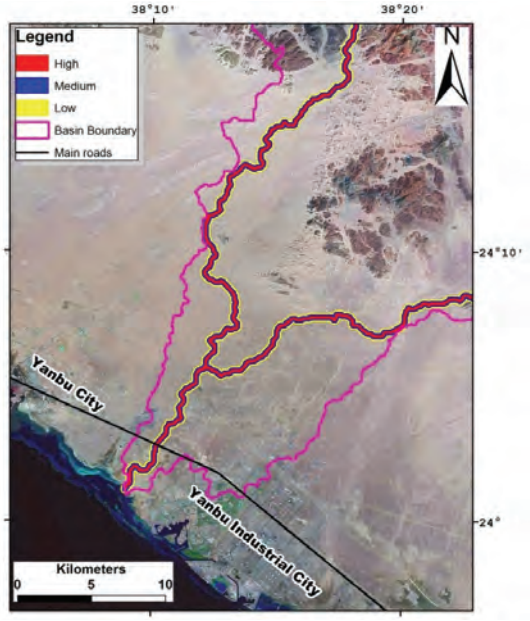


Fig. 10. Flood risk zonation map at the delta of Wadi Fara'a.

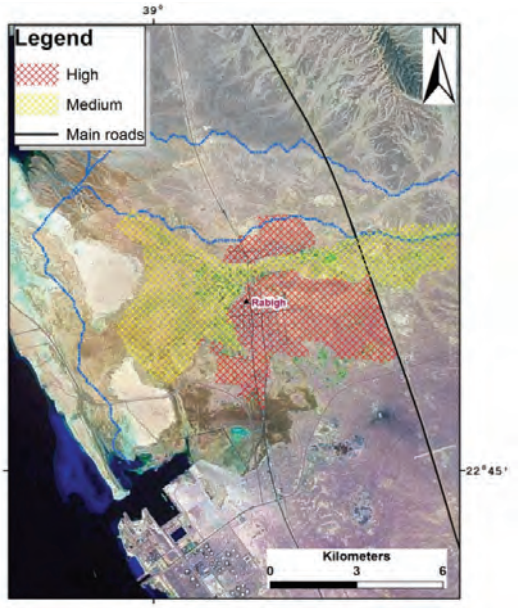


Fig. 11. Distribution of land use risk classes in Rabigh area.

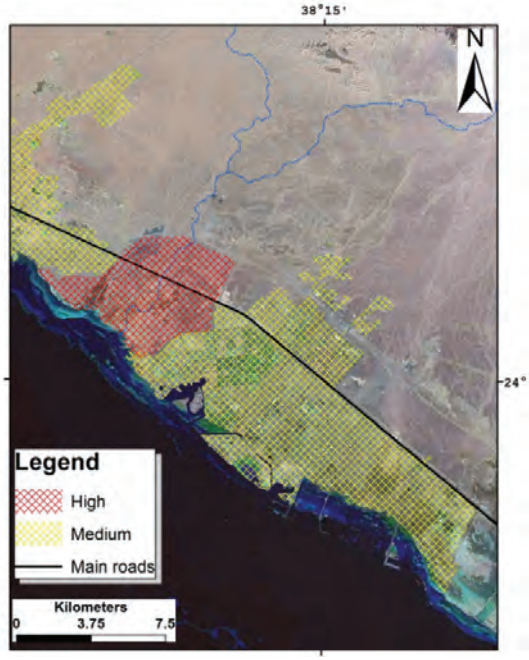


Fig. 12. Distribution of land use risk classes in Yanbu area.

Conclusion

Depending on the previous risk analysis of Wadi Rabigh and Wadi Fara'a which would assist in finding the best flood control solution through locating the safe areas for future development and planning in the region. The importance of the study area stems from the fact that it includes two important economic cities in the western part of Saudi Arabia. In addition, Yanbu is an important harbour for the oil industries. The emergence of King Abdullah Economic city (KAEC) in Rabigh city is adding another important value to this part of the country. The location of hazard zones would assist in determining dam locations and the location of human settlement and activities. It is recommended that for the future expansion and development of these cities and other towns in this part of Saudi Arabia the high parts of the coastal plain should be used due to the fact that the lower lands and areas that come across wadi channels are characterized as high flood risk zone. It is recommended that detailed and thorough studies be conducted for all basins in order to deepen the understanding of the flood risk associated with storms in the region.

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استخدام نظم المعلومات الجغرافية لتحديد الأخطار الناتجة عن السيول لبيئة المدن مع التطبيق على مدينتي ينبع ورابغ غرب المملكة العربية السعودية

أحمد عبدالله المضيان

قسم الجغرافيا، جامعة الملك عبدالعزيز،

ص. ب. ٨٠٢٥٨، جده ٢١٥٨٩ – المملكة العربية السعودية

المستخلص. يتميز غرب المملكة العربية السعودية بالجفاف وكون الأمطار فيه متغيرة بشكل شديد مكانيًا وزمنيًا. وتحدث السيول الفجائية عقب الأمطار الشديدة مما يؤدي إلى خسائر في الأرواح وتدمير للممتلكات، وعلى امتداد هذا الجزء من المملكة العربية السعودية والممتد على طول الساحل الشرقي للبحر الأحمر حيث تقع مدن كبيره تكتسب أهمية بالغه من الناحية الاقتصادية. وتهدف هذه الدراسة إلى استخدام تقنيات نظم المعلومات الجغرافية في تحديد وتصنيف المناطق المهددة بأخطار السيول في كل من مدينتي ينبع ورابغ، ولقد تم في هذه الدراسة تحديد المناطق المهددة بأخطار السيول ومن ثم صنفت إلى ثلاثة فئات وربط ذلك باستخدامات الأرض وغطائها في هذه المناطق مما مكن من التوصل إلى أن المخاطر الناتجة عن السيول لبيئة هاتين المدينتين وللإنسان فيهما كانت في الغالب تصنف على أنها متوسطة الخطورة. ولقد وجد أن هذه الأخطار ناتجة عن وقوع معظم استخدامات الأرض والطرق في منطقة الدراسة بجوار مجاري الأودية الرئيسية والقنوات المتفرعة منها، إضافة إلى ذلك تم تحديد الأماكن المعرضة لمخاطر السيول الناتجة

عن الأمطار الغزيرة المحلية هناك حيث وجد أن أخطار السيول والتي تواجهها مدينة رابغ تتركز في الأجزاء الشمالية والشرقية منها أما بالنسبة لمدينة ينبع فوجد أن الأخطار الناتجة عن السيول تتركز في الأجزاء الوسطى والجنوبية منها.

الكلمات الدالة: فيضانات، تحليل مخاطر، البيئة الحضرية، نظم المعلومات الجغرافية، ينبع، رابغ