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CASE STUDY

FLOODS IN EL BAYADH CITY: CAUSES AND FACTORS

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ABSTRACT

Over the last two decades, climatic changes have played a major role in increasing the frequency of floods. El Bayadh city in Algeria has experienced many floods over the last years; the worst flood occurred in October 2011, which affected both population and property.

In this paper, some of the local parameters that contribute to flooding in El Bayadh city were analyzed. These include the constriction caused by urban expansion at the edges of Wadi Deffa, which crosses the city, considerably reducing its cross-section and thereby increasing the risk of flooding. The lack of storm drain designs for severe rainstorms contributes to the stagnation of storm water, further increasing the risk. A reduction in the cross-section of the Wadi leads to a change in the flow velocity, which contributes to the overflow.

To mitigate the risk, a redevelopment of Wadi Deffa in the zones that are at risk of overflow is necessary. For this purpose, a flood hazard map of the October 2011 flood was realized based on a numerical simulation using HEC-RAS software and the ArcGIS system. This map can be used as a reference to plan the necessary actions to mitigate flooding in El Bayadh city.

Keywords: Floods, HEC-RAS, Wadi Deffa, El-Bayadh city, Algeria.

INTRODUCTION

Floods have become a major concern due to the loss of lives and property they cause. Although they have less precipitation, arid and semiarid regions are not immune to this danger. In Algeria, many of these regions have suffered from this phenomenon. For example, floods were recorded in Adrar in 2004 (3 dead), Ghardaïa in 2008 (47 dead with a flow of 3200 m3/s), Bechar in 2008 (8 dead), El Bayadh in 2011 (12 dead), Tamanrasset in 2015 with 13 dead and in 2018 with 5 dead, Illizi in 2019 (1 dead), Saida in 2020 (02 dead) and M'sila in 2021 (6 dead) (Civil Protection). These floods are usually characterized by sporadic rainstorms of short duration and high intensity (Hachemi and Benkhaled, 2016). Fig. 1 shows some damage caused by these floods.

A combination of factors contributes to the occurrence of these floods, including climate change and population growth (Linde et al., 2010). The latter leads to urban expansion, which has become one of the most serious environmental issues (Al Saud, 2015). Urbanization considerably increases the risk of flooding (Nirupama and Simonovic, 2007), especially when the constructions are erected on the edges of the Wadi, as is the case in Algeria's arid and semiarid regions (Hafnaoui et al., 2020). In addition, other factors, such as rainstorms, vegetation reduction and changes in hydrologic regimes in river basins, also play a role (Chang et al., 2013).

a) Flood of October 2008 in Ghardaïa

b) Flood of October 2008 in Bechar

c) Flood of October 2011 in El Bayadh

Figure 1: Examples of floods in Algeria's arid and semiarid regions

Situated in the semiarid regions of Algeria, El Bayadh city witnessed many floods over the last years; the worst was in October 2011. The latter affected both population and properties. Understanding the causes that affect the occurrence of floods helps to suggest appropriate solutions to reduce these risks, and several investigations have been conducted on the factors that contribute to flooding. Saghafian et al. (2008) studied the effects of land use changes on flooding in the Golestan watershed (Iran). Precipitation amount and intensity, urbanization, and population growth were among the factors investigated by Chang et al. (2009) to determine the causes of flooding in Gangwon Province (Korea). Hafnaoui et al. (2009) investigated the impact of climate and morphological factors on floods in Doucen city (Algeria). Youssef et al. (2016) assessed the causes of flash floods in Jeddah city (Kingdom of Saudi Arabia); different causative factors were analysed. These include geomorphologic features, anthropogenic effects and urban area changes, drainage networks, rainfall analysis and climatic changes. Hachemi et al. (2019) analyzed the effects of morphometric characteristics on flash flood responses in the El Bayadh region. Nezzal et al. (2015) delimited the hazard zone of the Wadi Hamiz for different levels; the results showed that precarious habitats are the most exposed to the risks of flooding. Kouadio et al. (2018) and Hountondji et al. (2019) analyzed several factors that contribute to flood risk, including climate variability, land use, population behavior, topographical accidents, and storm drainage. Second, the authors proposed a flood management plan that helps minimize flood risks.

The realization of flood hazard maps using numerical modeling is among the solutions that mitigate the risk of flooding. A combination of GIS using the HEC-GeoRAS application and HEC-RAS software has been used in many studies (Desalegn and Mulu, 2021; Namara et al., 2022; Jagadeesh and Krishna Veni, 2021). This paper analyses, in the first part, the factors that contributed to floods in El Bayadh city. The effect of land use change, storm drainage systems and morphometric characteristics will be analyzed. In the second part, the October 2011 flood flow will be estimated based on the limits traced by the technical service of El Bayadh municipality. The roughness coefficient and the flood flow regime will be discussed. The flood hazard map for October 2011 will be presented using ArcGIS and HEC-RAS software.

MATERIAL AND METHODS

Study area

El Bayadh Province is located in the semiarid southwest of Algeria. El Bayadh city (Study area) is the capital of El Bayadh Province; it lies between 33°40’30” to 33°41’40” N latitude and 01°00’00” to 01°01’60” E longitude. Wadi Deffa is the main watercourse crossing the city. Fig. 2 shows the location of El Bayadh city.

El Bayadh territory is divided into three geographical bands parallel to the Mediterranean Sea, successively from north to south: the zone of high steppe plains, the zone of the Saharan atlas and the pre-Saharan zone. The El Bayadh region has two climate types: semiarid in the north and arid in the south (El Zerey et al., 2009; Regagba, 2012).

In the study area, the average annual rainfall equals 265.68 mm/year. These data were obtained from the National Meteorological Office (NMO) from 1988 to 2011. Fig. 3 shows the annual and average annual rainfall in the study area.

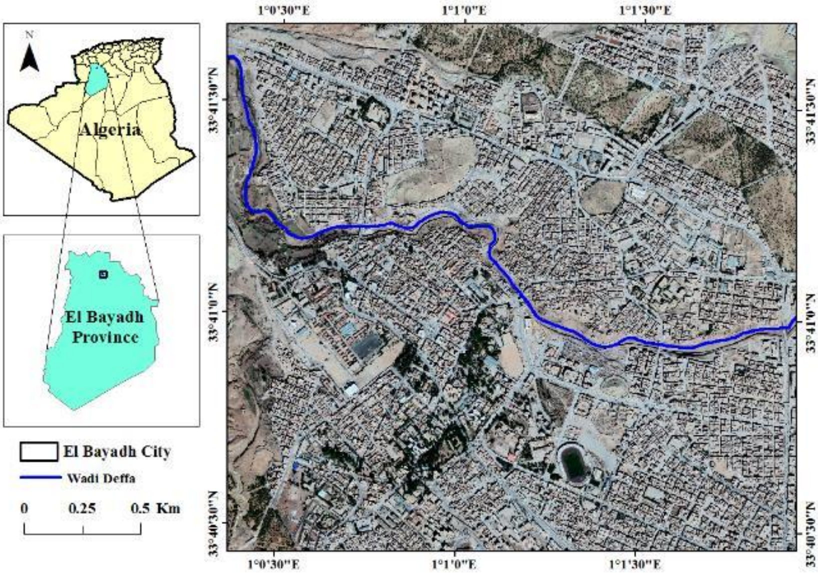

Figure 2: Location of El Bayadh city

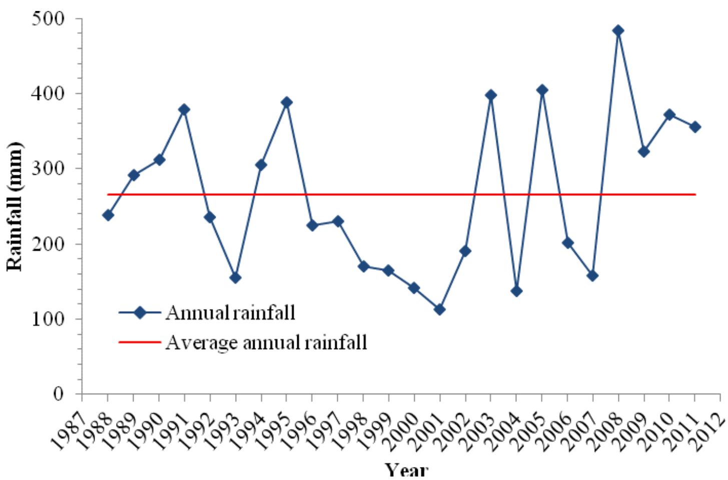

Figure 3: Distribution of the annual rainfall during 1988-2011 (*Source: Meteorological station of El Bayadh*).

The annual amount of precipitation in 2008 was the largest in this period, with a value of 484.4 mm, which was nearly double the average annual rainfall.

The most important floods in El Bayadh occurred in October 2008 and 2011, and the flood on 1 October 2011 was the largest in terms of losses (Hafnaoui et al., 2020). Fig. 4 shows that the month of October is the rainiest month.

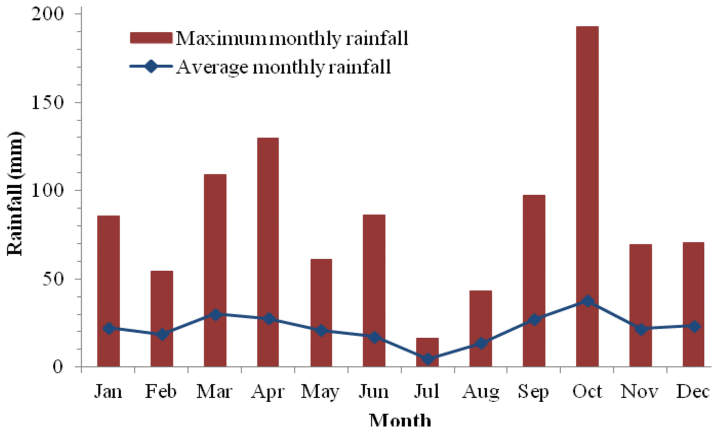

Figure 4: Distribution of the average and maximum monthly rainfall during 1988-2011 (*Source: Meteorological station of El Bayadh*).

The highest rainfall was recorded in October, with a monthly average of 37.67 mm and a maximum of 192.8 mm. July is considered the month with the least rainfall, with a monthly average equal to 4.78 mm and a maximum of 16.5 mm.

Population growth

The population growth rate of El Bayadh city is very significant (3.8% per year). According to the Algerian National Statistics Office, the population estimated at 15221 in 1966 reached 28176 inhabitants in 1977. This number increased to 41119 in 1987 and then to 60127 in 1998. The latter almost doubled in 2015, where it attained 108017. Fig. 5 shows the population growth of the city.

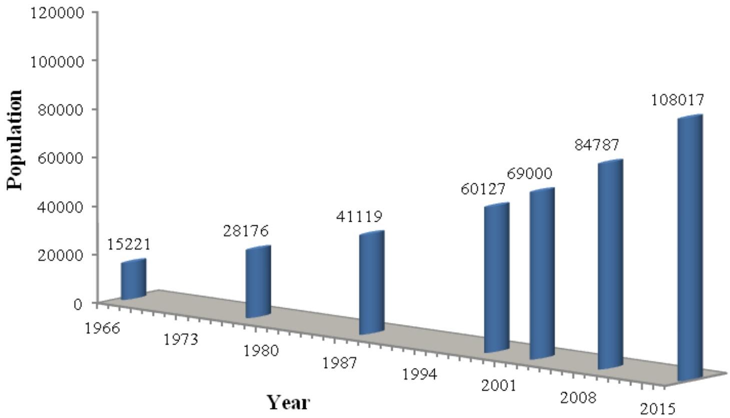

Figure 5: Population growth of El Bayadh city during 1966-2015 (*Source: Algerian National Statistics Office*).

Flood of October 2011

The October 2011 flood is one of the most devastating floods that affected El Bayadh city. This flood occurred because of the overflow of Wadi Deffa, which crosses the city, leaving 12 dead, tens injured, 2 collapsed bridges and hundreds of destroyed houses (Civil Protection 2014). Hafnaoui et al. (2020) estimated the flow of the October 2011 flood using a hydrologic study and based on the amount of precipitation (60 mm) recorded by the El Bayadh meteorological station (National Meteorological Office 2013) for a flow of 426.45 m^3/s. More information about the hydrological study can be found in Hafnaoui et al. (2020). In this research work and for a realistic estimate, the flow of the October 2011 flood will be based on a hydraulic study.

Flow estimate of the October 2011 flood

After the October 2011 flood, the technical service of El Bayadh municipality determined the limits of the flood to assess the damage to buildings and houses. Due to a lack of hydrometric data in Wadi Deffa, the estimate of the flood was based on the limits traced by the technical service of El Bayadh municipality. The geometry of the study area was determined using the HEC-GeoRAS application of the ArcGIS system to trace Wadi Deffa and the limits of the flooded area. This was based on the global Digital Surface Model (DSM) database (ALOS World 3D - 30 m, AW3D30) with a resolution of 30 m downloaded from the Japan Aerospace Exploration Agency (JAXA) (https://www.eorc.jaxa.jp/ALOS/en/aw3d30/) and Google Earth while taking into consideration buildings and bridges. HEC-RAS 4.1 software that works with the ArcGIS system through the HEC-GeoRAS application was employed to simulate the mentioned flood. Fig. 6 shows the limits traced by the technical service and the cross-section chosen to estimate the flow. Fig. 7 shows the geometry of Wadi Deffa using the HEC-GeoRAS application in ArcGIS.

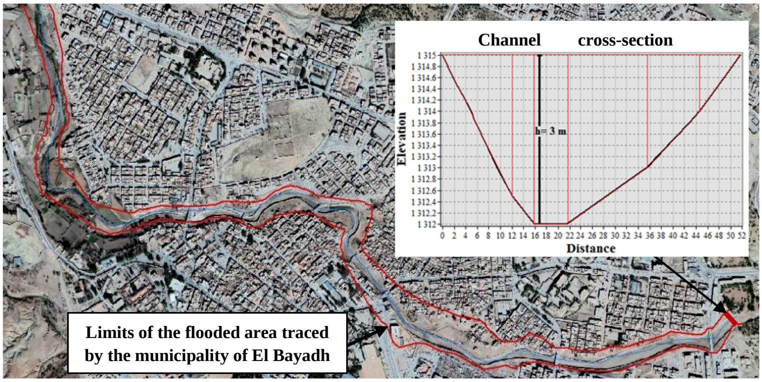

Figure 6: Limits of the October 2011 flood

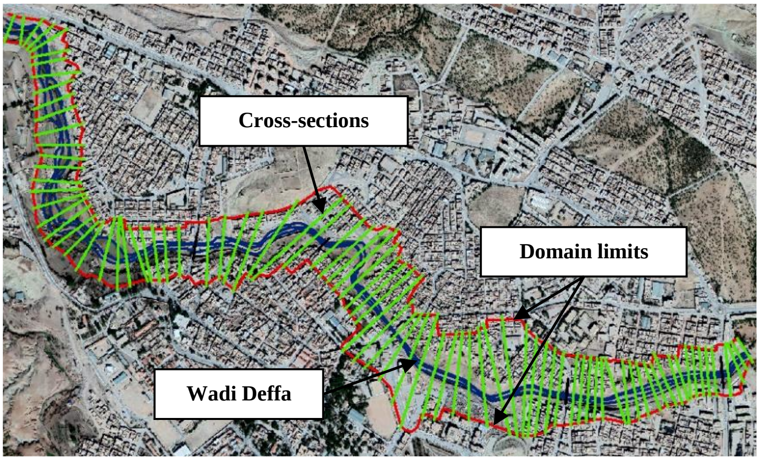

Figure 7: Geometry of the study area using the HEC-GeoRAS application in ArcGIS

HEC-RAS software has been used in many studies. For instance, in (Ahmad et al., 2010); Suriya and Mudgal, 2012; Hafnaoui et al., 2013; Yamani et al., 2016; Patel and Gundaliya, 2016; El-Shinnawy et al., 2017; Lahsaini and Tabyaoui, 2018; Abdulrazzak et al., 2019; Bekhira et al., 2019; Bekhira et al., 2019; Kubwarugira et al., 2019; Kumar et al., 2020; Madi et al., 2020; Pathan and Agnihotri, 2021; Asitatikie et al., 2021; (Salman et al., 2021), it was used for the numerical simulation of floods as well as for the realization of flood hazard maps.

The estimate of the October 2011 flood flow was based on the Manning-Strickler formula given below (Chow, 1959):

$$Q = \frac{1}{n} A R_h^{2/3} \sqrt{S_0} \quad (1)$$

where A is the wetted area, R_h is the hydraulic radius, S_0 is the channel slope and n is the Manning coefficient. The interval of the Manning coefficient n of the study region varies between 0.025 s/m$^{1/3}$ and 0.035 s/m$^{1/3}$ (Chow, 1959). Fig. 8 shows the geometry of Wadi Deffa in HEC-RAS software.

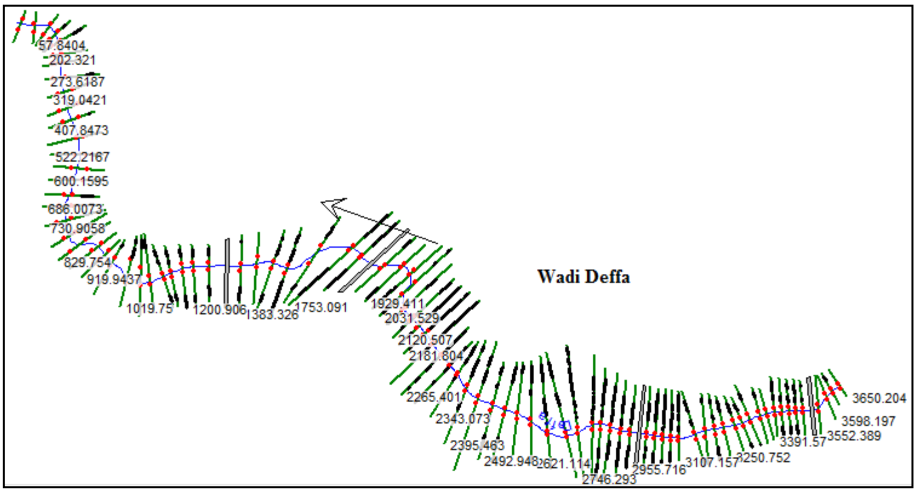

Figure 8: Geometry of Wadi Deffa in HEC-RAS software

To obtain more approximate limits than those traced by the technical service, three values of the roughness coefficient were proposed for this study, n = 0.025; 0.03; 0.035 s/m$^{1/3}$, through which three values of the flow were obtained: Q = 458.7, 382.3, and 327.7 m^3/s. The cross-sectional area was estimated at 94.5 m^{2,} and the channel slope was 0.0068.

RESULTS AND DISCUSSION

Land use change

An increase in population has been followed by an increase in the number of dwellings. The impact of urbanization on flooding risks has become increasingly evident (Chang and Franczyk, 2008). Urban growth in El Bayadh city translates into land use change. Indeed, this urban expansion reduces the cross section of the Wadi and renders some areas vulnerable to flooding. Fig. 9 shows two pictures of the same section of the city taken in 2003 and 2019. The area surrounded by red in the second picture represents the new dwellings built over the last years. The new dwellings were built next to Wadi Deffa. This indicates that the urban expansion in the city has not taken into account the major limits of the Wadi and the likelihood of overflows. This change in land use reduces the cross-section of the Wadi, which thereby increases the risk of flooding.

a) Google Earth 07/2003

b) Google Earth 07/2019

Figure 9: Urban expansion of El Bayadh city

Storm drainage systems

The lack of storm drains capable of containing severe rainstorms increases the risk of flooding in the city. Fig. 10 shows stagnation of water in the streets of El Bayadh city after the October 2011 flood, which reveals the inability of the storm drains to evacuate storm water.

Figure 10: Stagnation of water after the October 2011 flood (El Bayadh municipality)

Morphometric characteristics

The form and dimensions of the Wadi play an important role in reducing or increasing flood risk. The rapid transition from the supercritical to subcritical flow regime leads to the formation of a hydraulic jump. This transition simultaneously causes a decrease in the flow velocity and an increase in the water level downstream, which leads to flooding (Hafnaoui and Debabeche, 2020). To investigate the effect of this factor, three cross-section values were selected (Fig. 11) as follows: A_1 = 66.7 m^2; A_2 = 12.1 m^2 and A_3 = 6.4 m^2. One can observe a decrease in the cross-section areas in the flow direction, which contributes to the overflow of the Wadi. Furthermore, the continuous decrease in the Wadi area leads to a decrease in upstream flow velocity. This, in turn, leads to stagnation of water in this section and thereby contributes to overflows.

The low flow velocity can be explained by the presence of deviations in the Wadi, as is the case with the Deffa Wadi; its nonrectilinear shape contributes to reducing the flow velocity and consequential overflows.

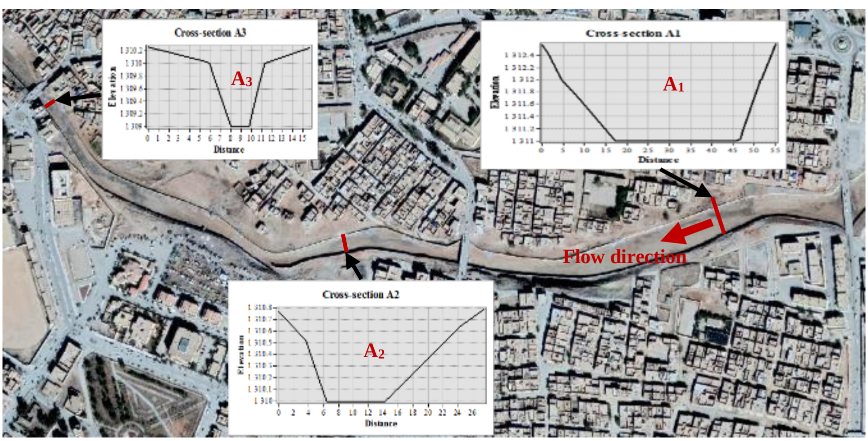

Figure 11: Cross-section changes in Wadi Deffa

Numerical simulation of the October 2011 flood

The numerical simulation of the October 2011 flood was carried out through two stages: in the first stage, the effect of the roughness coefficient change n was analyzed, while in the second stage, the type of flow regime was investigated.

The proposed flows for this simulation are Q_1 = 458.7 m^3/s for n = 0.025 $s/m^{1/3}$; Q_2 = 382.3 m^3/s for n = 0.03 $s/m^{1/3}$; and Q_3 = 327.7 m^3/s for n = 0.035 $s/m^{1/3}$.

For this simulation, depths upstream and downstream are considered critical as boundary conditions, and the flow regime is assumed to be steady and mixed. Fig. 12 shows the limits of the October 2011 flood traced by the technical service of El Bayadh municipality and the simulated flooded areas for the three proposed flows.

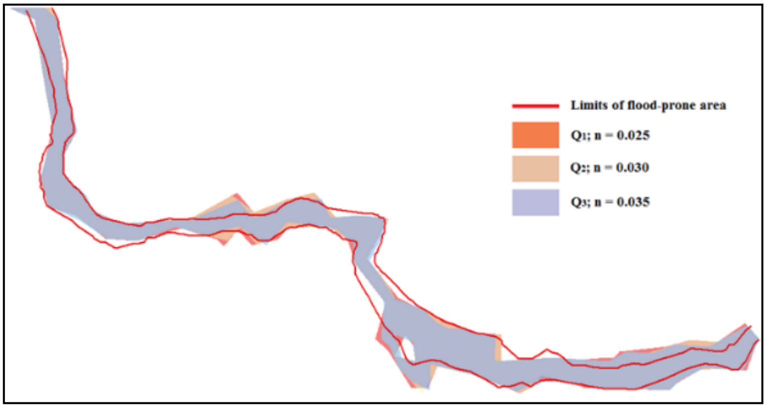

Figure 12: Limits of flooded areas for the proposed flows

A comparison between the limits of the proposed flows shows that the flow limits Q_2 and Q_3 are closer to the limits traced by the technical service. However, the flow limits Q_2 = 382.3 m^3/s for n = 0.03 $s/m^{1/3}$ cover a larger area compared to that of the technical service. It can be seen that the limits of some simulated regions do not agree well with those traced by the technical service; this could be due to the resolution of the digital model used.

To provide an idea of the flow regime in this flood, three flow regimes are proposed: subcritical, mixed and supercritical for the flow Q = 382.3 m^3/s.

Fig. 13 shows the simulation result of these three flow regimes.

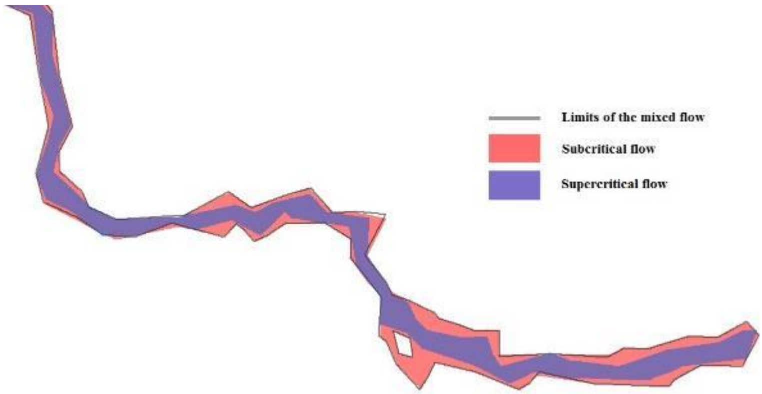

Figure 13: Flow regime of the October 2011 flood

The subcritical flow regime is closer to the limits of the mixed regime, which gives an indication that the flow regime of the October 2011 flood was subcritical.

To finalize the flood hazard map, the ArcGIS system was utilized. The final map of the October 2011 flood is illustrated in Fig. 14. The surface of the flooded area is estimated at 0.316 km^2, with a maximum water depth of 7 m. This map can be used as a reference for appropriate land use planning and flood management in flood-prone areas.

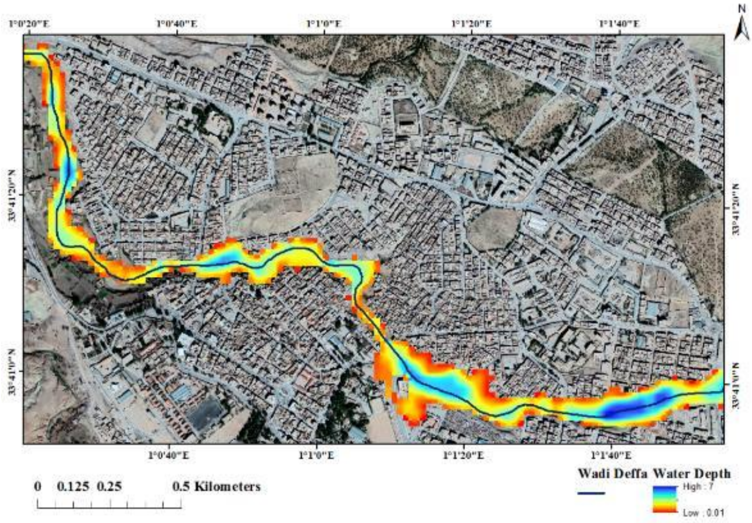

Figure 14: Flood hazard map of October 2011

Due to the previous development operation of Wadi Deffa by the local authorities, as well as the difficulty of relocating the population living in areas at risk of flooding, we suggest building dikes upstream of El Bayadh city to minimize the risk of flooding.

CONCLUSIONS

In this work, several factors that contributed to the occurrence of floods in El Bayadh city were studied, the most important being the urban expansion, storm drainage systems and morphometric characteristics of the Wadi. The presence of dwellings on the edges of the Wadi has considerably narrowed its cross-section, which augmented the flood risk. A decrease in the cross-section of the Wadi leads to decreased flow velocity, which in turn contributes to overflow of the Wadi. Additionally, the inability of the storm drains to contain severe rainstorms increases the risk of flooding in the city. Redevelopment of Wadi Deffa in the zones that are at risk of overflow is necessary. Based on the flood hazard map, flood-prone areas can be identified.

In this study, the October 2011 flood was simulated by HEC-RAS software, and the estimated flow was approximately 382.3 m^3/s. Comparison between the flood limits simulated by the HEC-RAS software and the one traced by the technical service of El Bayadh municipality shows good agreement. The flood hazard map of October 2011 drawn up in this study can constitute a useful tool to plan the necessary actions to mitigate flooding in El Bayadh city.

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