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FAICEL TOUT[a]

ASSESSING URBAN VULNERABILITY TO FLOOD RISK. A CASE STUDY IN BATNA CITY, IN NORTHEAST ALGERIA

Abstract

Based on a binary model that takes into account the physical characteristics of the watershed and the different social and economic characteristics of the Algerian city of Batna, we tried to clarify the vulnerable areas to flood risk. The study relied on geographic information systems and considered many factors that could affect the response of the watershed, namely height, slopes, permeability, proximity to major water courses, topographic wetness index, drainage density, normalized difference vegetation index, height above nearest drainage, population density, housing type, public equipment, and population. The research also considers a common area among four previous studies which was identified as a risk zone. The results indicate a high urban vulnerability in the city centre, near Al Maseel and Al-Hizam protection canals and wadi Al Gourzi. In contrast, the areas of medium vulnerability extend over large areas of the city. These results are related to the change in land use and illegal and legal expansion on non-urbanizable areas which are supposed to be subject to easement rights, and these results are mainly due to the physical properties of the watershed, as it provides suitable conditions for the emergence of runoff water, and the low-lying areas of it favor flooding, which can make it difficult to propose economic structural protection measures within the city, considered to be a drainage area for the watershed, and which will be a real obstacle for the authorities to get rid of the flooding problem in Batna.

Keywords: flood; vulnerability; GIS; city; Batna.

a Institute of Urban Techniques Management, cities and health Laboratory. University of Constantine 3, The New City Ali Mendjeli.B.P. ‘B’ 72, 25000 Constantine Argelia. faicel@univ-constantine3.dz

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EVALUACIÓN DE LA VULNERABILIDAD URBANA AL RIESGO DE INUNDACIONES. ESTUDIO DE CASO DE LA CIUDAD DE BATNA, AL NORESTE DE ARGELIA

Resumen

El presente trabajo se centra en clarificar las zonas vulnerables al riesgo de inundación en la ciudad argelina de Batna a partir de un modelo binario que tiene en cuenta las características físicas de la cuenca y los diferentes rasgos sociales y económicos. El estudio se basa en sistemas de información geográfica y contempla diversos factores que podrían afectar a la respuesta de la cuenca, como son la altura, las pendientes, la permeabilidad, la proximidad a los principales cursos de agua, el índice de humedad topográfica, la densidad de drenaje, el índice de vegetación de diferencia normalizada, la altura sobre el drenaje más cercano, la densidad demográfica, el tipo de vivienda, el equipamiento público y la población. Los resultados indican una alta vulnerabilidad urbana en el centro de la ciudad, cerca de los canales de protección de Al Maseel y Al-Hizam y del wadi de Al Gourzi. Por el contrario, las zonas de vulnerabilidad media se extienden por amplias zonas de la ciudad. Estos resultados están relacionados con el cambio de uso del suelo y la expansión ilegal y legal en zonas no urbanizables que se supone que están sujetas a derechos de usufructo, debido principalmente a las propiedades físicas de la cuenca, ya que proporciona condiciones adecuadas para la aparición de aguas de escorrentía, y sus zonas bajas favorecen las inundaciones, lo que puede dificultar la propuesta de medidas económicas de protección estructural en el área urbana, considerada una zona de drenaje de la cuenca, y que constituirá un verdadero obstáculo para que las autoridades se deshagan del problema de las inundaciones en Batna.

Palabras clave: inundación; vulnerabilidad; SIG; ciudad; Batna.

Introduction

Geographic information systems are considered effective tools for analyzing and assessing natural hazards and managing associated disasters (Abdulrazzak et al., 2019; Hammami et al., 2019), and they allow cities and their most important areas to prepare for scenarios that include different degrees of risk. In recent decades, their use has taken an upward trend in the study of floods, which are a major concern in many regions of the world (Al-zahrani et al., 2017), as an attempt to increase the resilience of cities and reduce their vulnerability, coinciding with the increase in extreme precipitation and the recurrence of this phenomenon in various cities worldwide (Shale et al., 2020).

Batna in Algeria is one of the cities that has received much attention from researchers in this context (Bella, 2021; Guellouh, 2017; Harkat, 2021; Slimani, 2020), as it represents a model city for the study of flooding and is mainly related to its position within the watershed (figure 1). These studies have resulted in the identification of flood risk areas for different return periods, and they unambiguously express the poor position of the city of Batna and the need for more measures to protect the city.

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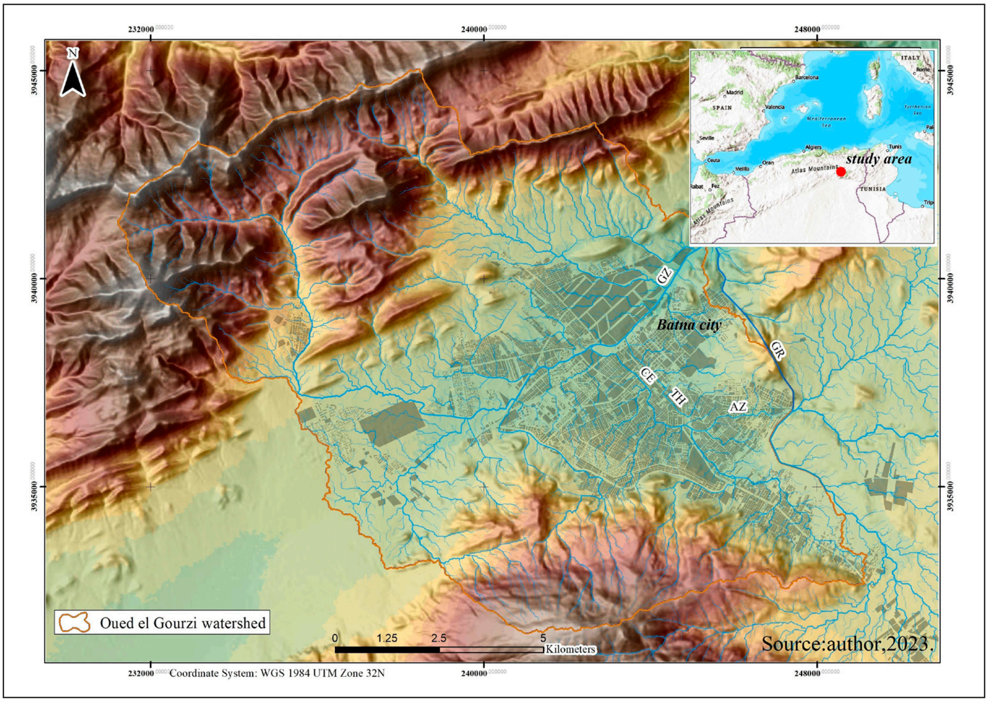
Through this research, we try to highlight one of the measures that can be adopted to assess the areas of vulnerability, as well as the preparation of authorities and individuals to develop plans that contribute to reducing the damage that these floods can cause.

The establishment of vulnerability maps is one of the most important procedures and non-structural measures that are adopted to reduce the potential damage of floods (Fariza et al., 2020), and it helps to assess the readiness of areas to be protected against this risk according to selected criteria (Rincón et al., 2018), on the basis of which the vulnerability of each area to this hazard and the places presenting this vulnerability are determined (Ajjur & Mogheir, 2020).

Building a flood sensitivity model is complex and accurate (Towfiqul Islam et al., 2021), relies on a multi-criteria analysis, and must take into account many topographic, hydrologic, and other factors that are typically associated with the occurrence of flooding (Rincón et al., 2018). Thus, the importance of the results increases by adopting many qualitative criteria and setting acceptable values for the weights of these benchmarks (Ajjur & Mogheir, 2020).

Figure 1. Study area



Source: author (2023).

Methodology

To build this model, we relied on many factors that we considered to be closely related to the phenomenon of flooding and which have been adopted in many studies of a similar nature (Cao et al., 2016; Costache, 2019; Danumah et al., 2016; Elsheikh et al., 2015; Fariza et al., 2020; Hallil & Redjem, 2022; Hammami et al., 2019; Slimani & Kalla, 2017; Tehrany et al., 2014). The study was carried out using the Weighted Overlay tool, one of the Arc toolbox mechanisms, which can be relied on greatly in decision-making in the determination process of appropriate sites for various purposes (Slimani & Kalla, 2017). The quality of the results of this tool is largely associated with the number of criteria used and their close relationship and real impact on the element studied (Rincón et al., 2018), which in our study represent these sensitive areas to flood risk. The outcomes can evolve depending on the weights assigned to each criterion, which express its importance (Rincón et al., 2018).

The study was carried out using the model in figure 2, and it is clearly divided into two categories: social and economic vulnerability factors, and a category that combines physical vulnerability features. The data entered are marked in blue.

In order to unify the cell values for all the criteria used in the model and to ensure its functionality, we have chosen the cell value of 30 meters for all of them, which is quite frequently the value relied upon in similar studies. This value can also be considered the highest available accuracy shared by the various free raw data.

Many studies (Cao et al., 2016; Costache, 2019; Danumah et al., 2016; Elsheikh et al., 2015; Hammami et al., 2019; Tehrany et al., 2014) refer to physical criteria that can be used to assess physical vulnerability. In addition, research works by Fariza et al., 2020; Hallil & Redjem, 2022 and Slimani & Kalla, 2017 indicate criteria that can serve to assess social as well as economic vulnerability.

Criteria used in the model

Criteria related to the physics of the watershed

Previous research: The model takes into account the results of four previous studies (Bella, 2021; Guellouh, 2017; Harkat, 2021; Slimani, 2020), where we identified a common area between these which is exposed to high flows in an estimated return period of 100 years and was assigned the first place in the reclassification, while the remaining of the area was positioned in the second place.

Drainage density: This is also an important element in prevention models (Ogden et al., 2011). Drainage density expresses the length of streams per unit area (km/km^2) (Hammami et al., 2019). The annexed map shows sections with high drainage density, which are at a higher risk than others, as they represent an advanced network that can affect adjacent areas.

Permeability: This is a factor that greatly affects the basin's response to rainfall. The higher the permeability, the lower the possibility of surface runoff and flooding, and vice versa. In our study, it was determined according to the hydrogeological map issued by the National Agency for Water Resources, which takes into account both geological formations and soil quality. We have identified two categories:

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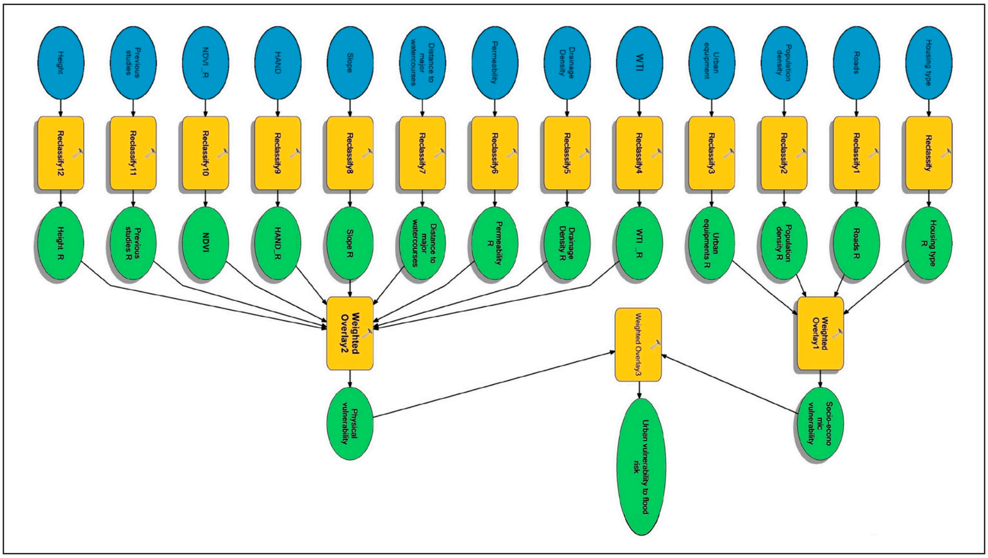
one with low permeability that includes even the urban area, and another one with medium permeability, present in a small percentage.

Figure 2. The structure of the vulnerability model used



Source: author (2023).

Slope: It is also one of the factors affecting flood, as it has an impact on the speed of water (Abu Al-Majd et al., 2020) and the duration of runoff (Ajour and Mughir, 2020). The slope also helps to identify areas prone to flooding, since these are usually located in flat areas (Rincon et al., 2018), normally not exceeding 3 %, and therefore a decrease in the degree of slope is considered as an increase in risk.

The slope map in figure 3 shows the details of the categories used; the map was created with a digital elevation model with an accuracy of 5 meters.

Regarding the classes used in the reclassification, the first class is given to slope (0-1 %), but it is also assigned the second (2-3 %), the third (3-8 %), the fourth (8-12 %) and the fifth position (in more than 12 % of the cases).

Height: This is an influencing factor, and it is highly related to flooding (Hammami et al., 2019; Towfiqul Islam et al., 2021), as the low areas of the basin are flood-prone areas, especially near the drainage points, and the possibility of flooding decreases with the increase in height and near the watersheds' boundaries. The importance of using this factor increases with the range of height between the highest and lowest value in the watershed also going up; in our watershed it reaches 1000. Therefore, this factor is effective in building the model. Figure 3 shows the classes that have been adopted.

Distance to major watercourses: Areas near major rivers are frequently affected by flooding (Rincón et al., 2018), and we included this criterion by adopting the proximity of the important wadies in the watershed, which are wadi Al Gourzi (GZ), wadi Hamla, wadi Saqn, wadi Azzeb (AZ), and wadi Bouydan previously or wadi Tazoult. It also relied on the proximity of the 1 G protection channel, the Thalweg (TH), Hizam (CE) and the protection channels on the southern side of the city. We used the distance tool in the Arc toolbox, as seen in figure 3, showing the watercourses network that was considered and the classes that were adopted in the reclassification.

Regarding the classes used in the reclassification, the first one is given to distances less than 50 m, the second one to 50-100 m, the third class to 100-200 m, the fourth category to 200-500, and the fifth one to more than 500 m.

Topographic wetness index (TWI): TWI is an important index used to estimate the extent to which topography controls the hydrological process (Xiao et al., 2016). It can be considered as a critical factor in flood vulnerability study models. In our analysis, we relied on a method originating from Beven & Kirkby (1979) and it determined one of the most dangerous areas that represent the cells in which water can accumulate. The index takes into account the flow accumulation and the slope, and it also gives very reliable results in determining the immersion areas. The results of the use of the index are presented in figure 4.

Normalized Difference Vegetation Index (NDVI): With an increase in vegetation cover comes an increase in rainfall interception rate and permeability, which in turn leads to a delay and decrease in the percentage of water that can participate in the formation of surface runoff. The index can be obtained by the following formula: NDVI = (Band 5 - Band 4) / (Band 5 + Band 4), where Band 5 represents the infrared band and Band 4 represents the red band for Landsat8.

The natural breaks classification method was used to divide the vegetation into five categories, and the spatial distribution of these categories is shown in the map. In general, it can be said that the first type after reclassification represents the urban area, while the fifth one stands for the least risky category, which represents the forests of the Belzma National Park and part of the Ish Ali Mountain forests.

Height above nearest drainage: This criterion can be applied in various fields and disciplines (Nobre et al., 2011) to assess vulnerability effectively. It was developed using DEM and drainage network data (Rincon et al., 2018), and we utilized the method described by Dilts (2015) to identify flood-prone areas at different elevations near the drainage network.

Socioeconomic criteria

Housing type: Individual housing is the dominant pattern in the city of Batna, and much of it represents illegal housing. The map in figure 4 shows that a lot of individual housing is located along the major watercourses; in contrast, collective housing is generally found far from the city centre, which has been identified in various studies as prone to flooding.

Population density: Population density can be considered as the most important element in the assessment of social vulnerability because its height is directly related to damage increase in case of disasters. The highest densities shown in figure 4 refer to the neighbourhoods of Bouaqal, Al Shuhada

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and Al Zamalah, while the second rank is found in the park Afforage, Bouzoran, the old centre of the city and the southern extensions. It is also clear that some of the major waterways, as identified in map (d) of figure 3, run through densely populated areas in the city. In general, it can be said that the density decreases whenever we go to the outskirts of Batna, which can be mainly linked to the services provided by the city centre.

Public equipment: This was reclassified into four categories. The first one includes strategic equipment, i. e., health equipment, security equipment and units in charge of intervention and civil protection. The second type includes educational institutions in general, while administrative and industrial equipment has been assigned the third rank. As for the rest of the commercial and service equipment, they have received rank 4 (figure 4).

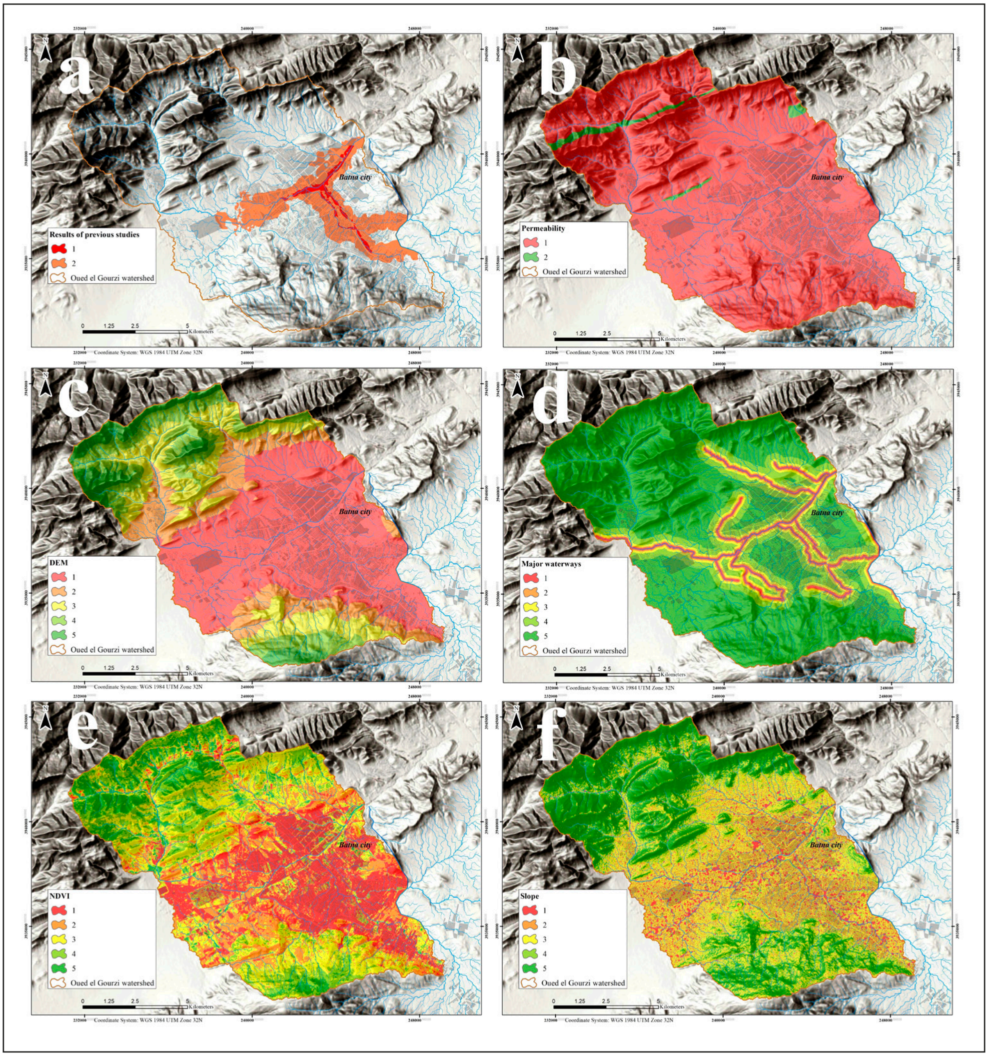
Roads: We have reclassified these roads according to three ranks, the first one including the main and primary roads; in general, these are the roads that are considered an extension of the national roads and those having heavy traffic in the urban area. The secondary roads have been given rank 2, while tertiary and residential roads were assigned rank 3 to reconcile the types of roads and increase the importance of those which are primary and residential (figure 4).

The weights of the criteria used in the model

The determination of these weights depends on knowing the actual impact of each criterion on fragility and its association with the onset of flooding, which cannot be determined accurately. In this study we relied upon close weights for all criteria, but more importance was given to factors giving more accurate results than others. Accordingly, we assigned the highest percentage to the topographic wetness index as well as to the proximity to major waterways for criteria related to watershed physics, as they better reflect the areas that are actually exposed to inundation problems.

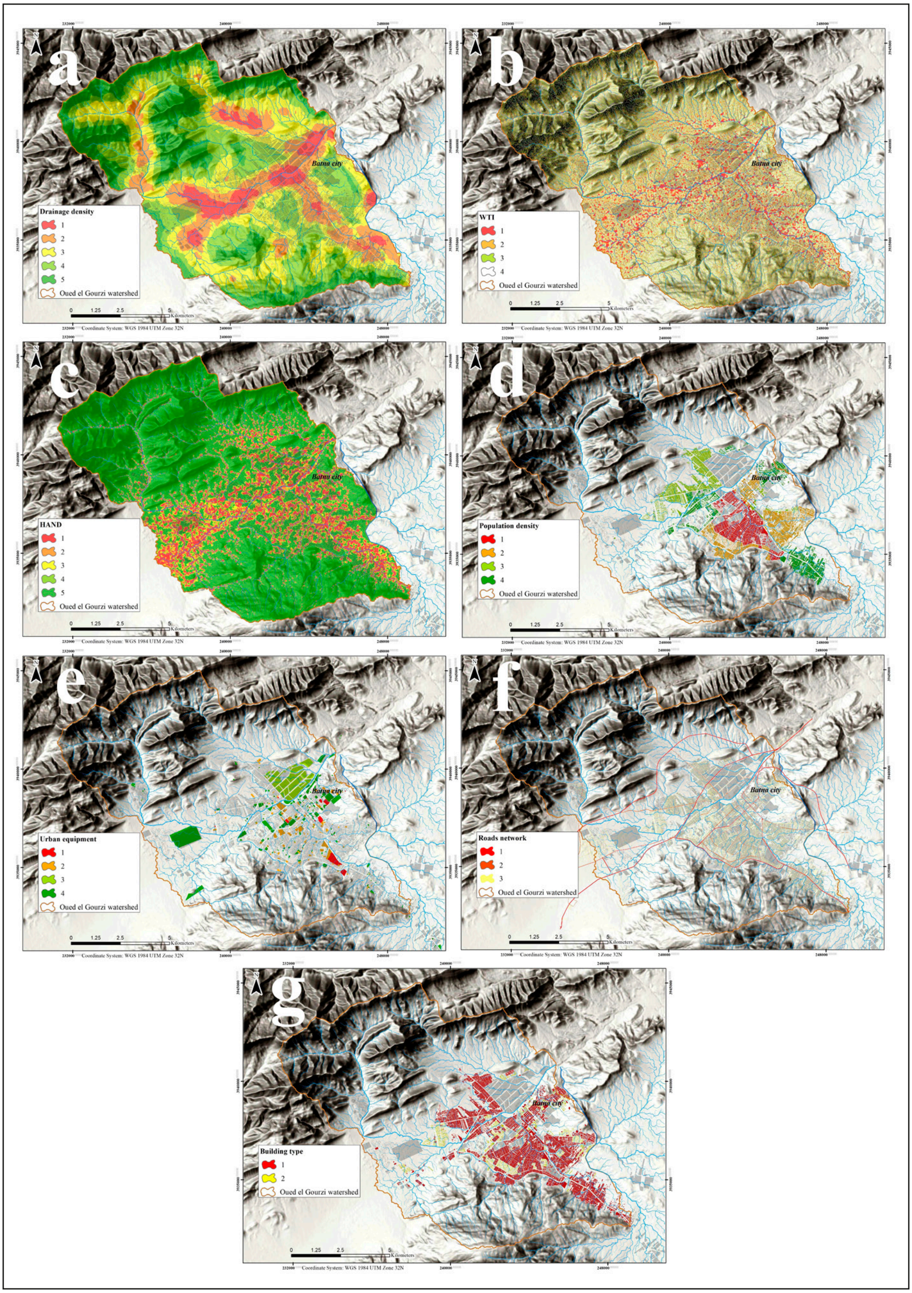
The following weights have been selected for the criteria associated with watershed physics: permeability (11 %), WTI (14 %), slope (10 %), distance to major watercourses (13 %), drainage density (11 %), height above nearest drainage (11 %), NDVI (8 %), height (11 %), and results from previous studies (11 %). Regarding the importance of socio-economic criteria, the population density was given 30 %, public facilities 30 %, housing type 20 %, and roads another 20 %.

Figure 3. Criteria used in the model. (a) Previous studies, (b) permeability, (c) height, (d) distance to major watercourses, (e) NDVI, (f) slope



Source: author (2023).

Figure 4. Criteria used in the model: (a) Drainage density, (b) topographic wetness index or TWI, (c) height above nearest drainage or HAND, (d) population density, (e) public equipment, (f) roads, (g) housing type



Source: author (2023).

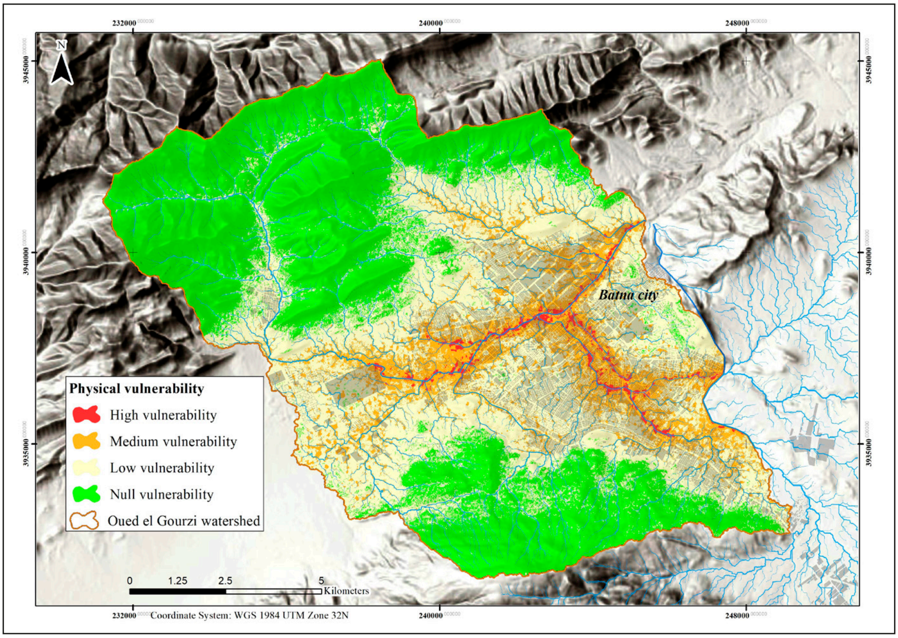
Results and discussion

Physical vulnerability: The results of the physical vulnerability study give an acceptable and appropriate representation of the areas that are very sensitive to flood risk. This research took into account many elements, and areas of high vulnerability were determined after using these factors, which include the places adjacent to the old path of wadi Tazoult, the Al Maseel and Al Hizam protection canals, and the areas adjacent to wadi Al Gourzi, as well as the zone in which wadi Hamla meets wadi Al Gourzi; while the areas of medium vulnerability occupy a large section of the city.

These results synthesise the influence of geomorphological factors on the watershed and confirm the concept of "bowl city" (Naim Harkat, 2021). Despite the aspects of uncertainty raised by the quality and accuracy of the data, the absence of historical maps expressing the floods that have affected the region in the past, and the difficulty of taking into account all the structural changes that have occurred in the area and their effects on the watercourses, many of the areas identified by the map actually represent those that have been affected (Harkat et al., 2020) and are still affected by flooding to this day.

Reducing physical vulnerability to flood risk will be a fundamental requirement in the future, especially with climate change and its impact on the way rain falls. This will be a major challenge for authorities, as the city's situation offers no easy options for protection. This is particularly true for the eastern side, which can be considered as the most dangerous area of the basin (Tout & Ghachi, 2023) and will make additional protection projects very costly.

Figure 5. Physical vulnerability

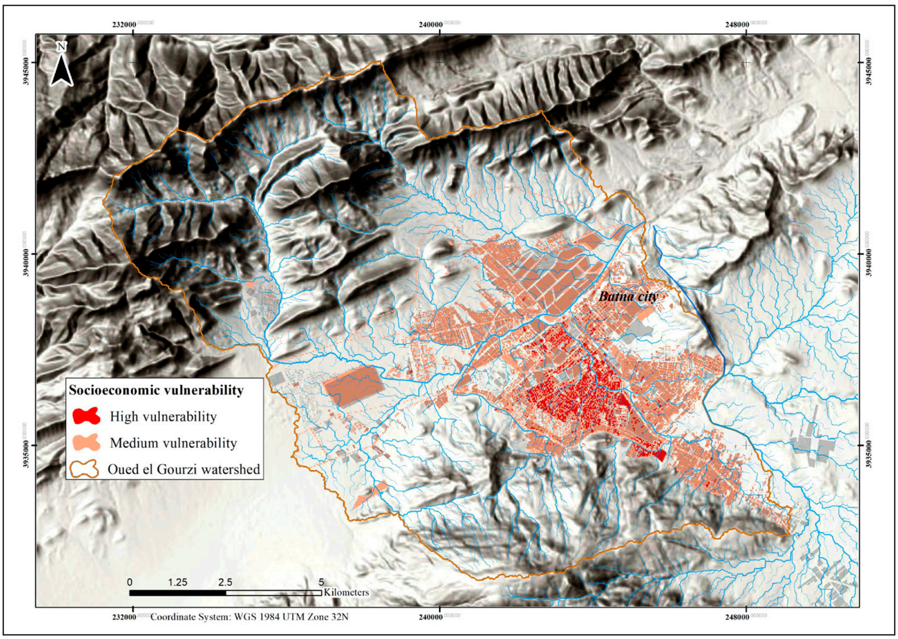


Socio-economic vulnerability: The map shows that the central area of the city, including the neighbourhood of Al-Zamala, Al-Shuhada and Bouaqal, is the most vulnerable area due to converging criteria of vulnerability, such as the high population density, the spread of individual housing, the density of strategic facilities, and the passage of the most important roads. A large part of the city has also been classified in the second category of vulnerability.

These results show that there is no real awareness of the critical situation of the city in the basin, and no real interest in flood risk on the part of inhabitants, which is reflected by irresponsible building behaviour that has led to a significant increase in the level of fragility in areas with a high susceptibility to flooding. In addition, authorities have failed in the choice of safe zones when identifying certain sites for urban facilities, which makes the problem much more complex.

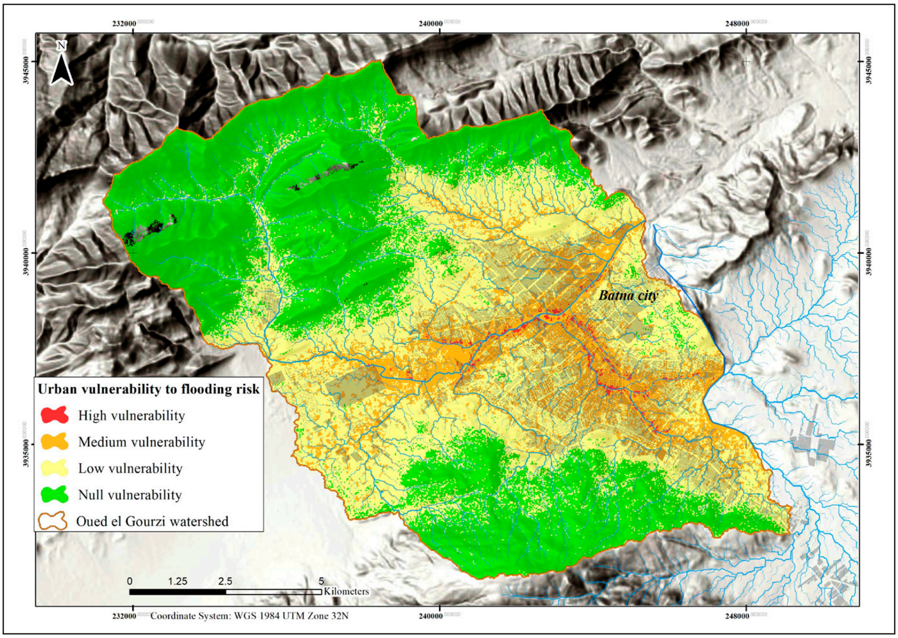
Reducing socio-economic vulnerability will undoubtedly require greater awareness so that residents support efforts to protect the city and use all available means to do so, as well as urgent measures concerning buildings and equipment located in dangerous areas, which also include security and health facilities responsible for responding to crises. It will be necessary to draw up construction plans that meet safety requirements in the face of these risks. Authorities should also focus on supporting existing laws, particularly those relating to planning and reconstruction, with materials that guarantee better protection of sites of social and economic importance against the risks of flooding and similar hazards, and thus endorse the law. The local government should also manage natural hazards through the necessary executive decrees and find solutions to the problems associated with coping with this type of risks.

Figure 6. Socio-economic vulnerability



Urban vulnerability to flood risk: Figure 4 shows the most vulnerable areas in relation to the city and takes into account the combination of physical, social and economic vulnerability factors, where the areas of great fragility are located near the protective canals Al maseel, Al Hizam and wadi Al Gourzi, as well as it is clear on the basis that a large part of the city is of moderate vulnerability. This map also reflects a bad behaviour in urbanization conducted by the population, as they build in illegal areas and follow the authorities, who turn a blind eye and provide with stability factors such as urban facilities and various networks with the lack of real assessment about the danger this entails, thus receiving a large number of people and strategic equipment responsible for either intervention or management. This would put the blame on the authorities in charge for not having taken the necessary measures to prevent these errors, which are likely to cause major disasters in the future.

Figure 7. Urban vulnerability



The study carried out by Slimani & Kalla (2017), which focused on the same area of study and used a similar methodology, states that the urban sector of Bouakal is the most fragile part of this city, and vulnerability extends throughout the urban area and even to the outskirts, while the middle area of the city, as well as the adjacent ones, are defined as non-fragile and have witnessed many floods in the past. This may be due to the type of criteria adopted, their importance or the quality of the data. In contrast, in our study, which relied on other criteria, we found that the middle zone of the city represents great vulnerability and is an area of great social, economic and administrative importance. It is also located in an area with a topography that favours the formation of floods and runoffs, and despite the structural protection measures put in place by the authorities, it still suffers from significant floods to this day and is jeopardized by major floods that could be caused by the exceptional rainfall that characterizes the region, particularly with the poor state of the drainage network.

This study underlines the need to adopt geographic information systems as a means of decision-making support for the authorities, even if their use may come up against certain difficulties, particularly with regards to data supply. Moreover, some methodologies which are associated with exploiting these systems raise doubts about the results as in our study, particularly since it relies on expert opinions and judgments to assess the importance given to the criteria, but it is supposed to replace older methods of vulnerability assessment and flood risk management and increase the level of protection for cities (Souissi et al., 2019).

Conclusion

In order to prepare cities to face flood risk, first it is necessary to assess their strengths and weaknesses and intervene accordingly to reduce these vulnerabilities. In this study, we used 13 criteria, including 9 which were related to the physical properties of the watershed, to determine the vulnerable areas of Batna; its results showing that the city's places of vulnerability occupy a large area, and the most susceptible to flooding are the ones along the two downtown protection canals Al Maseel and Al Hizam due to the combination of most physical, social and economic weaknesses. Furthermore, because of the city's location, this study aims to open up the discussion with authorities in order to draw more attention on flood risk and to prepare structural and non-structural measures to reduce the weaknesses of the city, as well as to stop the urbanization activity or to organize and adapt it according to the degrees of danger to which it is exposed.

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