RESEARCH ARTICLE

GIS-Based Multi-criteria Decision-Making Techniques and Analytical Hierarchical Process for Flash Flood Risk Assessment Due to a Possible Dam Break in Urban Arid Environment: Case Study of Biskra City, Southern Algeria

Meriem Boultif[1] · Billal Kheloufi[2] · Ali Hachemi[1,3] · Leila Mimeche[2]

Abstract

Urban flooding is the most frequent and damaging of all natural hazards, including those caused by dam breaks. One flood mitigation and control method is using flood risk maps to provide helpful information. This study aims to map the three parameters of urban flooding: exposure, vulnerability, and flood risk following a hypothetical failure of the Gazelles fountain dam (Manbaa Al-Ghozlan) in the city of Biskra (40 km downstream of the dam) through a multi-criteria decision-making process (MCDM). Six influencing factors were used for the vulnerability assessment: land use, distance from significant watercourses (Oued), distance from drainage accumulation, elevation, population density and distance from main roads. The influence of each factor was examined by attributing weights to each criterion according to its impact on urban flood vulnerability. A flood risk map that can evaluate the extent of damage and its economic implications is made based on hazard and vulnerability maps. Based on pixel values, the flood risk map has been divided into four classes: very high, high, moderate and low. The results indicate that more than 63% of the area is at high risk. The water depth in these areas may exceed 10 m in the case of dam failure. The constructed flood risk map is an informative tool to assess critical damage for decision-makers in arid and semi-arid areas.

Keywords Dam-breach · Arid regions · Remote sensing image analysis · Multi-criteria decision-making (MCDM) · Analytic hierarchy process (AHP) · Flood risk mapping

Introduction

Flash floods are one of the most dreaded extreme events among all natural hazards. due to its serious damage and heavy losses on several social, economic and infrastructure aspects, especially in developing countries (da Silva et al., 2020). The effects of flooding are anticipated to intensify because of current societal and economic factors and settings, including rising population, expanding economy, and climatic change. In order to create efficient flood prevention strategies, it is necessary to comprehend the physical and spatiotemporal properties of risk factors (exposure and vulnerability) (Tanoue et al., 2016). Therefore, the need to understand floods mechanism through assessment and monitoring methods and develop procedures to prevent and mitigate their potential impact is a significant challenge to researchers, engineers, and stakeholders, especially in an arid region. Due to their fragile nature and particularity as an ecosystem and their climate characterized by prolonged droughts, sudden flood rains, and different hydrology, arid and semi-arid regions present significant scientific, technological, and practical obstacles. (Saber et al., 2015), in addition to that, and given other factors such as abrupt peaks,

✉ Meriem Boultif
  boultif.meriem05@gmail.com

  Ali Hachemi
  alihachemi.hyd@gmail.com

[1] Ecology of Arid Ecosystems and Climate Risks Division, Scientific and Technical Research Center on Arid Regions CRSTRA, Biskra, Algeria

[2] LARGHYDE Laboratory, Department of Civil Engineering and Hydraulics, Faculty of Sciences and Technology, Mohamed Khider University, Biskra, Algeria

[3] Research Laboratory in Subterranean and Surface Hydraulics -LARHYSS, Université Mohamed Khider, Biskra, Algeria

variability, irregularity of rainfall frequency and variability of rainfall events, the majority of North African and Middle Eastern towns lack adequate precise safety measures against these disasters (Gitz et al., 2016). Moreover, many cities near waterways (Oueds or Wadi) in the arid areas of North Africa and the Middle East are essential population centres with a high urban density, making these regions most vulnerable to flash floods caused by intense rainfall or dam breaks (Elfeki et al., 2018). Therefore, managing water resources is key to sustainable growth in these areas (Abdrabo et al., 2020). Managing water resources and water-related risks in these areas is a challenge due to many factors, including inadequate management of water and sediment, dual catastrophe events (floods and droughts), limited data access and quality, and a lack of a comprehensive understanding of the Wadi (Oued) Flash Floods (WFF) processes and suitable WFF approaches (models, strategies, and planning) (Sumi et al., 2022), due to limited studies, lack of climatic data as well as their characteristic of short duration, small areal extent and high flood peaks (Hamlat et al., 2021).

The flood risk analysis from dam failure is relatively recent due to urban agglomerations growth and concentration in the lower reaches of the reservoirs (Bales et al., 2001; Balogun & Ganiyu, 2017; Butt et al., 2013). Due to the lack of technical knowledge, the complexity, variety, and involvement of numerous stakeholders in flood control problems (Kopackova et al., 2007), it is essential to opt for studies that take into account this complexity and variety, notably, multicriteria analysis decision making (MDCM). It is possible to handle the decision complexity caused by the absence of objective measures in multi-criteria decision support systems, restricted data, and excessive uncertain probability distributions by merging value judgments and technical information in an organized decision frame (Levy et al., 2007; Li et al., 2012). MCDM tools have been used in flood management to provide decision-makers (DMs) with a systematic framework to address these complex issues. AHP-GIS is often used to identify areas vulnerable to flooding based on several factors that describe and induce this vulnerability, such as morphological and meteorological hydrological factors, such as precipitation patterns, slopes, drainage, elevation, and land use species (Armenakis & Nirubama, 2014). In order to improve flood risk assessment and emergency management, the Analytical Hierarchy Process (AHP) is an MCDA technique. The hierarchy is a linear top-down layout with a target (or a source node or group) at the highest levels of factors (components or groups) representing alternatives and decision criteria and links between factors concentrated only on elements at the lower level (Levy et al., 2007).

Although Algeria is the most sensitive North African country to climatic variability, with huge damages due to inundation events, the knowledge of flashfloods and their mitigation is minimal (Sumi et al., 2022). In the past decades, Algeria has experienced successive periods of drought and increased urban needs simultaneously with population growth. Gradually, the waterways (Oueds) borders are exposed, while urban settlements tend to occupy the oueds beds. In other situations, the major bed became unstable, where it was piped, rerouted, or filled, as it is in the research region. The city of Biskra in southeastern Algeria is a desertic region experiencing increasing development in the urban extension, especially in recent years; the city lies on the banks of a vital waterway that has seen many major flood events that have caused loss of life and material damage. Thus, this work aims to map the flood risks caused by the failure of the Gazel Fontaine dam (about 40 kms from the Biskar downstream).

Methodology

Case Study

Biskra City is situated in the south-east of Algeria at 34,877°, 34,822° North, 5,799° to 5,706° East, isolated from the Mediterranean Sea by 205 km of mountains and high lands, and features a dry climate with significant seasonal variations. With an average annual temperature of 20.05 °C that ranges between 3.75 °C in December to 41.54 °C in July. Additionally, the area receives 307.69 mm of rain on average each year, ranging from 6.81 mm in July to 36.82 mm in November (Benedib, 2021). This area is situated at an altitude of 177 m above sea level with a flat terrain where the slope gradient is very low (Fig. 1).

Biskra is situated at the foothill of the Aures Mountains and 40 km downstream The Gazelle Fountaine Dam with a capacity of 55.49 hm³ and at the confluence of Wadi El-Hai and Wadi Djemora, which all together form Wadi Biskra that crosses the centre of Biskra city, on the other hand, Biskra knew an increasing population growth which has influenced the urban extension (Boumsenegh, 2007), the analysis on land-use change between 2003 and 2020 shows a significant urban extension around the main watercourse (Oued Biskra) where the wadi-bed was disturbed, with regression of rangelands and bare soil (Fig. 2).

The Gazelle fountain Dam is a heterogeneous earthen dam with 385 m length, and a height of 42.5 m (elevation of 390 NGA) above the streambed for an initial capacity of 55.49 hm³ (Fig. 3). The dam was inaugurated in 2000 and was operational in 2006 to regulate Oued Elhai flooding and to irrigate more than 1,100 hectares of agricultural El-Outaya region (NASP, 2003). The waters of Oued El-Hai and Oued Tamtam feed the Gazelle Fountain Dam, located between 347 and 2134 m of altitude, with an annual regime of more than 20 hm³. The basin extends over two climatic zones with a combined area of more than 175,871 hectares:
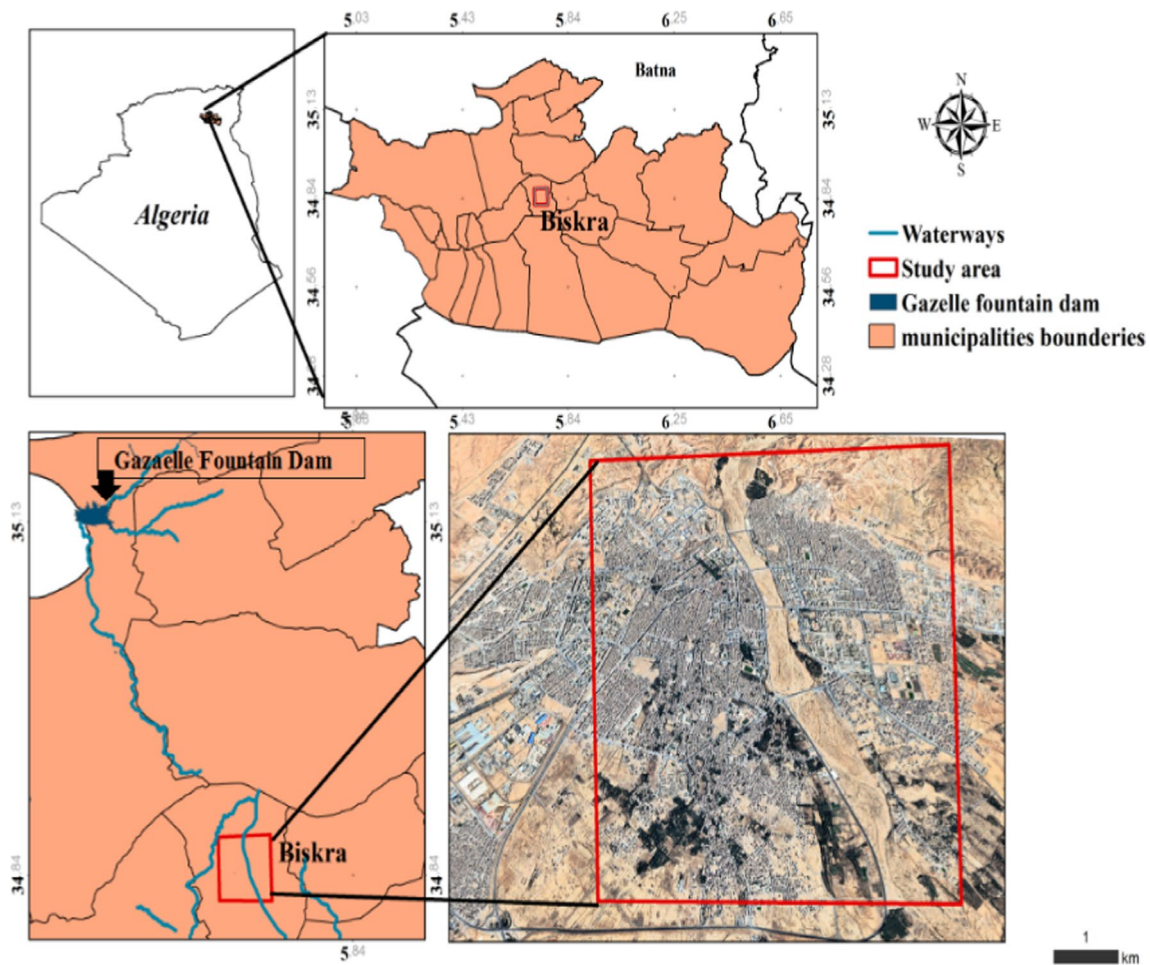
Fig. 1 Localization of the study area

a desert zone in the province of Biskra and a semi-arid zone in Batna, each with an area of 32.739.71 ha. This region is characterized by a flat terrain, of which 74.25% do not exceed 12 °C, while 25.75% of the watershed has slopes greater than 12 °C (Bendib, 2021).

Data Acquisition and Description

In this study, several data sources are employed to map the six levels of criterion. Table 1 shows the data sources and a description of the data.

Vulnerability Assessment

Input Criteria

The GIS tool was used here to collect and proceed with six (6) different thematic layers according to their weights: Landuse, distance from the main watercourse (Oued), distance from the drainage accumulation, Elevation, population

density and distance from the main roads (Fig. 4). The fuzzy concept was applied using the fuzzy adhesion tool in the GIS environment. The thematic layers acquired from the various criteria were further standardized to create a foundation for their comparison. The characteristics of the raw data, expert judgment, and expert expertise serve in determining the estimated adhesion functions (Fig. 5). MS Small (Small mean standard deviation) and MS Large (Large mean standard deviation) membership features were used to resampling the different criteria maps (Chukwuma et al., 2021). Small Mean Standard Deviation (small MS) and Large Mean Standard Deviation (large MS) (Luo & Dimitrakopoulos, 2003) are transformation functions that are determined from the control parameters of the shape of the medium multiplier and the standard deviation multiplier, as well as lower and higher thresholds that identify the range in which to apply the function; MSLarge Fuzzy is more appropriate if very large values are more likely to be members of the set; furthermore, it is used when high input values of a factor are more likely to lead to a flooding vulnerability, while fuzzy MS is more
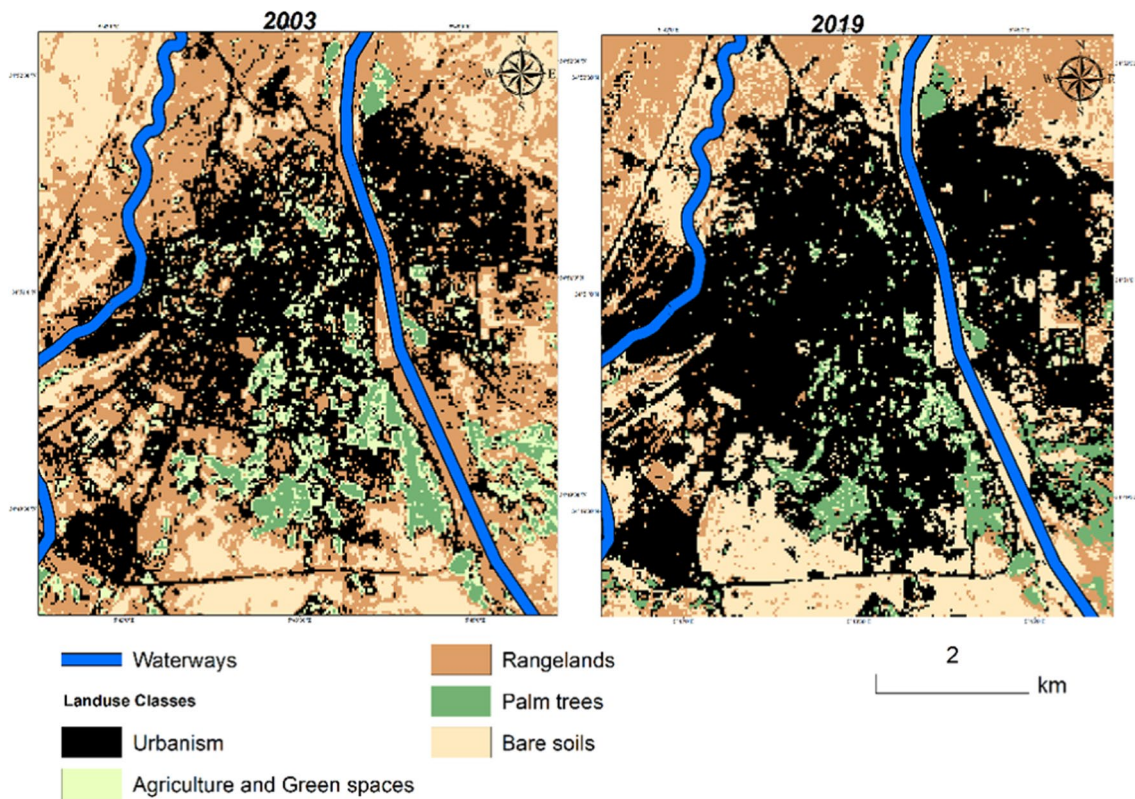
Fig. 2 City expansion change between 2003 and 2019

appropriate if very small values are more likely to be members of the group and small values are more likely to induce flood vulnerability, defined according to the specified mean and standard deviation, with criteria values that improve the flood index set to 1 and those that do not support the flood vulnerability index set to 0 (Okonufua et al., 2019).

Distance from the Major Waterway Stream

Flood vulnerability and susceptibility are higher in areas near a major waterway or river (Njoku et al., 2018; Rafiei-Sardooi et al., 2021; Singh & Pandey, 2021), DEM was used to map the hydrographic network using the hydrology tool in ArcGIS software, than the polyline of Oued Biskra was extracted, and the euclidian distance was performed in order to map the distance classes from it, the case of Biskra, major waterway (Oued Biskra) of 300–500 m in length crosses the city and splits it into two main parts: Higher Area (El Alia) and a lower area (Old city), this layer was obtained by calculating the euclidian distance from the major watercourse Oued.

Distance from Drainage Accumulation Distance

Obtained after a DEM treatment, Areas that are far from drainage systems are susceptible to flooding (Islam et al., 2022; Mahmoud & Gan, 2018; Rafiei-Sardooi et al., 2021). This layer was obtained by mapping flow accumulation using the hydrology tool based on a 30 m DEM, to obtain a polyline of the gullies of the flow accumulation, then the Euledian distance analysis from these gullies was performed to obtain the distance from the drainage accumulation layer.

Elevation

Elevation influences flow direction and accumulation, as well, as water depth, (Khosravi et al., 2016; Rafiei-Sardooi et al., 2021), the elevation criterion layer, was obtained using an obtained 10 m resolution DEM, from radar images of sentinel 1 (Table 1: data sources and description and amplitude image was created for the sentinel 1 image, then geometric terrain correction using range doppler terrain correction in ESA SNAP software was applied to output the 10 m DEM. The city of Biskra has a generally flat aspect, most of the city neighborhood are located at altitudes that range between 81 and 110 m a.s.l higher elevation are situated outside of the city, at the northern part.
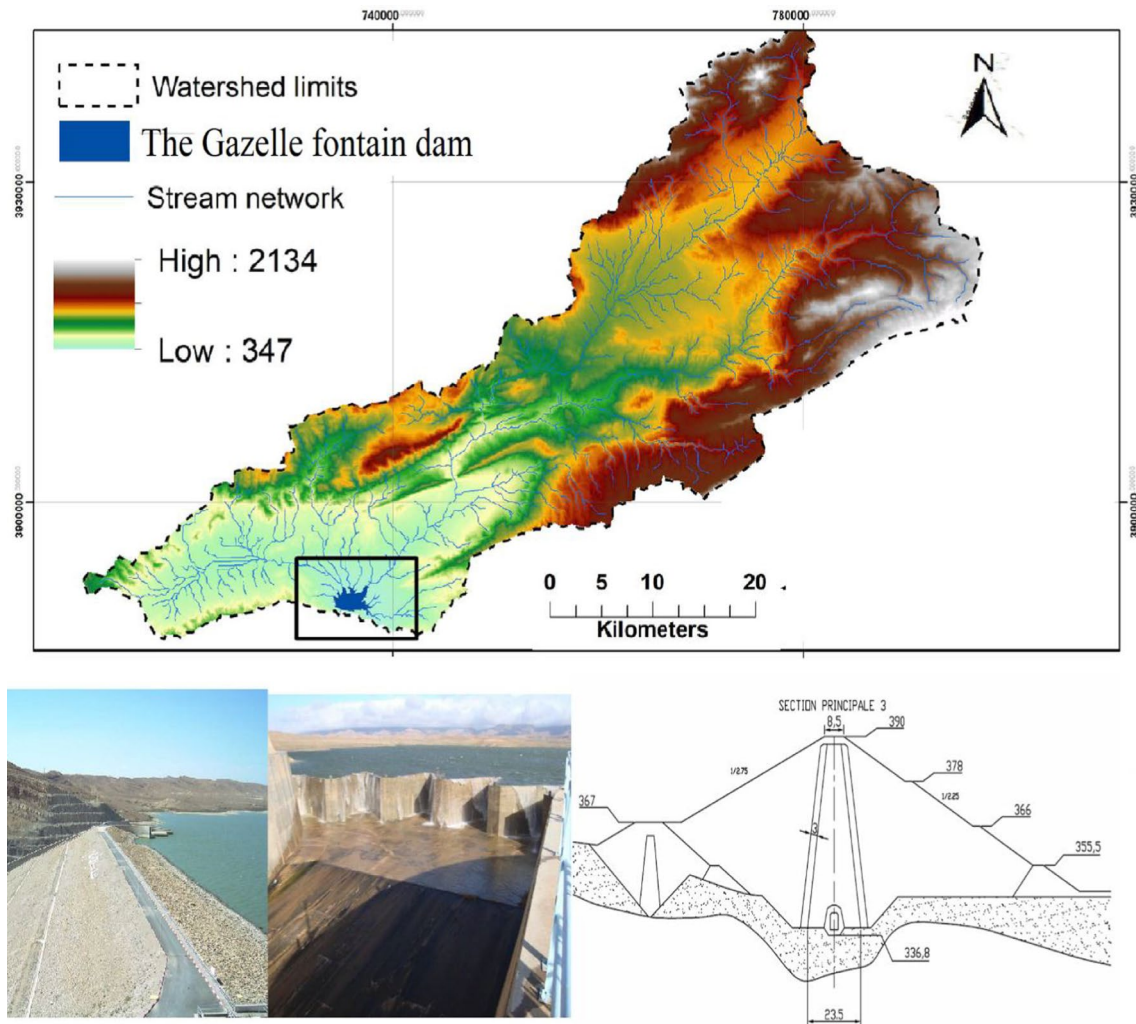
Fig. 3 The gazelle fountain dam (modified from (Bendib, 2021)

Table 1 Data sources and description

Data description	Purpose of use	Source and resolution
Digital elevation mode (DEM) 30 resolution	drainage accumulation and distance from the major waterway	Alos Global Degital surface model (3DW-30 M) down-loaded from AW3D30 DSM data map (jaxa.jp)
Digital elevation mode (DEM) 10 m, resolution	Land surface elevation mapping	Radar image sentinel S1A SLC IW, of SAR-C instrument downloaded from https://scihub.copernicus.eu/dhus/#/home
		Using ESA SNAP for Terrain correction
		Major status Topographic maps for confirmation
Satellite images	Landuse mapping via supervised classification	Landsat 8 satellite images, of 30 m resolution, downloaded from EarthExplorer (usgs.gov), of March, 16 th, 2021
Population density data	To represent population density classes in the city of Biskra	Local municipality census, based on the national census of 2018
Road Network	To map distance from roads of the city,	Development and Urban Master Plan, and Open Street Maps

Distance from major oued
- 1483 to 2000 m
- 976 to 1482 m
- 471 to 975 m
- 0 to 475 m

Distance from drainage accumulation
- 265 to 453 m
- 187 to 265 m
- 81 to 186 m
- 0 to 80 m

Elevation classes (m a.s.l)
- 81 to 100 m
- 110 to 120 m
- 130 to 140 m
- 150 to 180 m

Landuse Units
- Bare soil and Rangelands
- Palms, Agriulture and green spaces
- Urban

Population density classes
- 1
- 2
- 3

Distance from streets
- 313 to 413 m
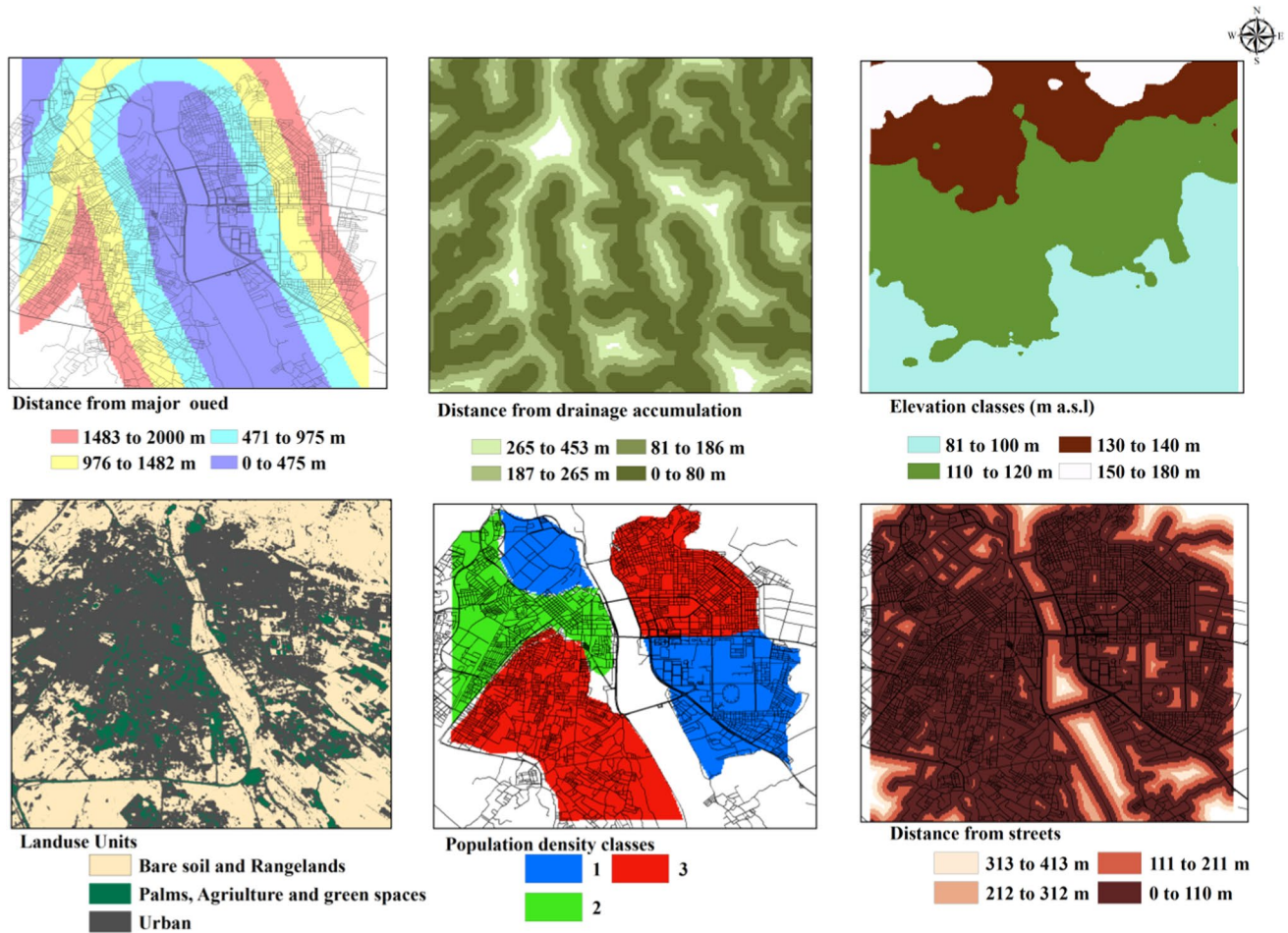- 212 to 312 m
- 111 to 211 m
- 0 to 110 m

Fig. 4 Criteria layers

Landuse

Water flow and infiltration have a significant relation with soil occupation. Therefore, landuse is a crucial factor while mapping and assessing flood vulnerability and flood risk, landuse classification units were relied upon in many flood vulnerability studies (Abdrabo et al., 2020; Chukwuma et al., 2021; Islam et al., 2022; Rafiei-Sardooi et al., 2021; Singh & Pandey, 2021; Sumi et al., 2022; Versini et al., 2010), the landuse layer was obtained using a supervised maximum likelihood classification of a Landsat satellite image, landuse classes are: Urban agglomerations, vegetation (agriculture and green spaces), rangelands, palm trees, and bare soil.

Population Density

Highly populated regions have a higher vulnerability to flooding than regions with low population densities (Rafiei-Sardooi et al., 2021), population units were classified into three different classes according to density statistics (1) High density and an extensive commercial activity characterizes

the lower (old city) as well as, the higher city (El-Alia,) and (2) Medium density in residential neighbourhoods somewhat far from the city centre, (3) Low density in newly built parts of the city, some of these areas are still under construction, this classification was obtained according to local authorities and based on the 2018 national census.

Distance from Roads

During floods, The road network plays a vital role in the identification of vulnerable areas to flooding in an urban environment; the closer a region is to the road Roads are impervious and quickly inundated, thus areas near them are more vulnerable to floods (Versini et al., 2010; Zhao et al., 2019), distance from roads was obtained based on the development and urban master plan (DUMP), provided by local authorities in addition to open street maps, once the polyline is obtained, a euclidean distance analysis is performed to obtain the final layer of distance from different roads.
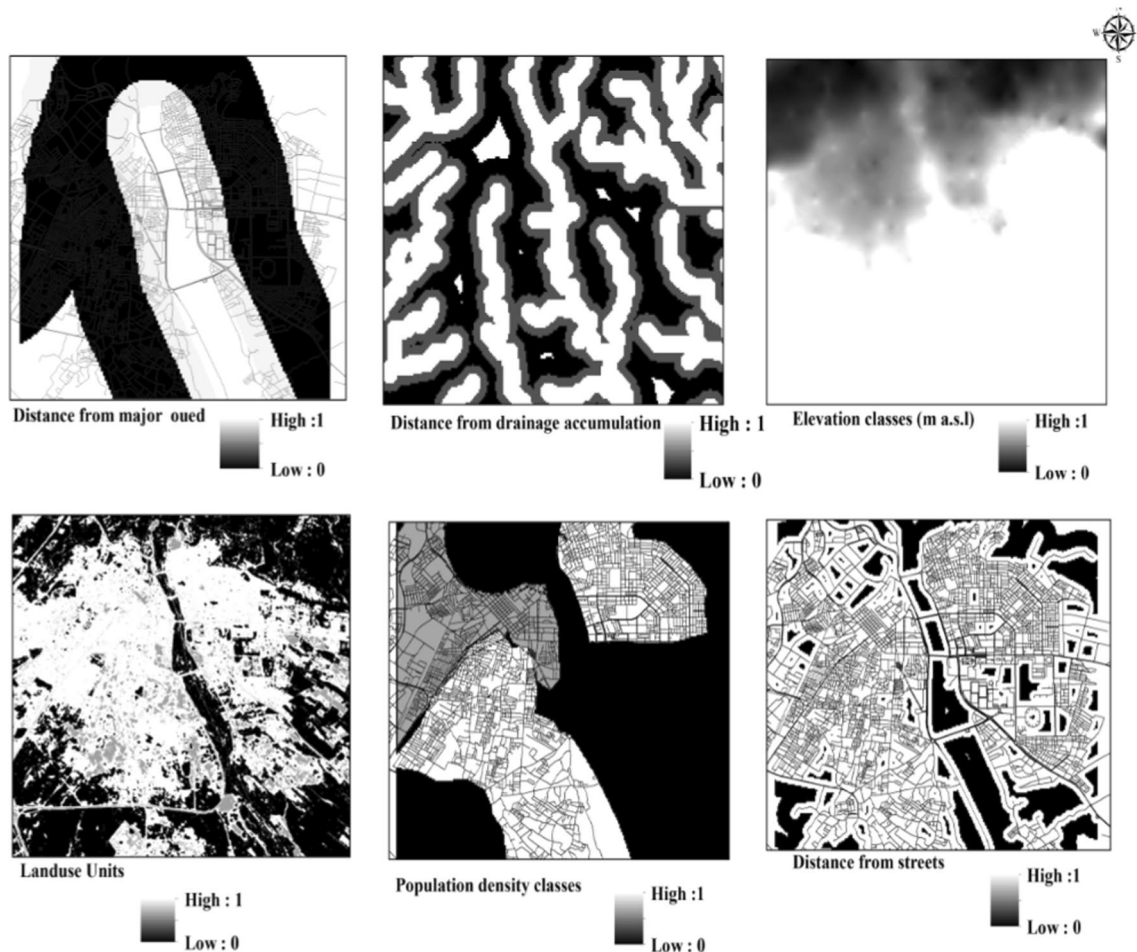
Fig. 5 Fuzzified criteria maps

Multicriteria Analysis: Analytical Hierarchy Process

The analytical hierarchy process AHP (Saaty, 1988) was applied to weight the above criteria; this approach can be used to derive flood priorities from a matrix of pairs of comparative flood judgments that lead to weighting each criterion based on its impact on vulnerability to urban flooding. The final flood map was derived from the sum of the weights multiplied by the rate of each criterion (factor) (Kittipongvises et al., 2020), the main advantage of using the AHP pairwise comparison method is the ability to obtain a reliable vulnerability more flexible and easier to update the map (Kittipongvises et al., 2020), the degree of vulnerability to flooding is calculated as follows:

$$H = \sum_{i=1}^{n} WiXi \qquad (1)$$

where H is the degree of vulnerability to flooding, n is the number of the factors, Wi the weight of each individual factor i, and Xi is the rating of each individual factor i.

The hierarchical composition) is used to combine the resulting flood priorities into a hierarchy. The flood vulnerability vector derived from pairwise comparisons represents the impact of a given set of criteria in one component on another system criterion (Levy et al., 2007; Saaty, 1988).

First, a series of pairwise comparisons is established of these criteria according to their relative importance and their influence on flood vulnerability, a scale of numbers that ranges from 1 to 9 is used to indicate the importance or dominance of one factor compared to another (Saaty, 1988). On this scale, the value 1 means that the importance of each factor (criterion) in relation to another is equal while the value 9 between two factors shows that one is extremely important than the other. Reciprocal numbers can also be used for the inverse relationship. A pair comparison of n criteria is presented in an evaluation matrix (n*n) (Hadipour et al., 2020) as follows:

$$A = aij = \begin{Bmatrix} 1 & aij & a1n \\ 1/aij & 1 & a2n \\ 1/a1n & 1/a2n & 1 \end{Bmatrix} \qquad (2)$$

where A = [aij] represents the intensity of the expert's decision of one factor to be important over another, compared alternative aij and all comparisons i, j = 1, 2....n (Hadipour et al., 2020; Kittipongvises et al., 2020; Saaty, 1988).

Then, the eigenvector (Vp) is obtained by calculating the geometric mean in each line, Vp values determine the weights to be attributed to each criterion whose sum must be equal to 1 (Boultif & Benmessaoud, 2017) (Table 2).

Then the decision map is built after a weighed sum aggregation (WSA); by multiplying each standardized criterion layer by its coefficient of respective weighting.

Hazard Simulation

The HEC-RAS (Hydrologic Engineering Center River Analysis System) hydrodynamic model is used to create a flood exposure map for overflowed dam failure scenarios. The water level in the dam is supposed to be at a normal level when a flood with peak discharges of $4500 \, \text{m}^3 \, \text{s}^{-1}$ occurs, which is more than 1.5 times the total discharge capacity of the dam spillway. The breach parameter of the scenario is estimated according to Froehlich (2008) and given in Table 2. The 2D flood propagation was then modelled using HEC-RAS v5.

The HEC-RAS v5 solves the full 2D Saint Venant equations (Quirogaa et al., 2016):

$$\text{ContinuityEquation} \frac{\partial \xi}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \qquad (3)$$

where h is water depth (m), ξ is the surface elevation (m) p and q are the specific flow in the x and y directions (m^2/s),, g is the acceleration due to gravity (m/s), n is the Manning resistance, ρ is the water density (kg/m^3), xx, yy and xy are the components of the effective shear stress and f is the Coriolis (s^{-1}) (Quirogaa et al., 2016).

Flood Risk Calculation

The above criteria will undergo an AHP (Saaty, 1988); this approach can be used to derive flood priorities from a matrix of pairs of comparative flood judgments that lead to weighting each criterion based on its impact on vulnerability to urban flooding. The final flood map was derived from the sum of the weights multiplied by the rate of each criterion (factor) (Kittipongvises et al., 2020); the main advantage of using the AHP pair comparison method is the ability to obtain a reliable vulnerability and more flexible and easier to update the map (Kittipongvises et al., 2020), the degree of vulnerability to flooding is calculated as:

$$Risk = Vulnerability * Hazard \qquad (6)$$

Both vulnerability and hazard maps underwent a fuzzy membership analysis before multiplying the two layers using the raster calculator tool in ArcGIS software; the MSlarge membership was used because higher values of vulnerability and hazard indicate a higher risk value.

$$\text{MomentumEquation} : \frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) = -\frac{n^2 pg \sqrt{p^2 + q^2}}{h^2} - gh\frac{\partial \xi}{\partial x} + pf + \frac{\partial}{\rho \partial x}\left(h\tau_{xx}\right) + \frac{\partial}{\rho \partial y}\left(h\tau_{xy}\right) \qquad (4)$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) = -\frac{n^2 qg \sqrt{p^2 + q^2}}{h^2} - gh\frac{\partial \xi}{\partial y} + qf + \frac{\partial}{\rho \partial y}\left(h\tau_{yy}\right) + \frac{\partial}{\rho \partial x}\left(h\tau_{xy}\right) \qquad (5)$$

Table 2 Assigned weights

Criterion	Weight
Distance from major Oued	0,429,444
Landuse units	0,182,922
Distance from drainage accumulation	0,253,296
Population density	0,052941
Elevation	0,053463
Distance from main roads	0,059542

Results and Discussion

Vulnerability Criteria Mapping

Conditioning criteria were selected based on data availability, literature review, and expert opinion; these criteria have undergone a fuzzy resampling membership concept before being aggregated using the final weighted sum; MS Small membership was used when the lower values

translate a higher vulnerability, e.g., distance from the major oued, elevation, and distance from drainage accumulation. The larger membership was used when higher values indicate a higher vulnerability degree, e.g., population density (Fig. 5).

Vulnerability Map

The assigned weights to each criterion in (Table 2) were used in a weighted sum approach using ArcGIS 10.4 software in order to estimate flash flood vulnerability; the result is a classified map according to pixel values into four different vulnerability classes: The low vulnerability class Occupies 7.24%; these areas are mainly situated away from the city center and the dense urban network and from flow accumulation areas. Moderate vulnerability Areas occupy nearly 25,24% of the city area; these areas are relatively distant from the major waterway (Oued Biskra) but are relatively of low elevation and characterized by a high population density and a denser road network; this area is a part of the old city were the houses and especially the road network are less developed.

High vulnerability class occupies 27 28%, characterized by a higher population density, commercial activity and popular markets, situated on low elevation around the city centre are the old city; old houses are concentrated in this area, some of which are over a hundred years old. Areas of very high vulnerability occupy 40, 24% of the study area, mainly around the significant watercourse (Oued) and in areas of higher density, situated in the centre of the old city, and on the El Alia section. In addition to high population density, these areas are characterized by narrow, bifurcated roads and overlapping buildings, especially in the Old city, making intervention in the event of a flood very difficult.

Hazard Map

In case of a dam failure (Table 3), a submerged area measuring 13.21 km^2 becomes a critical concern; the water depth in some parts of the city of Biskra can reach a staggering 43 m, posing a significant threat to residents. Within the submerged area, approximately 12.85% (1.68 km^2) experiences water depths between 0 and 1.8 m notably some parts of the old city. Another 11.32% of the total emerged area

Table 3 Overtopping breach parameters

Top of dam elevation (m)	390
Breach bottom elevation (m)	362
Brach bottom width (m)	118
Side slope (H:V)	1
Breach development time (hrs)	2

(1.48 km^2) will potentially be emerged by 1.9 to 5 m of water around the city centre, the equipment area, and the train station. While water could reach from 5 to almost 43 m of depth on 9.6 km^2 of the submerged surface which is more than 70% of the total area; this part presents one of the largest population density centres in the city mainly near the major Oued where the depth ranges between 11 and 43 m (Haret El Oued Area), as well as El Alia section that contains the principal hospital, the central university and many administrative buildings (Fig. 6b).

Risk Map

The risk is the result of vulnerability and exposure multiplication. For this, these two factors were mapped and then fuzzified before the risk calculation (Fig. 7).

The risk-situated zone covers an area of 2.84 km^2. Within this zone, approximately 22.25% is classified as a low risk zone, making it relatively safer in case of potential hazards, mainly far from the city centre, the major Oued and on the peripheries of the El Alia section.

Areas of moderate risk occupy 14.27% of the zone, indicating a need for cautious monitoring and planning, mainly on some parts of the old city and the Northern part of El Alia (residential neighbourhoods). The equipment zone is also within this area, it has a significant economic importance, due to the factories and warehouses located there, in addition to the railway and the train station, which is a vital centre for the logistics supply in the region.

Conversely, high and very high-risk regions, spanning 8.12 km^2, constitute a significant 63.48% of the risk-prone surface. These areas pose substantial threats to the population due to their situation on mainly residential neighbourhoods. It is crucial to implement robust safety measures and emergency preparedness in these regions, considering their dense population.

Notably, this high-risk area is inhabited by tens of thousands of people, as well as many popular markets, shops and several vital infrastructures, including the principal hospital, children and maternity hospital, the central university, banks, hotels, schools, health institutions, and an administrative district that houses numerous government buildings. The concentration of essential facilities further underscores the need for disaster resilience planning and mitigation strategies (Fig. 8b).

Conclusion

The main objective of this study was to assess and spatially depict the flash flood risk degree within the city of Biskra, situated in the South East of Algeria, through a comprehensive mapping of vulnerability and exposure factors.
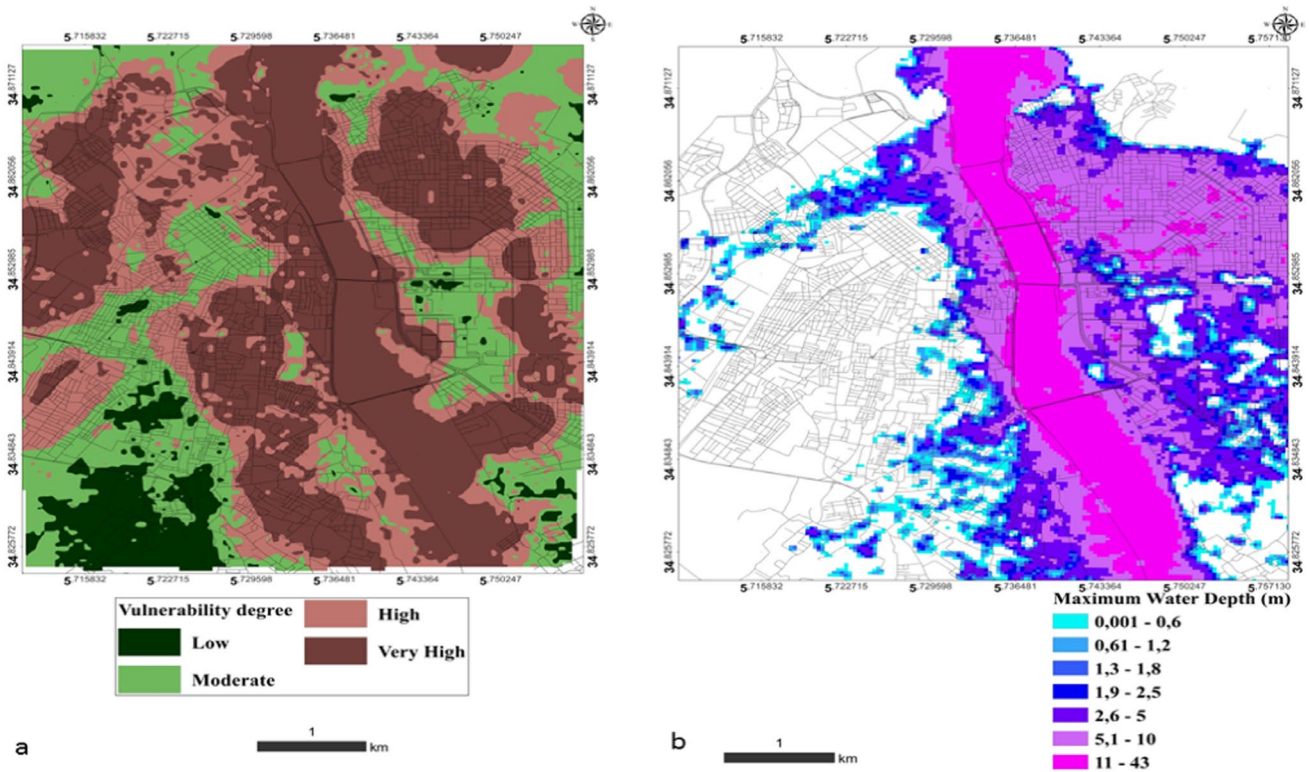
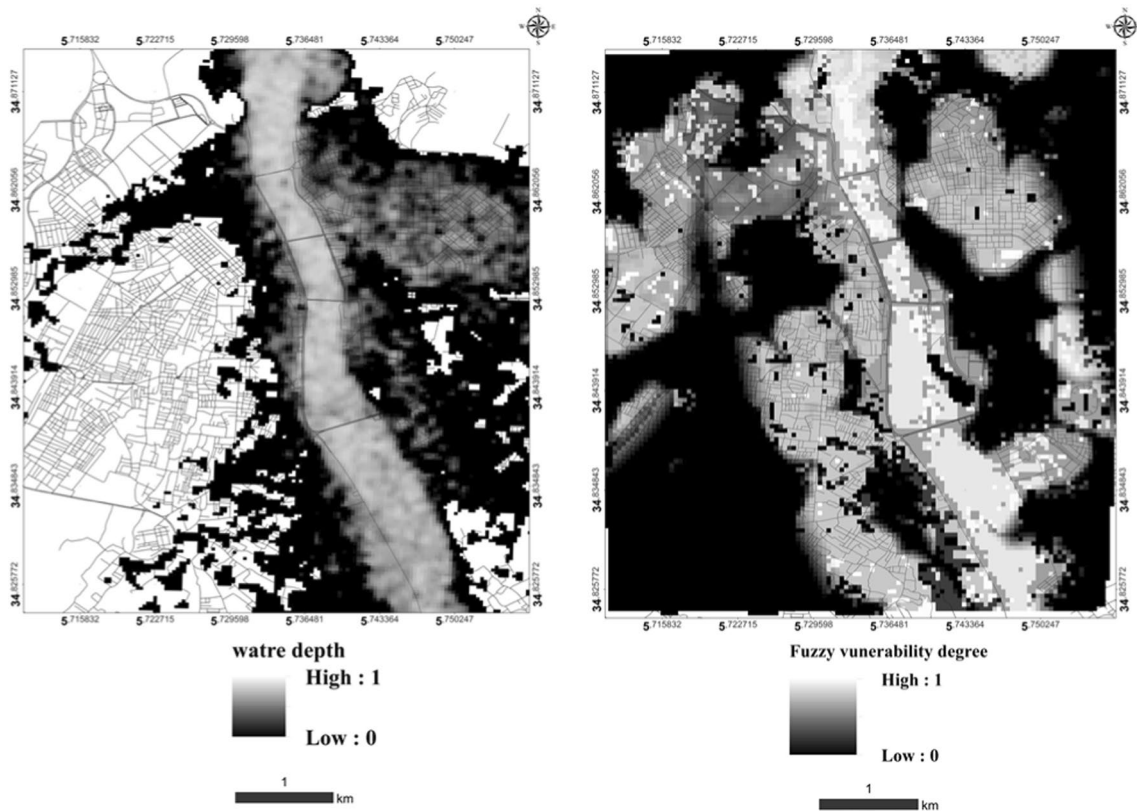**Fig. 6** Output maps; **a** Vulnerability map, **b** exposure map

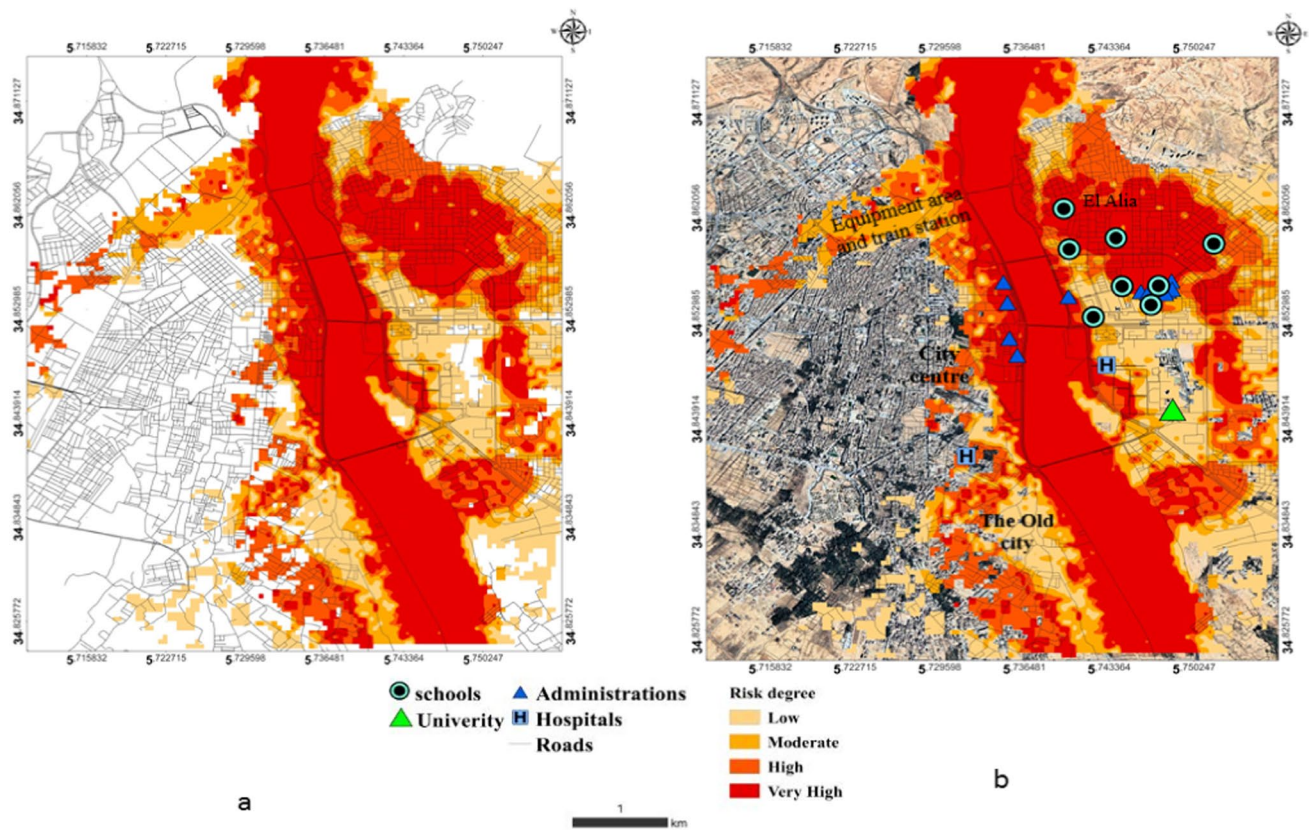**Fig. 7** Fuzzified vulnerability and hazard map

Fig. 8 Output risk map, **a** extension of risk degree, **b** risk degree and succeptible damaged facilities

Employing a GIS-based methodology, the research utilized the AHP multicriteria analysis to evaluate six pivotal factors: distance from major waterways, flow accumulation, elevation, land use, population density, and distance from roads and streets, which played a crucial role in determining vulnerability. Additionally, a HEC-RAS simulation was employed to assess exposure, specifically evaluating water depth and potential flooding areas in the event of dam failure.

The outcomes of this analysis yielded two crucial maps—a vulnerability map categorized into four distinct degrees: low, moderate, high, and very high, and an exposure map categorized by different water depth classes. To ensure precision, both vulnerability and hazard maps were fuzzified before calculating and mapping the overall risk degree, categorized as low, moderate, high, and very high.

The results show that the risk area is located on a surface of 2.84 square kilometres, of which, the majority are located in the El Alia region and adjacent areas of the water stream (Oued Biskra). The peripheries of the city and areas that are relatively far from the waterway and flow areas have a low risk to flash floods. Some parts of the Old City are located in areas of moderate risk due to the old age and the fragility of buildings, in addition to the equipment area, which is

dedicated to industry and storage; it has a critical economic importance, as well as the train station, making it necessary to intervene in order to protect this area.

Al-Alia region in the northeast is mostly situated at high and very high-risk areas; it is a highly populated section of Biskra. Located close to the waterway (Oued Biskra) while a large part of buildings in this area is constructed without regard to the natural flow accumulation of water. El Alia also includes many administration facilities, infrastructure, residential buildings, shops and a popular market. Haret El Oued region is also a classified area with a high risk due to its alignment with the main water stream, its low altitude and its containment of a large number of ancient popular homes, residential buildings and several important facilities such as the city's main post centre, court and general police directorate.

The main purpose of developing these comprehensive maps is to provide stakeholders with an effective decision-making tool, facilitating their tasks in devising optimal management plans. Additionally, these maps serve to communicate the risk situation prevailing in various parts of the city and to caution against the haphazard expansion of residential neighborhoods near the mainstream of the oued; by providing essential insights into flood risk, this research aims

to promote informed decision-making and proactive urban planning to enhance the city's resilience to flash floods.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical approval Ethical approval is not applicable for this article.

References

Abdrabo, K. I., Kantoush, S. A., Saber, M., Sumi, T., Habiba, O. M., Elleithy, D., & Elboshy, B. (2020). Integrated methodology for urban flood risk mapping at the microscale in ungauged regions: A case study of Hurghada, Egypt. *Remote Sensing, 12*(21), 3548. https://doi.org/10.3390/rs12213548

Armenakis, C., & Nirupama, N. (2014). Flood risk mapping for the city of Toronto. *Procedia Economics and Finance, 18*, 320–326. https://doi.org/10.1016/s2212-5671(14)00946-0

Bales, J., Sarver, K. M., & Giorgino, M. J. (2001). *Mountain Island Lake, North Carolina: Analysis of Ambient Conditions and Simulation of Hydrodynamics, Constituent Transport, and Water-quality Characteristics, 1996–97* (Vol. 1, No. 4138). US Department of the Interior, US Geological Survey.

Balogun, O. S., & Ganiyu, H. O. (2017). Development of Inundation Map for Hypothetical Asa Dam Break using HEC-RAS and ARC GIS. *Arid Zone Journal of Engineering, Technology and Environment, 13*(6), 831.

Bendib, A. (2021). High-resolution Alos Palsar for the Characterization of Water Storage at the Fountaine Des Gazelles Dam in Biskra, Eastern Algeria. *Journal of the Indian Society of Remote Sensing, 49*, 1927–1938. https://doi.org/10.1007/s12524-021-01365-y

Boultif, M., & Benmessaoud, H. (2017). Using climate-soil-socioeconomic parameters for a drought vulnerability assessment in a semi-arid region: Application at the region of El Hodna, (M'sila, Algeria). *Geographica Pannonica, 21*(3), 142–150. https://doi.org/10.5937/GeoPan1703142B

Boumsenegh, A. (2007). Les inondations dans la ville de BISKRA Causes et Impacts. Magister thesis. Faculty of Engeneering science,University of El Hadj Lakhdar, Batna

Butt, M. J., Umar, M., & Qamar, R. (2013). Landslide dam and subsequent dam-break flood estimation using HEC-RAS model in Northern Pakistan. *Natural Hazards, 65*, 241–254. https://doi.org/10.1007/s11069-012-0361-8

Chukwuma, E. C., Okonkwo, C. C., Ojediran, J. O., Anizoba, D. C., Ubah, J. I., & Nwachukwu, C. P. (2021). A GIS based flood vulnerability modelling of Anambra State using an integrated IVFRN-DEMATEL-ANP model. *Heliyon.* https://doi.org/10.1016/j.heliyon.2021.e08048

da Silva, L. B. L., Humberto, J. S., Alencar, M. H., Ferreira, R. J. P., & de Almeida, A. T. (2020). GIS-based multidimensional decision model for enhancing flood risk prioritization in urban areas. *International Journal of Disaster Risk Reduction, 48*, 101582. https://doi.org/10.1016/j.ijdrr.2020.101582

Elfeki, A., Al-Shabani, A., Bahrawi, J., & Alzahrani, S. (2018). Quick urban flood risk assessment in arid environment using HECRAS and dam break theory: case study of Daghbag Dam in Jeddah, Saudi Arabia. In *Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions: Proceedings of Euro-Mediterranean Conference for Environmental Integration (EMCEI-1), Tunisia 2017* (pp. 1917–1919). Springer. https://doi.org/10.1007/978-3-319-70548-4_553

Froehlich, D. C. (2008). Embankment dam breach parameters and their uncertainties. *Journal of Hydraulic Engineering, 134*(12), 1708–1721.

Gitz, V., Meybeck, A., Lipper, L., Young, C. D., & Braatz, S. (2016). Climate change and food security: Risks and responses. *Food and Agriculture Organization of the United Nations (FAO) Report*, *110*(2).

Hadipour, V., Vafaie, F., & Kerle, N. (2020). An indicator-based approach to assess social vulnerability of coastal areas to sea-level rise and flooding: A case study of Bandar Abbas city, Iran. *Ocean & Coastal Management, 188*, 105077. https://doi.org/10.1016/j.ocecoaman.2019.105077

Hamlat, A., Kadri, C. B., Guidoum, A., & Bekkaye, H. (2021). Flood hazard areas assessment at a regional scale in M'zi wadi basin, Algeria. *Journal of African Earth Sciences, 182*, 104281. https://doi.org/10.1016/j.jafrearsci.2021.104281

Islam, M. M., Ujiie, K., Noguchi, R., & Ahamed, T. (2022). Flash flood-induced vulnerability and need assessment of wetlands using remote sensing, GIS, and econometric models. *Remote Sensing Applications: Society and Environment, 25*, 100692. https://doi.org/10.1016/j.rsase.2021.100692

Khosravi, K., Nohani, E., Maroufinia, E., & Pourghasemi, H. R. (2016). A GIS-based flood susceptibility assessment and its mapping in Iran: A comparison between frequency ratio and weights-of-evidence bivariate statistical models with multi-criteria decision-making technique. *Natural Hazards, 83*, 947–987. https://doi.org/10.1007/s11069-016-2357-2

Kittipongvises, S., Phetrak, A., Rattanapun, P., Brundiers, K., Buizer, J. L., & Melnick, R. (2020). AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand. *International Journal of Disaster Risk Reduction, 48*, 101612. https://doi.org/10.1016/j.ijdrr.2020.101612

Kopackova, H., Komarkova, J., & Sedlák, P. (2007). Knowledge pre-processing in decision making. In *7th WSEAS International Conference on APPLIED COMPUTER SCIENCE, Venice, Italy*.

Levy, J. K., Hartmann, J., Li, K. W., An, Y., & Asgary, A. (2007). Multi-criteria decision support systems for flood hazard mitigation and emergency response in urban watersheds 1. *JAWRA Journal of the American Water Resources Association, 43*(2), 346–358. https://doi.org/10.1111/j.1752-1688.2007.00027.x

Li, Q., Zhou, J., Liu, D., & Jiang, X. (2012). Research on flood risk analysis and evaluation method based on variable fuzzy sets and information diffusion. *Safety Science, 50*(5), 1275–1283. https://doi.org/10.1016/j.ssci.2012.01.007

Luo, X., & Dimitrakopoulos, R. (2003). Data-driven fuzzy analysis in quantitative mineral resource assessment. *Computers & Geosciences, 29*(1), 3–13. https://doi.org/10.1016/S0098-3004(02)00078-X

Mahmoud, S. H., & Gan, T. Y. (2018). Urbanization and climate change implications in flood risk management: Developing an efficient decision support system for flood susceptibility mapping. *Science of the Total Environment, 636*, 152–167. https://doi.org/10.1016/j.scitotenv.2018.04.282

Njoku, C., Efiong, J., Uzoezie, A., Okeniyi, F., & Alagbe, A. (2018). A GIS multi-criteria evaluation for flood risk-vulnerability mapping of Ikom local government area, cross river state. *Journal of*

Geography, Environment and Earth Science International, 15(2), 1–17. https://doi.org/10.9734/jgeesi/2018/40527

Okonufua, E., Olajire, O. O., & Ojeh, V. N. (2019). Flood vulnerability assessment of Afikpo South local government area, Ebonyi State, Nigeria. *International Journal of Environment and Climate Change, 9*(6), 331–342. https://doi.org/10.9734/ijecc/2019/v9i630118

Quirogaa, V. M., Kurea, S., Udoa, K., & Manoa, A. (2016). Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: Application of the new HEC-RAS version 5. *Ribagua, 3*(1), 25–33. https://doi.org/10.1016/j.riba.2015.12.001

Rafiei-Sardooi, E., Azareh, A., Choubin, B., Mosavi, A. H., & Clague, J. J. (2021). Evaluating urban flood risk using hybrid method of TOPSIS and machine learning. *International Journal of Disaster Risk Reduction, 66*, 102614. https://doi.org/10.1016/j.ijdrr.2021.102614

Saaty, T. L. (1988). *What is the analytic hierarchy process? Introduction In our everyday life, we must constantly make choices concerning what tasks to do or not to do, when to do them, and whether to do them at all*. University of Pittsburgh.

Saber, M., Hamaguchi, T., Kojiri, T., Tanaka, K., & Sumi, T. (2015). A physically based distributed hydrological model of wadi system to simulate flash floods in arid regions. *Arabian Journal of Geosciences, 8*, 143–160. https://doi.org/10.1007/s12517-013-1190-0

Singh, G., & Pandey, A. (2021). Flash flood vulnerability assessment and zonation through an integrated approach in the Upper Ganga Basin of the Northwest Himalayan region in Uttarakhand. *International Journal of Disaster Risk Reduction, 66*, 102573. https://doi.org/10.1016/j.ijdrr.2021.102573

Sumi, T., Kantoush, S. A., & Saber, M. (2022). *Wadi flash floods: Challenges and advanced approaches for disaster risk reduction*. Berlin: Springer.

Tanoue, M., Hirabayashi, Y., & Ikeuchi, H. (2016). Global-scale river flood vulnerability in the last 50 years. *Scientific Reports, 6*(1), 36021. https://doi.org/10.1038/srep36021

Versini, P. A., Gaume, E., & Andrieu, H. (2010). Assessment of the susceptibility of roads to flooding based on geographical information–test in a flash flood prone area (the Gard region, France). *Natural Hazards and Earth System Sciences, 10*(4), 793–803.

Zhao, G., Pang, B., Xu, Z., Peng, D., & Xu, L. (2019). Assessment of urban flood susceptibility using semi-supervised machine learning model. *Science of the Total Environment, 659*, 940–949. https://doi.org/10.1016/j.scitotenv.2018.12.217