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RISK OF FLASH FLOODS SYNCHRONISED WITH THE HANDLING OF ANTHROPOGENIC ACTIVITIES IN THE CITY. CASE OF THE CITY OF KHENCHELA

Abstract: With the consequences of global climate change, convective and torrential rain are causing severe flooding and major damage, particularly in the city. They play a key role, given the specific characteristics of the city in terms of the size of its population, the impermeability of developed soils, daily activities, car traffic, the dumping of waste and building rubble in run-off waterways, the inadequacy and unsuitability of drainage infrastructures, uncontrolled urbanization, etc. The aim of this article is to address the problem of flooding in cities. The aim of this article is to address the problem of flooding in the town of Khenchela, which has experienced accelerated and uncontrolled growth on flood-prone land in recent decades. The method used is a combination of cartographic visualization in GIS and parametric using the analytical hierarchy process (AHP) method, through research into the impact of natural hazard factors linked to climate change, such as soil type, rainfall intensity, topography and proximity to water channels, on the one hand, and anthropogenic vulnerability factors such as : the grouping of inhabitants in collective housing areas, the mobility of major roads, the concentration of economic activities, and the distribution of school facilities. The results of this study show that 12% of the city's surface area is highly or moderately exposed to the risk of flooding. It also shows that these percentages are recorded in the New Extensions, which have the highest population density in relation to the city as a whole (with 25,000 inhabitants/km²).

Keywords: natural risk, vulnerability, flash floods, anthropogenic activities, AHP Method, Khenchela

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Introduction

Under the effect of the incessant development of humanity and its excessive needs in primary industrial materials and new forms of production, to satisfy the technological progress of the great world powers; the planet is experiencing major operational and management disorders. The climate changes significantly experienced are considered to be the main cause of provocation of major natural risks, threatening the life of man and all living beings on the planet.

Consequently, a natural hazard refers to any action or event that can put people's lives in danger; obviously, it is accompanied by material and immaterial damage, as well as loss of life and damage to real estate and personal property (Ercole, 1995). "*Qualified as a major risk, any probable threat to man and his environment that may arise as a result of exceptional natural hazards and/or as a result of human activities*" .

Over the years, risk classification has been updated for every country in the world. Eighteen natural hazards are listed in Algeria's calendar of major risks, according to their degree of seriousness and importance with flood risks ranked third, just after seismic and geological risks.

Flooding, which is defined as the submergence of land adjacent to the minor bed of a watercourse (Larousse, 2008) are the result of global warming caused by the greenhouse effect, which leads to irregular rainfall, showers and convective rain, a situation that is at the root of rising run-off levels and the formation of floods.

The consequences of these risks differ enormously between rural and urban environments. In addition to the natural conditions considered to be exogenous, the latter is subject to other purely endogenous conditions. Between the two, the urban environment remains between hazards and vulnerability (Damienne, 2007).

Certainly; the hazards corresponding to climate change are natural and linked to meteorological variations, but the factors of vulnerability are linked to human activities, which further complicated disastrous consequences of these risks and are the main driving force behind these changes (Parry et al., 1996; United Nations, 2024).

The metamorphosis of Algerian cities has been significant in recent decades, as a result of social and cultural changes in society, manifested in accelerated and sometimes ill-considered urban growth, particularly in terms of exposure to the risk of flooding (Ercole, 1995); which is why their management failures are increasing (Abubakar et al., 2022). If the situation is accompanied by long periods of drought alternating with heavy rainfall (Redjem, 2020); the area is at risk of flooding.

The synchronisation of convective rainfall with the times when human activities are carried out can lead to a high risk of exposure to flooding and an increase in the amount of material and human damage.

In this way, we are looking for the degree of association between the places most vulnerable to flood risk and those that are most anthropogenic and most polarised in the city.

Anthropogenic activities are related to the activities most frequently carried out and which result in significant concentrations of the population in the city, i.e. activities related to shopping, schooling, housing and mobility(B Mérenne Schoumaker, 1982; Le Corbusier, 1957).

Controlling these phenomena requires the use of modern techniques aided by remote sensing of geographical information systems to make critical points exposed to the risk of flooding more detectable and proactive intervention more effective.

The subject of major risks of a general nature and floods in particular has caused much ink to flow. The majority of works on this subject address the issue of risks on relatively large scales; the particularity that our vision carries is the limitation of the effects of this risk on the urban environment whose surface area is restricted but the disasters are immense.

After reviewing some similar works dealing with the same subject from different angles, it is important to remember that the study of flooding in urban environments presents particularities linked to the nature of the environment and the behaviour of the population; however, most of the works dealt with agreed that the main cause of flooding in urban environments is due to torrential rain and to urbanisation and accelerated and thoughtless urban growth in at-risk areas (Alexis Hamdja Ngoniri & All, 2024; Ercole, 1995). The situation becomes even more complicated when the urban fabric in question is denser and older. Factors such as geographical location, soil type and soil cover are also decisive factors (Sevim Pelin Ozkan, 2015). Apart from this, even if urbanisation is carried out properly and urban infrastructures are appropriate, the nature of these risks is a permanent handicap when it corresponds to periods of use of the city. Scientific studies have shown that the risk of flooding when people are trapped in their vehicles is one of the causes of the highest level of damage in urban areas (Damienne, 2007; Jean-Louis Ballais, 2017).

Prevention methods are mainly based on the history of events and cartographic and digital data, with collaboration between the various parties involved (Ercole, 1995).

The risk map is one of the documents required for all planning operations (Valérie, 1994). The method most frequently cited in these studies is multi-criteria analysis based on the ascending hierarchical process (AHP), the hazard criteria of which differ according to the situation, but the majority relate to: slope, altitude, Euclidean distance, vertical distance and the topographical humidity index (Ngoniri & All, 2024), flow accumulation, land use and rainfall intensity (Ozkan, 2015), geology and distance from the drainage system (Faye, 2021).

Locally; With the uneven distribution of the population across Algeria (ONS, 2008), the region has been the scene of major flooding events (Alger, Ain Defla, Bouira et Tizi Ouzou, la région de la Mitidja, Khenchela, Guelma, Ghardaïa, Bechar, Illizi, Naama...) (Djellouli & Saci, 2003; Nouri, 2016).

Most researchers have agreed, almost unanimously, that the treatment of flood risk issues in the urban environment is only done by taking into account the combination of all the determining factors of the risks of this phenomenon. So, in addition to the natural hazard factors linked to the event itself, other important factors are linked to the behavior of users. The particularity of our point of view is based on the management of the use of the most active areas of the city by the user, in the face of the determining factors mentioned above. Thus, it is considered important to include collective housing estates, the perimeters of schools and universities, markets and points of concentration of economic dynamics, major roads as vulnerability factors.

The aim of this research is to develop a method for remote sensing and identifying areas of vulnerability in the city using parametric data and cartographic supports.

The aim is to establish a proactive action plan to aid decision-making and management, and to ensure that flood risks are properly controlled for a sustainable city of the future.

The choice of the study area is mainly due to the accelerated expansion of this town on relatively flat, fertile and floodable land, at the foot of an adjacent mountain. The increase in the frequency of flood-related events in the city in recent decades and its location in a semi-arid zone characterised by scrubland vegetation and irregular rainfall.

The subject of flood risk in towns and cities is a topical one, fuelled by the gradual increase in the urban population and the impact of climate change on towns and cities.

Presentation of the study area

The Aurès basin stretches along 35° North latitude and 6-7° East longitude. The Aurès lies at the crossroads of the two major areas that make up the Algerian-Tunisian Saharan Atlas (Herkat, 2004), Characterised by its steep slopes, cedar and Aleppo pine forests, it is home to the highest point (Jebel Chélia, 2328 m) of the Algerian-Tunisian Saharan Atlas range, natural springs, streams and valleys (Ballais, 1989). The massif is now shared between the wilayas of Batna, Biskra, Oum el Bouaghi, Tébessa and Khenchela.

The town of Khenchela lies at the foot of the Aurès mountain range, at an altitude of 1159 metres. Recent history tells us that the town was founded in the 19th century on a hill of sloping ground, backing onto the Chabord mountain to the west and bounded to the east by the Oued Boughoggal (Figure 1).

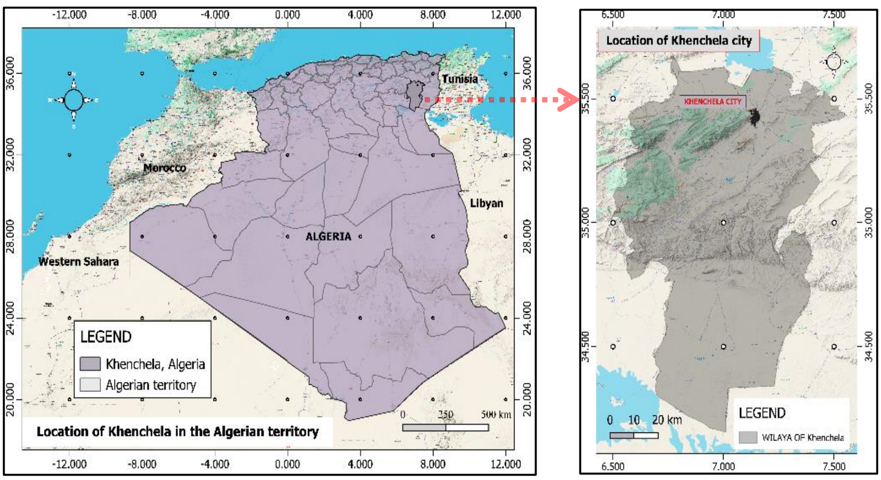


Fig. 1. Situation of the city of Khenchela (Source: Authors, 2024).

After the country's independence, the town of Khenchela underwent major extensions to its urban environment, accompanied by a large increase in population 'with a density of 4,164 inhabitants per km² (Meddour, 2012a) and 25,000 inhabitants/km² in the new urban centres (Protection Civile, 2024), this is the cause of its excessive need for infrastructure, housing and facilities. The remote geographical location of the original site, and the legal nature of the land to the north, encouraged the town to expand southwards, an operation that took place on fertile agricultural land with a relatively flat morphology (Figure 2).

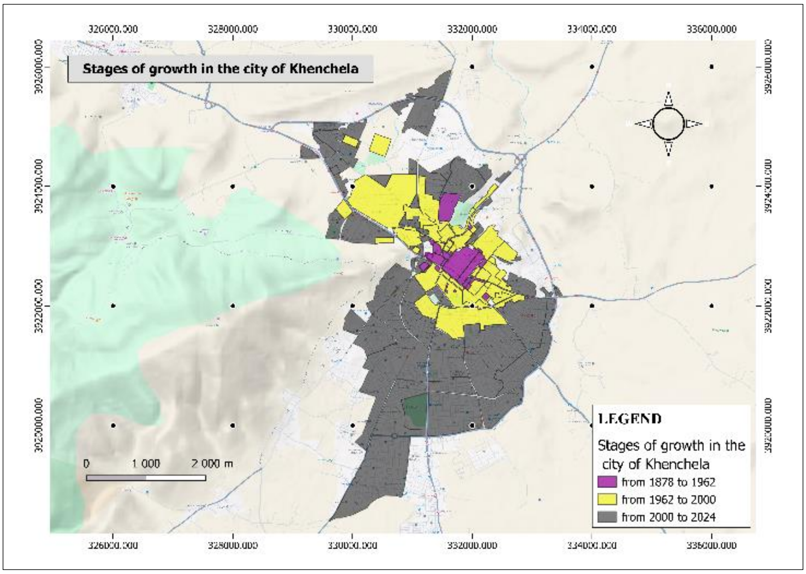


Fig. 2. Stages of growth in the town of Khenchela (Source: Authors, 2024).

The Khenchela region is part of a grid framed by two mountain ranges: the Tellian range to the north and the Atlas range to the south (Marc, 1983); is made up of four main geographical areas: the forested mountains of the Aurès, the plateaux and plains to the north and the steppe rangelands to the south (Khenchela, 2007; interieur.gov.dz, 2021).

The geology of the town of Khenchela is characterised by Triassic diapirs, which generally occur in fault zones and areas of low resistance, rising to the surface of the ground and outcropping (Khenchela, 2007; Meddour, 2012b).

Its climate is determined by the characteristics of the semi-arid region to which it belongs(Côte Marc, 1983); It is continental to the north and almost Saharan to the south. The average temperature is 17°C and rainfall averages 356.8mm (Khenchela, 2011; Meddour, 2012b; ONM, 2024).

The history of past floods in the town of Khenchela shows that they have all occurred in areas adjacent to the mountain at the back of the town. Recent flooding events in the city's recent history include at least five fatal floods in 1985, 2010, 2012, 2012 and 2013 (Protection Civile, 2024). The main cause of this is the significant spread of the town over areas more exposed to these risks.

Materials and methods

Data Sources

For the flood risk map, the parameters selected for our model are distance to the hydrographic network, land use, slope, rainfall intensity and topographic elevation which represent the most important parameters used for the calculation of flood risks in urban areas (Youssef et al., 2016; Tehrany et al., 2014; Rahmati et al., 2016; Nefeslioglu et al., 2008). The hydrographic network, slope and topography were extracted from the SRTM digital elevation model (DEM) images with a resolution of 30 meters using QGIS software(USGS, 2024). The land use map was digitized from high-resolution Google satellite images, where we identified urban areas, green spaces and bare soils based on the texture present in the study area (Earth, 2024). For the rainfall intensity, we used the data from the rainfall map of the Wilaya of Khenchela provided by the National Agency for Water Resources (ANRH, 2024; Station, 2024). The following table (Table.1) shows the data source for each parameter.

Table 1. Data used with their sources for the flood risk map.

Data	Data type	Data Source
DEM	1 Arc, 30 m	USGS
Precipitation	Raster map	ANRH
Satellite image	Raster map	Google satellite

Source: Authors 2024

Flood vulnerability assessment in Khenchela is essential due to the increasing flooding in Algeria. This model includes socio-economic factors such as proximity to schools (Education Departement, 2024), housing type (Housing Departement, 2024), distribution of economic activity (Trade Departement, 2024), and road traffic levels (Transport Department, 2024). Data for each parameter were collected through field surveys and digitized in QGIS, creating a spatial database.

Because of the complex interactions between natural hazards and human activity factors, we are considering inviting multi-criteria methods (MCDM) (Kamoona & Budayan, 2019; Yang et al., 2013; Darko et al., 2019; Koc et al., 2023) and particularly the Analytical Hierarchy Process (AHP) method (Myers & Alpert, 1968) then (R. W. Saaty, 1987); combined with geographic information systems (GIS).

The aim of this approach is to measure the relative importance of flood-related risks in the urban environment (Rahmati et al., 2016; Ali et al., 2019; Surwase, et al., 2019) by assigning weights to the various quantitative and qualitative criteria (Dağdeviren et al., 2004).

This study is structured in Bi lecture:

The first one is cartographic and is used to map natural hazard factors, namely: topography, soil lithology, surface slopes, precipitation and climatology, relief and watercourses; and secondly, to map vulnerability factors linked to human activities, namely:

- Attractive economic and commercial areas.
- Residential areas.
- Major road traffic routes.
- Educational and university facilities.

The second one focuses on calculating weights and weight assessments for each parameter, using the Analytical Hierarchy Process (AHP). Once the weights have been determined, we will produce vulnerability and hazard maps, which we will combine to produce a comprehensive flood risk map.

Analytical Hierarchy Process (AHP) steps

AHP is based on three primary steps: the first is used to construct the hierarchy, in which the decision problem is structured in a multi-level hierarchy, typically comprising the overall objective at the top, followed by criteria, sub-criteria (if any), and finally alternatives at the bottom (Qiao et al., 2019; Wang et al., 2008).

The second deals with pair-wise comparison method (Wang et al., 2008), which allows decision makers to compare criteria and alternatives in pairs, assigning them values representing their relative importance. These comparisons are made on an odd scale from 1 to 9 according to the importance of the factors. The selection of the 1 to 9 range was made after several attempts to obtain a satisfactory result for the study of the topic. this scale are generally applicated in several study for flood risk hazard assessment (Akindele & Todome, 2021; Karymbalis et al., 2021; Wu et al, 2022).

- 1 represents equal importance between two elements.
- 3 represents moderate importance of one element over another.
- 5 indicates strong importance.
- 7 denotes very strong importance.
- 9 signifies extreme importance of one element over another.

Intermediate values (2, 4, 6, 8) are used for judgments that fall between the main values (Aydin & Birincioğlu, 2022; Tukimin et al., 2021).

Finally, the third stage includes a consistency check to ensure that the comparisons are logically consistent. This step consists of calculating the consistency ratio (CR) (Wang et al., 2008), which indicates whether the judgments are acceptably consistent.

Key Equations in Analytical Hierarchy Process

The key equations of this method aim to determine:

The pairwise comparisons for each criterion or alternative which are arranged in a matrix form (Figure 3). For n elements, the pairwise comparison matrix A is an n × n matrix, where a_{ij} represents the relative importance of element i over element j: $A = [a_{ij}]$ (Aydin & Birincioğlu, 2022; Tukimin et al., 2021).

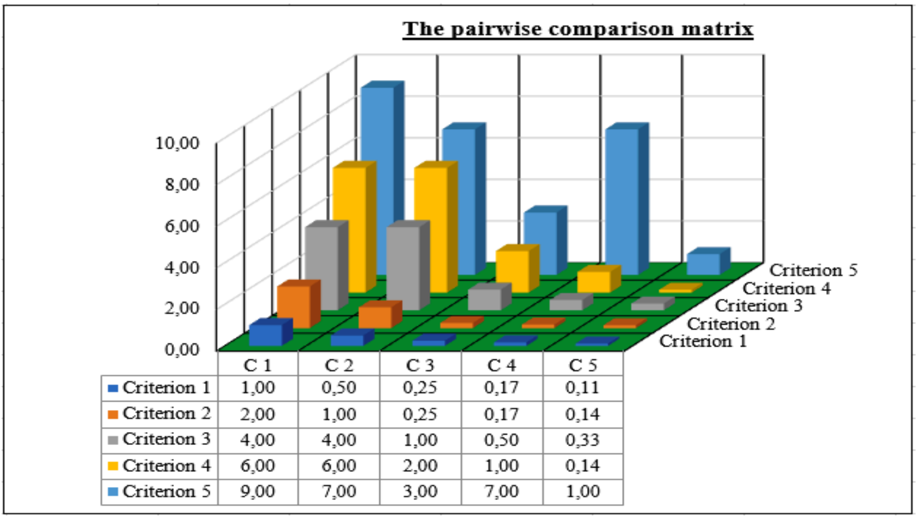


Fig. 3. The pairwise comparison matrix

On the other hand, each element in a column of the pairwise matrix A is divided by the sum of that column to create a normalized matrix A':

$$\grave{a}_{ij} = \frac{a_{ij}}{\mathrm{sum}(a_{aj})} \quad (1)$$

The weight (or priority) for each element, represented as W_i, is calculated by averaging the normalized values in each row:

$$W_i = \frac{\mathrm{Sum}\ (\grave{a}_{ij}}{n} \quad (2)$$

These weights W_i indicate the relative importance of each criterion or alternative concerning the overall goal (Saaty, 1987).

And finally, to measure consistency, the maximum eigenvalue λ_{max} is calculated and then used to find the Consistency Index (CI) as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n - 1)} \quad (3)$$

Here, n is the number of elements being compared. A lower CI indicates more consistent judgments (Wang et al., 2008).

The **Consistency Ratio (CR) (Table 2)** is used to determine if the level of inconsistency is acceptable. CR is calculated by dividing the Consistency Index (CI) by the Random Consistency Index (RI), which is a benchmark based on matrix size (Saaty, 1990):

$$CR = \frac{CI}{RI} \quad (4)$$

Table 1: RI values depending on criteria numbers (n= 1–09)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45

Source:(Saaty, 1990).

The Random Consistency Index (RI) values vary based on n, with commonly used values provided in a standard table. If CR<0., the pairwise comparisons are considered consistent; otherwise, revisions may be necessary.

Geographic Information Systems

Geographic Information Systems (GIS) provide a spatial framework for visualizing and analyzing the weighted criteria derived from AHP. GIS enables:

- Data Integration: Combining multiple datasets to view geographic relationships.
- Spatial Analysis: Techniques like buffer analysis, overlay analysis, and reclassification support complex spatial decisions.
- Visualization: Produces maps and models that illustrate intersecting criteria for easier interpretation and decision-making.

The integration of AHP and GIS allows for the application of AHP-derived weights to spatial data, generating visual representations that help identify key areas based on multiple criteria. Together, they form a robust decision-support system adaptable to various fields, from urban planning to environmental management.

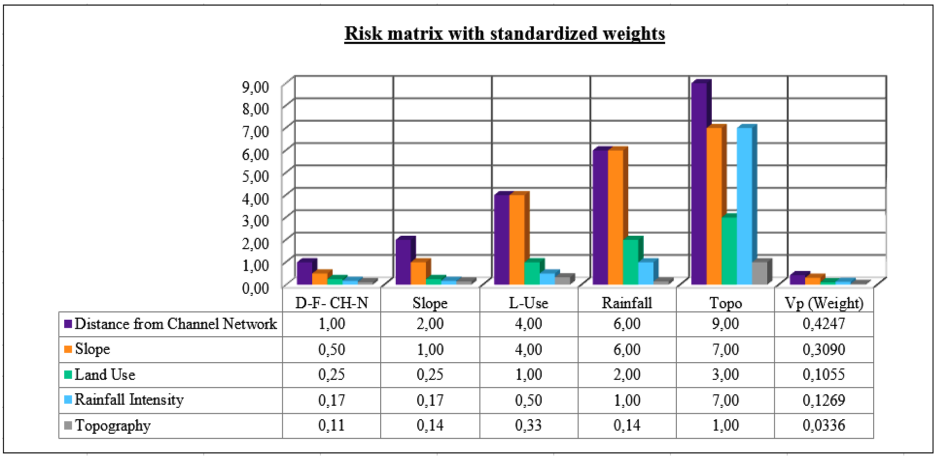
The flood risk analysis

In risk assessment, it is crucial to evaluate hazard and vulnerability criteria together to accurately determine risk scores. This approach, widely adopted in risk assessment, has been emphasized by numerous researchers (Wisner et al., 2004; Masood and Takeuchi, 2012; Dandapat and Panda, 2017; Chakraborty and Mukhopadhyay, 2019). The fundamental equation for calculating risk is expressed as follows (Blaikie et al., 2004; Chakraborty & Mukhopadhyay, 2019; Dandapat & Panda, 2017; Masood & Takeuchi, 2012):

$$R = HxV \tag{5}$$

where:
R represents the risk, H denotes the hazard level, V corresponds to vulnerability Hazard Risks in Khenchela area.

The hazard matrix (Figure 4) presents the pairwise comparison of the five main criteria that influence flood risk in Khenchela: distance from the canal network, slope, land use, rainfall intensity, and topography. These criteria are compared on a scale of 1 to 9 to determine their relative importance (Saaty, 1987), with a higher value indicating a greater influence on flood risk.

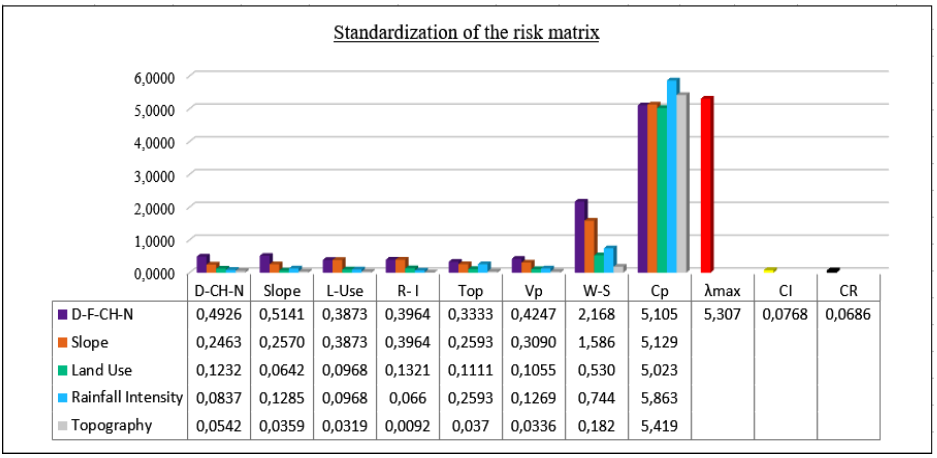


	D-F- CH-N	Slope	L-Use	Rainfall	Topo	Vp (Weight)
Distance from Channel Network	1,00	2,00	4,00	6,00	9,00	0,4247
Slope	0,50	1,00	4,00	6,00	7,00	0,3090
Land Use	0,25	0,25	1,00	2,00	3,00	0,1055
Rainfall Intensity	0,17	0,17	0,50	1,00	7,00	0,1269
Topography	0,11	0,14	0,33	0,14	1,00	0,0336

Fig. 4. Risk matrix with standardized weights

The standardization of the criteria in this study (Figure 5) involved the calculation of the consistency ratio (CR) (Wang et al., 2008) to ensure the reliability of pairwise comparisons in the AHP method. The weight of each criterion was derived from the standardized comparisons, with the weighted sums and the maximum eigenvalue (λmax) confirming the consistency of the judgments.

The consistency index (CI) (Blaikie et al., 2004; Saaty, 1990) and CR were then calculated, resulting in a CR value of 0.0686, below the threshold of 0.1 (Blaikie et al., 2004; Chakraborty & Mukhopadhyay, 2019; Dandapat & Panda, 2017; Masood & Takeuchi, 2012). In our study the CR value calculated equal to 0.0686, below the threshold of 1%, This result indicates an acceptable level of consistency, validating the robustness and accuracy of the criterion weights in flood risk assessment, we note that there are several study of flood risk assessment was obtained a CR value close of our result like (Aydin et al., 2022) with CR equal to 0.05; (Helene, 2023) With CR equal to 0.07.

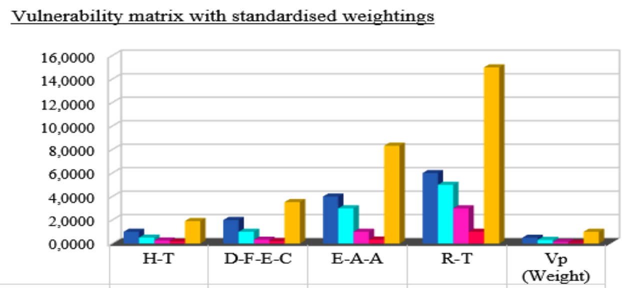


	D-CH-N	Slope	L-Use	R- I	Top	Vp	W-S	Cp	λmax	CI	CR
D-F-CH-N	0,4926	0,5141	0,3873	0,3964	0,3333	0,4247	2,168	5,105	5,307	0,0768	0,0686
Slope	0,2463	0,2570	0,3873	0,3964	0,2593	0,3090	1,586	5,129			
Land Use	0,1232	0,0642	0,0968	0,1321	0,1111	0,1055	0,530	5,023			
Rainfall Intensity	0,0837	0,1285	0,0968	0,066	0,2593	0,1269	0,744	5,863			
Topography	0,0542	0,0359	0,0319	0,0092	0,037	0,0336	0,182	5,419			

Fig. 5. Standardization of the risk matrix

Vulnerability Risks in Khenchela area

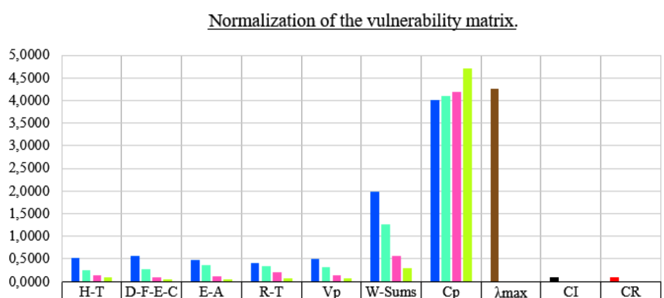
The vulnerability matrix provides a pair-wise comparison of the criteria that influence vulnerability to flooding in Khenchela, focusing on socio-economic factors. These criteria include housing type, distance from education centres, economic activity zone and road traffic. Each criterion was compared according to its relative impact on vulnerability, using the AHP scale from 1 to 9 (Figure 6).



	H-T	D-F-E-C	E-A-A	R-T	Vp (Weight)
Housing Type	1,0000	2,0000	4,0000	6,0000	0,4919
Distance fromEducation Centers	0,5000	1,0000	3,0000	5,0000	0,3093
Economic Activity Area	0,2500	0,3300	1,0000	3,0000	0,1362
Road Traffic	0,1660	0,2000	0,3330	1,0000	0,0626
Sum	1,9170	3,5330	8,3330	15,0000	1,0000

Fig. 6. Vulnerability matrix with standardised weightings (Authors, 2024).

The normalization of the vulnerability criteria (table) included the calculation of the consistency ratio (CR) in order to validate the reliability of the pairwise comparisons. The weight of each criterion was confirmed by the calculations of the weighted sums and the λmax. With a CR value of 0,0936 (< 0,1), the calculated ration is close than the value obtained in the study of (Kittipongvises et al., 2020) with CR=0.096 , and (Radwan et al., 2019) with CR=0.08. which confirm that the matrix showed an acceptable consistency, validating the robustness of the vulnerability criteria weights in the flood risk assessment (Figure 7).



	H-T	D-F-E-C	E-A	R-T	Vp	W-Sums	Cp	λmax	CI	CR
Housing Type	0,5216	0,5661	0,4800	0,4000	0,4919	1,9779	4,0200	4,2525	0,0842	0,0963
Distance from Education Centers	0,2608	0,2830	0,3600	0,3333	0,3093	1,2656	4,0900			
Economic Activity Area	0,1304	0,0944	0,1200	0,2000	0,1362	0,5703	4,1900			
Road Type	0,0870	0,0566	0,0400	0,0667	0,0626	0,2946	4,7100			

Fig. 7. Normalization of the vulnerability matrix (Authors, 2024).

Results

Result Hazard Risks

The Slope Map: The slope map of this city is divided into four segments, the slopes of which "<2°" "2°-5°" cover the majority of the surfaces of the urban perimeter of the city; the slopes of "5°- 8°" cover the outer belt of the city and then the slopes that exceed ">8°" concern the points going towards the crests of the city's watershed.

This representation shows that the points most exposed to the risks of runoff are located primarily in the middle of the southern part and the extreme north of the city (figure 8a). Runoff accumulates food at lower altitudes, which is the cause of the formation of mud torrents (Lahousse et al., 2016).

Land Use Types: The land use types of the study area derive their importance from their hydric permeability.

Since our study area corresponds to an urban environment, land uses are defined in three distinct categories: the category of soils located upstream of the city's watershed and characterized by plant cover and rough terrain, the category of paved, built and coated soils in the urban environment of the city, and the last category concerns bare land.

The entire study area is covered by the urban environment which has high roughness and low impermeability (Figure 8b).

Distance to Drainage Channels: It is obvious that the areas near watercourses are the most exposed to the risks of flooding and mud submersion. The distribution of intervals is defined by four classes: "0-20m", "20-50m", "50-100m" and >100m (Figure 8c).

The watercourses are distributed throughout the city but its southern part followed by its northern part are the most congested by collectors, which puts them more exposed to risks. All collectors discharge into the large river bordering the city on its eastern part.

Topographical Index: The topography index presents at least three benches between 1000 and 1100m on the lower part of the city, between 1100m and 1150m on most of the city and >1150mm for the western foothills of the city (Figure 8d).

On the other hand, this distribution represents a distinction in the lithological nature of the land, the lower part of which presents permeable lands rich in alluvium, the opposite case, ascending upwards where the roughness of the land and the flow speed of the water are higher.

Rainfall Intensity: The relationship between altitude and rainfall is clearly seen around this town, where the upper part of the catchment area receives more of rain than the lower part.

When the intensity of precipitation converges with the distinct nature of the soil and its water content, the level of saturation of the water tables is different.

In this case, the rough ground with little vegetation cover, which favours the flow of water upstream of the town, becomes a factor in soil erosion (figure 8e).

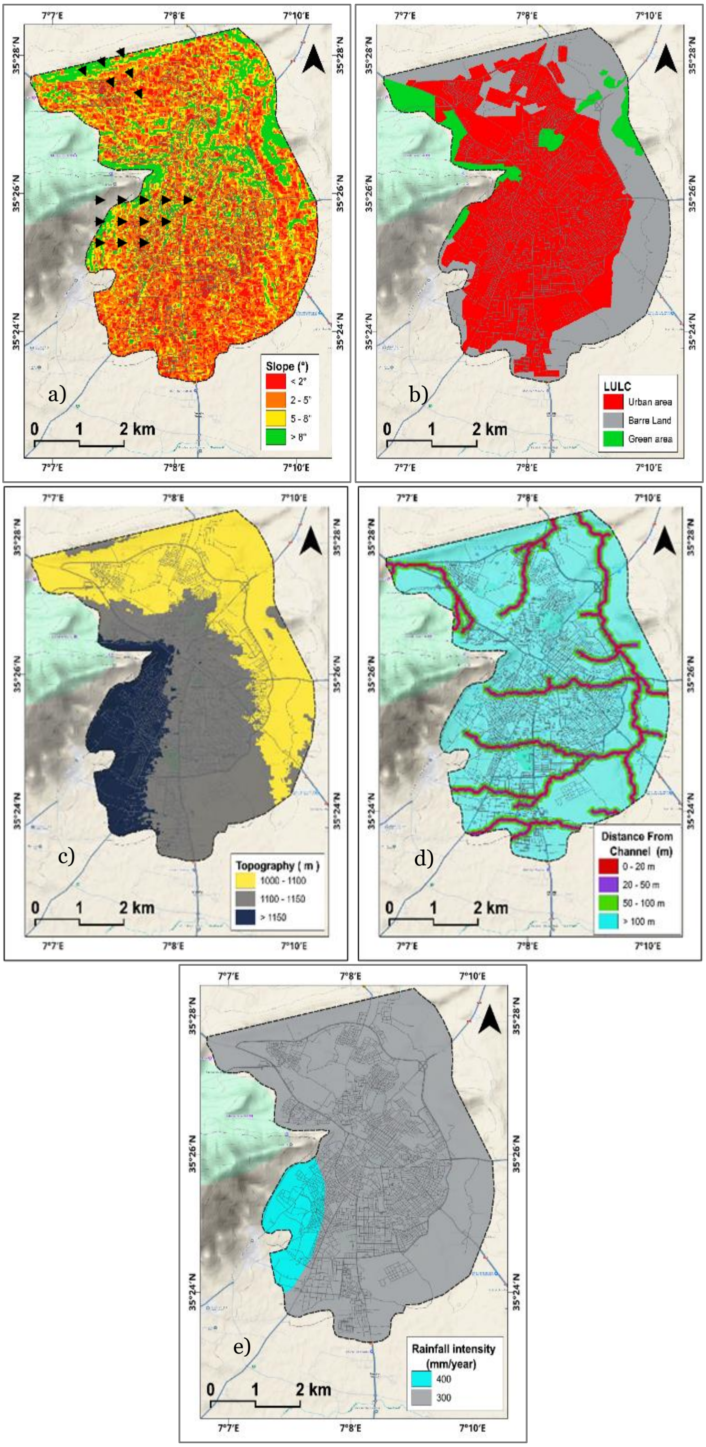


Fig. 8. Flood Parameter in the town of Khenchela: ***a)*** *Map of slopes.* ***b)*** *Map of Land Use Types.* ***c)*** *Distance to Drainage Channels.* ***d)*** *Topography Index.* ***e)*** *Rainfall intensity (Autors, 2024).*

Results Vulnerability Risks

Housing Type: Bringing together population masses and large car parks, under the effect of population density generated by the vertical concentration of residents and horizontal concentration of night-time vehicle parking; collective housing neighborhoods represent more vulnerability to exposure to flood risks than individual housing neighborhoods (Figure 9a). The extent of the damage caused by the risk of flooding on collective housing districts is not measured by their number but by their locations in the most vulnerable areas.

Distance from Education Centers: Throughout the year-round activity route, this type of facility houses a significant number of the population who can constitute large gatherings of people, particularly during the periods of entry or exit of pupils and students. The vulnerability of this type of facility is measured by concentric radii in relation to the grouping exits between: "<30m","30m-60m","60m-100m" and >100m. (Figure 9b).

Economic Activity Area: Markets, department stores, shopping boulevards, medical establishments, city center..., are all places where the population may gather; they may be exposed to hazards during daily errands, especially if floods coincide with shopping days and peak hours. An inventory of the concentration of economic activities in the city of Khenchela is carried out according to four classes (high, medium, low and negligible); shows that the city center and major traffic routes represent the backbone of this economic dynamic (Figure 9c).

Road Type: Urban traffic routes play the role of a gathering space for people in a state of movement conditioned by a limited space inside the vehicle, at the time of floods, accompanied by traffic congestion, users of these means find themselves trapped in their vehicles, the reason why the first victims of floods are always related to the use of vehicles and the importance of the roads determined by their dimensions, their shortcuts, their allocations in parking areas, their drainage in three categories (main, secondary and tertiary roads) (Figure 9d).

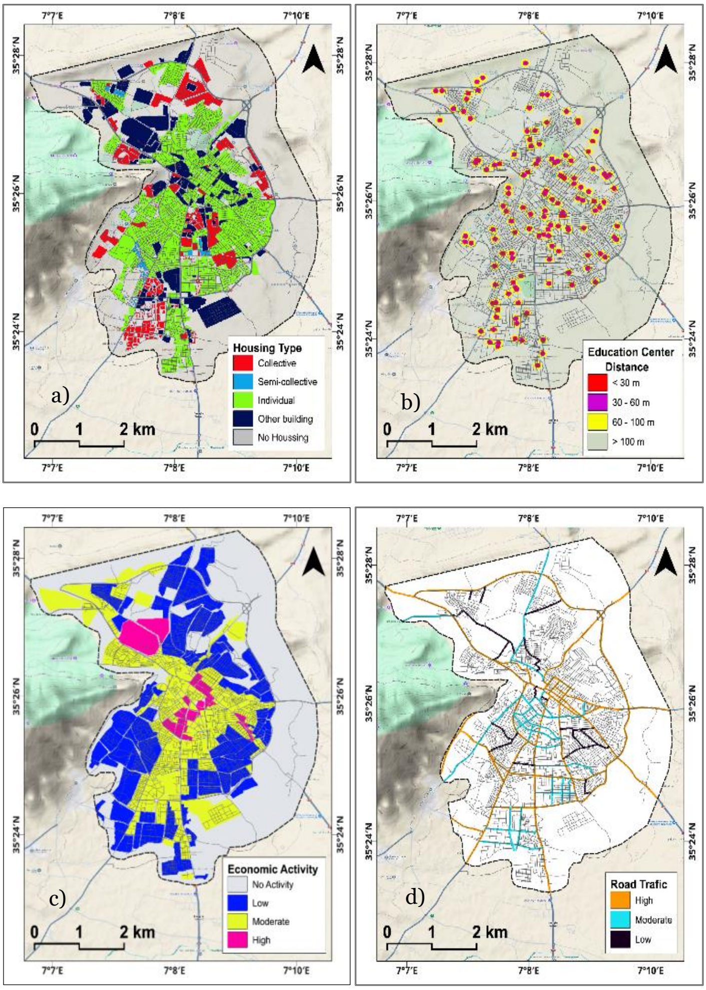


Fig. 9. Parameter of Vulnerability in the town of Khenchela. a) Housing Type. b) Distance from education centers. c) Economic activity area. d) Road traffic type (Authors, 2024).

Discussion

Discussion Flood Risk Levels:

Interpolation of all the risk analysis factors relating to natural hazards are divided in Figure 10, into four classes:

- High: this is seen along the entire length of the watercourses, with greater gravity at the lower points of the town, and greater intensity in and around the outlets of the run-off collectors.
- Medium: on the banks of rivers, on the upstream part of the South-West catchment areas of the city, supported by more precipitation.
- Low: on the lower parts of the city, which have more soil permeability and degrees of slopes of the high ground.

- Very low: especially on the crests of the catchment areas as well as the most rugged parts.

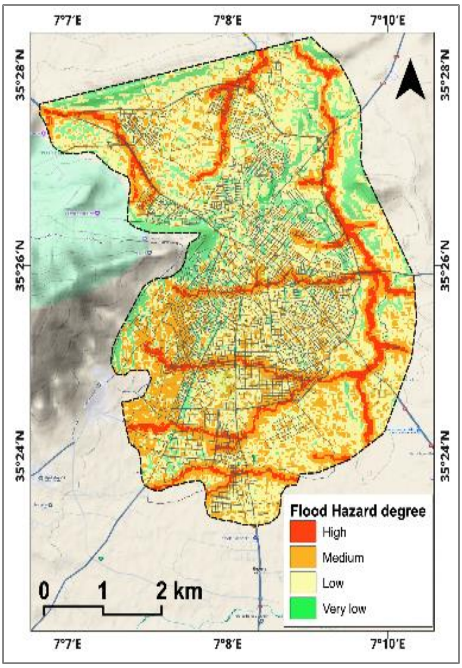


Fig. 10. Flood Risk Level in the town of Khenchela (Autors, 2024).

Discussion Degrees of Vulnerability

The degrees of vulnerability are distributed according to four types of places: high-risk places, represented in clouds grouped in three times (the middle of the city, the districts of the new northern urban pole and the residential districts of the NR 88; and the new southern urban pole) and clouds scattered throughout the city. What is important to grasp is the recorded relationship between vulnerability and the type of habitat, most of whose vulnerable points are superimposed on the residential cities of collective housing, followed by the points of concentration of economic activities. The effect of the main traffic routes, is noticeably present at the degrees of vulnerability (Figure 11).

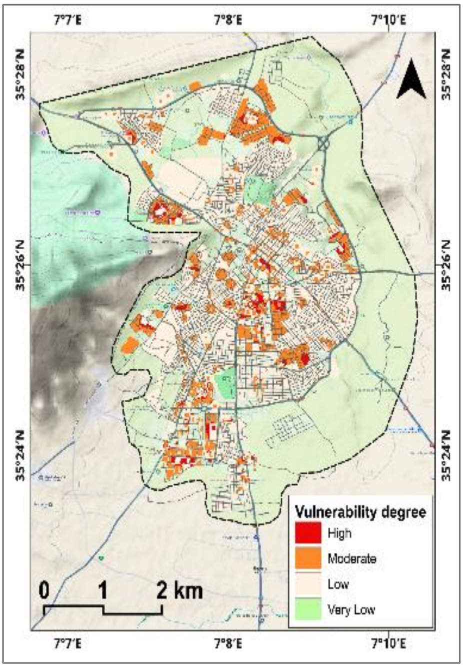


Fig. 6. Degrees of vulnerability in the town of Khenchela (Authors, 2024).

The cross-referencing of flood risk factors (Figure 10) and vulnerability factors (Figure 11) with the theoretical context of the hierarchical analytical model method for the city of Khenchela, resulted in the production of the final map (Figure 12), which illustrates the spatial distribution of flood risk areas in the city of Khenchela.

The classification of places according to the possible severity of risks in four main risk levels: high, medium, low and very low (Figure 12).

High and medium levels: with 12% of the total surface area, this is the middle of the city where the main roads meet with the centre of the economic dynamic and the concentration of apartment blocks; with relatively flat land. The new urban centre to the south of the city, made up of multi-family residential areas on flat land exposed to the outlets of the region's rivers. The residential and university estates in the new northern urban centre. What is important to grasp here is the correspondence recorded between the most vulnerable points with the highest population density of 25,000 inhabitants/km^2 and the historically flood-prone areas.

The degree of threat, low and very low, concerns certain areas of the city, but is much more widespread in the areas of future urbanisation and the ridge tops, which are not at risk.

This classification is based on a logical approach rather than a method of equal intervals, in order to take account of real variations in natural conditions (e.g. slopes, soil types) and urban conditions (e.g. population density, quality of infrastructure).

The data taken from the history of flooding in this city matches our results in certain areas, such as the new urban poles to the south and north of the city, which have been the focus of more attention on this issue. However, it has omitted certain points that should not be overlooked, such as the areas along the main roads, and the areas in the middle of the city, where the majority of economic activities, collective housing areas and many schools are concentrated. The vulnerability of these areas is largely due to the intensity of human activity.

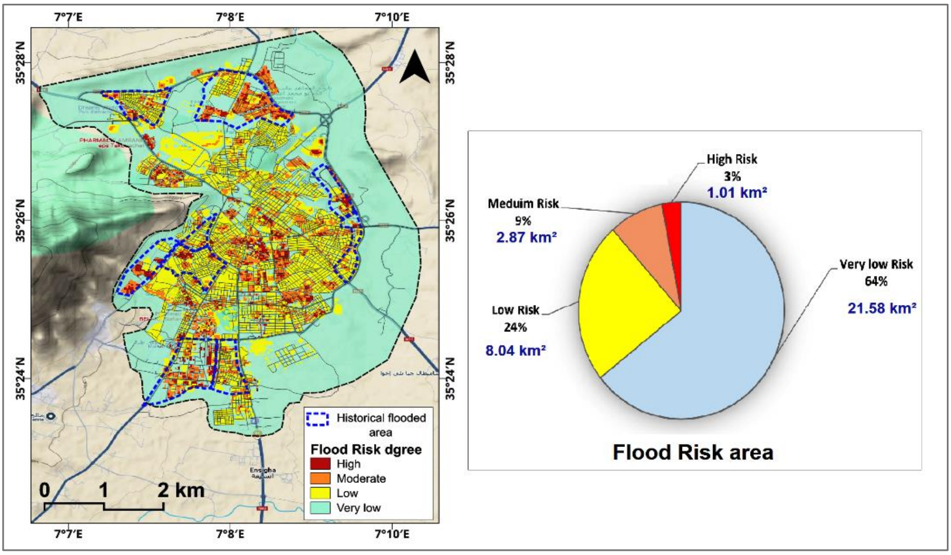


Fig. 12. Degrees of flood risk in the town of Khenchela (Authors, 2024).

Conclusion

The results of this study go hand in hand with the findings of the event history effected by the civil protection services presented earlier. The use of natural hazard maps, superimposed on vulnerability maps, highlights the problem through the detection and location of black spots which are more likely to be exposed to risks, and which need to be given greater attention and care to protect against the risks of flooding.

This study identified the areas most vulnerable to flood risk, and produced a risk map to help city stakeholders better manage the consequences of the phenomenon and avoid the loss of many lives and property. It also represents a pre-planning or post-planning urban model.

To this goal, this study invites stakeholders to take into account certain recommendations relating to urban issues by strengthening the city's resilience to these phenomena through:

- The redevelopment of the areas surrounding the town of Khenchela by reforestation and planting in the downstream areas of the catchment basin.
- The restriction of population polarisers around areas vulnerable to flooding.
- Raising awareness and mobilising society to take the necessary precautions against this phenomenon, especially around the city's weakest and most vulnerable points.
- Reallocating the areas concerned to less populated and less built-up areas (e.g. for gardens, wooded recreation areas and areas with permeable surfaces and grassed areas).

- Taking into account the data from this study in the reinforcement of water drainage infrastructures by oversizing the diameters of drainage networks.
- Setting up rainwater management infrastructures at vulnerable points in urban areas for later use (cleaning of public spaces, watering of gardens, etc.). This can be done in large collective housing estates in the eastern part of the town of Khenchela.
- Ongoing maintenance and cleaning of drainage infrastructure, with particular attention paid to the most vulnerable areas.
- Continuous monitoring and strict application of the provisions relating to the indiscriminate dumping of solid waste and the encroachment on land reserves through the construction of buildings or other infrastructure along or near watercours

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