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Naima Dilmi[1*], Hynda Boutabba[*]

** Management of Urban Techniques Institute, University Mohamed Boudiaf, M'sila, Algeria*

ASSESSING URBAN VULNERABILITY TO LANDSLIDES USING THE ANALYTIC HIERARCHY PROCESS (AHP). CASE STUDY OF THE MUNICIPAL HEAD OF DJEBAHIA IN ALGERIA

Abstract: Djebahia is an average city in the Algerian centre, reported to have many risks related to landslides, with very important indices of instabilities. The recurrence of damaging events in this locality has shown the fragility of its urban system. The main objective of this article is to analyse the urban vulnerability in Djebahia municipality by determining the physical condition of its urban structure. The procedures for the analysis of factors at the origin of the risk in this city are mainly derived from the spatial analysis program, represented by the geographic information system software (ARCMAP), which contains a set of tools facilitating the process analysis. The present research was based on the analytic hierarchy process (AHP) of Thomas Laurie Saaty (1990), which belongs to a series of multi-criteria approaches. The analysis showed three levels of urban vulnerability: high, medium, and low, while the elements most affected by landslides are equipment, collective, and individual housing. These results were translated into a map of urban vulnerability to landslide risk.

Key words: Djebahia, landslides, Analytic Hierarchy Process, urban vulnerability, geographic information system

[1] naima.dilmi@univ-msila.dz (corresponding author)

Introduction

The earth has a special life cycle characterized by the influence of many external factors; its surface constantly changes. All these changes automatically cause natural hazards (Abay et al., 2018; El Jazouli et al., 2019). At present, landslides are one of the most important natural hazards. This geological risk threatens many countries around the world, especially in mountain regions (Zhou et al., 2013). and has caused considerable damage to humans and the environment in general. Each year, more than 4,000 non-seismic landslides are registered around the world (Desodet et al., 2017). Sadly, despite all efforts to reduce landslides, their consequences will continue to endanger humans and their activities, and they cannot be accurately measured or predicted (Gokceoglu et al., 2005). Landslides are generally defined as the process of the descent of the earth's layers and their change from a stable physical state to an unstable physical state under the influence of gravitational forces (Varnes, 1994). As a result, landslides are generally related to physical environmental characteristics such as topography and soil type, and are sometimes linked to precipitation (Suryanarayana et al., 2021).

In this regard, there are new methodologies that ensure better understanding and management in order to effectively mitigate the damage caused by landslide risks. In the same context, there are many approaches used in scientific research to study and assess the risk of landslides, including deterministic, heuristic, and statistical approaches (Boyossoro et al., 2020). The deterministic method depends on analysing the stability of the slopes by returning to physical characteristics, especially those related to geotechnical data. This method requires accurate and disaggregated geological data and therefore cannot be applied to large areas but only to small-sized areas. The statistical method needs data on the factors causing danger as well as an inventory of the timing of ground movements (Sedan et al.,2013). These studies are based on statistics and links between different risk factors as well as the field distribution of ground movements (Guillard,2009). The heuristic method is based on the factor of expertise gained through site investigations as well as the interpretation of satellite images. Therefore, it is a geomorphological analysis of exposure to landslides, which is often indirect due to the ease and clarity of the analytical process (Visintainier & Turrni, 1995). Among the heuristic methods we find the method of hierarchy analytic process (AHP). This method is one of the most appropriate and widely used in the study of landslides (Lacasse & Nadim, 2009). All urban components threatened by landslides have been weighted and ranked according to their importance and urban function. The AHP method helps to prevent possible landslides. It is used in the proper planning of land use and future construction (Mezughi et al., 2012). This helps to streamline decisions on the allocation of funds for landslide risk management.

In Algeria, many cities suffer from landslides, given their location on sloping land. One of them is Djebahia, a commune in the department of Bouira. Serious damage has been recorded in recent years. In this context marked by the variety and severity of vulnerabilities, this paper aims to analyse the fragility of urban components to landslides in Djebahia, using the hierarchy analytic process proposed by (Saaty, 1990) as a first step, and then proceed to construct an urban vulnerability map with Sig-Ahm integration (Françis et al., 2020). It is important for urban risk managers to make accurate identification of high-risk areas in an urban area a must because, unlike other natural hazards, landslides do not take into account the return period as a leading criterion. major; and therefore, do not allow urban officials to prepare for this tragic natural event (Dai et al., 2002).

Study Area

Djebahia is located in the Djurdjura massif in the north-western part of Bouira Province, around 20 kilometres from it and 60 kilometres southeast of Algiers. Administratively, the study area belongs to the Kadiria district, which covers 73 km^2 and has an estimated population of about 18,000 people (ONS, 2008). The population is divided into seven primary agglomerations, with the remainder living in secondary areas (ONS, 2008, Offshore Northern Seas Exhibition, 26-29 August 2008).

Topography, lithology, and physical occupation of the soil studied are three factors whose combination defines the degree of risk of landslides (Desodet et al., 2017). Djebahia is located at the base of the great Kabylie, which is characterized by a more or less soft relief and a culminating altitude of 1244 m. Like the direction of the structures of the Tell Atlas, this set is oriented in its entirety in the east-west direction. Examination of the geological sheet shows that the central part of Djebahia is crossed from South-West to North-East by two ridges constituting the eastern termination of the Atlas of Tablat. The south-eastern part is distinguished by the absence of mountainous buildings (Benacherine, 2020). The topography of the study area is rugged. It has a series of level curves separated by valleys whose altitudes vary between 171 m and 993 m. The geological structure is composed of sandstone with high porosity. From the hydraulic point of view, Djebahia contains important water resources. It is crossed by important watersheds: the basins of Isser (N° 09), Soummam (N° 15), and coastal Algiers (N° 02). This water richness is favoured by the low permeability nature of the soil, the melting snow of Mount Djurdjura, and the heavy precipitation of rain water. The hydraulic network of this municipality is distinguished by the diversity of watercourses, so that all the secondary valleys branch out into the main valley. And the flow direction is from the south side to the north side of the region.

For rainfall, the annual average is between 400 and 600 mm per year. The wettest months are the first three months of the year, led by February with 91.16 mm. However, autumn showers are considered the most dangerous because they occur on soil that has lost cohesion during the summer dry season, making it possible to produce grooves and landslides (Hugoni, 2005; Slimi & Larue, 2010).

Methodology of Approach

The vulnerability of urban elements to natural hazards related to landslides in Djebahia municipality was analysed using the analytic hierarchy process. The objective of this analysis is to prepare a map of the exposure of the studied area to landslides using the geographic information system (GIS). To achieve this goal, the principles of hierarchy analysis are applied in order to obtain very important results, including the production of a comprehensive map showing the extent of exposure of urban components (housing, equipment, road network) and the degree of their exposure to this danger. The analysis included several analytical steps using data from remote sensing and statistics for the study area. The obtained map represents three levels of vulnerability: high, medium, and low. As for the elements most affected by the danger of landslides, they are individual and collective housing, followed by public equipment and roads.

Hierarchy Analytic Process (AHP)

The AHP is a quasi- qualitative method suggested by Thomas Laurie Saaty in 1990 (Rahaman et al., 2014). It is represented by a structural framework that helps to make a decision to solve a complex problem (Mezughi et al.,2012). it is used in various economic, environmental (Abed et al., 2011; Adimi et al., 2018) and geohydrological field, such as the assessment of the probability of erosion (Correia, 2007) and the study of the transformation of land use (Figueiredo, 2001). This method begins with several important stages. The first is the hierarchy of the problem studied, and then there is a phase in which priorities and weights are calculated. Sati (1990) developed a scale of 1 to 9 for the judgments of the elements of the comparison matrix according to the provisions released by the researcher (Tab.1). The normalized eigenvector T, used to quantify and evaluate the importance of each decision criterion, is calculated by the following formula:

$$T= (W1/\sum Wi \ W2/\sum Wi\ldots \ Wn/\sum i), \tag{1}$$

where Wi is the eigen vector of the matrix, which can be calculated using the following formula:

$$w = \left(II_{\int -1}^{n} w_{t\int}\right)^{1/n} \tag{2}$$

To test the existence of a logical relation between the different data, in other words, the coherence of the formulated response, TL Saaty proposes the calculation of the coherence index (CI) and the coherence ratio (RC) according to the following formulas:

$$C = \frac{(\lambda \mathrm{m} \quad -n)}{n-1} \tag{3}$$

where λmax = T.

The coherence ratio (RC) then constitutes the ratio between the coherence index (CI) and a random coherence index (CA) found in (Table 2). A consistency ratio (CR) whose value is less than 0.10 is considered acceptable. The coherence ratio is therefore equal to:

$$R = \frac{I}{C} \tag{4}$$

Tab. 1. Scale of judgments (1 to 9)

Importance	**Definitions**	**Explanation**
1.0	Equal importance of both elements	Two elements contribute equally to the property
3.0	One element is slightly more important than the other	Personal experience and appreciation slightly favor one element over another
5.0	One element is more important than the other	Personal experience and appreciation strongly favor one item over another
7.0	One element is much more important than the other	An element is strongly favored and its dominance is demonstrated in practice
9.0	One element is absolutely more important than the other	Evidence favoring one element over another is as compelling as possible
2, 4, 6, 8	Values associated with intermediate judgments	When a compromise is needed.

Source: Saaty, 1990

Tab. 2. Values of random coherences according to the order of the matrix

Number of criteria	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Ramos et al., 2014

Method of Analysis of Urban Components (Issues)

This stage of the research aims to analyse and study the urban structure of the study area. This analysis makes it possible to evaluate the losses and to identify the vulnerable urban elements and those which are most exposed to the natural risks linked to the landslides. The first step consists of the need to create a database for the study area using the geographical information software “ArcMap”. This database will use “open street map” data from the “Add base map” toolbar, where the urban components such as housing, public facilities, and road networks will be represented as “Shape file” layers. This geographic program contains several commands. We cite, among others, the orders of “raster calculator", which help to apply the mathematical equations and to combine the calculated weights to produce a final map which models the urban vulnerability of the study area in relation to landslides.

Analysis of the Built Environment of Djebahia: Housing and Equipment

Since the Athens Charter, housing, with its two individual and collective components, has been considered one of the fundamental pillars of town planning and the main function produced by the urban environment (Boutabba, 2011; Mili, 2018; Mezrag, 2018). As in most Algerian cities, Djebahia has experienced urban expansion since the administrative division of 1983 (Boutabba et al., 2012; Salamani & Boutabba, 2019), as well as after the construction of the East-West highway in Algeria. According to the land use plan of Djebahia (Figure 1), the urban structure of this commune is characterized by the predominance of individual dwellings erected in its majority in residential subdivisions and some neighbourhoods of illicit spontaneous habitat. The collective dwelling occupies a secondary position with a very small percentage (Figure 2). It has been planned in the context of rural development, as well as the opening up of roads leading to this locality.

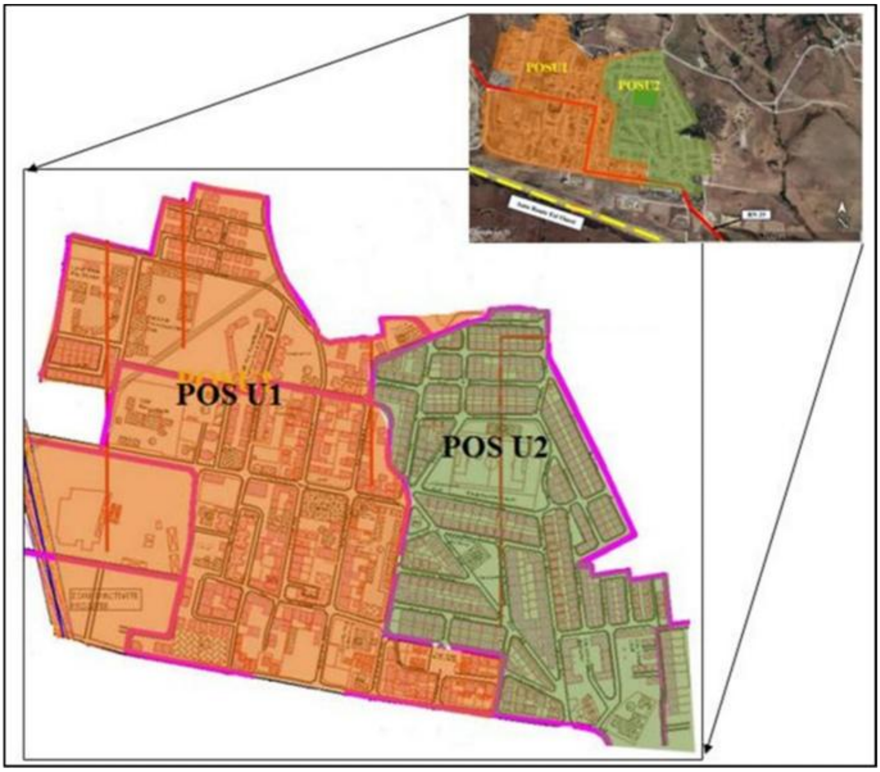

Fig. 1. Maps of POS 1 and 2 of the communal capital-Djebahia (Source: PDAU.2018+ modified by the authors based on Google Earth)

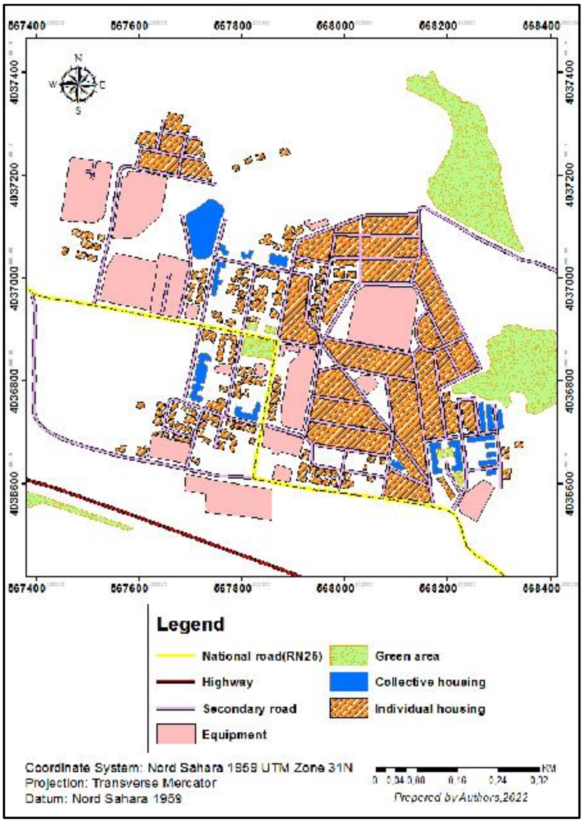

Fig. 2. Map of the urban components of the communal capital-Djebahia (Source: Prepared by authors with ArcGis10.3.1)

Recorded observations have shown that these urban components, shaped by collective individual housing, are affected by two types of degradation. The first type shows the problems of expansion and cracks in the outer walls of the buildings. The second relates to the decline and collapse of the earth's level (Figure 3). The latter is also due to the widening area of chaotic buildings erected in unusual areas, which has caused an increase in the load on the ground.

Fig. 3. Effects of landslides on the interior of collective dwellings (Source: Authors, 2021)

in addition to housing, public facilities are included in urban components. Djebahia has a single area of activity, two health centres, one vocational training centre, five school facilities including three primary schools, one high school, one EMF, two sports facilities, a single library and a polyclinic. Like in the housing sector, equipment is also affected by landslides, the results of which are manifested in the form of expansion in the joints of the equipment. This is an example of the vocational training centre "Djemaa Omar" and the school "Naçer Bey" (Figure 4).

Fig. 4. Effects of landslides on equipment (Source: Authors, 2021)

Analysis of the Unbuilt Environment of Djebahia: The Road Network

The road network has always been considered as the basic element of the typological classification of cities and is thus defined as organic, grid or checkerboard, or radio concentric, hence the importance of this urban component (Cardillo et al., 2006; Boutabba et al., 2014; Bendjedidi et al., 2018; Mili et al., 2019; Hamaina et al., 2021). The municipality of Djebahia is served by a road network consisting essentially of the national road (NR 25), which constitutes the main and structural axis of the city. A secondary road that represents connecting streets between the different parts of the municipality and the residential districts as well as the East-West highway that passes near the study area. The observation revealed a lot of damage related to landslides, especially on Derouaz, Alliouat, Djebri Aissa, and Dermouche Rabah, where huge faults were recorded (Figure 5).

Fig. 5. Effects of landslides on streets (A: Rue Louanas, B: Rue Djebri Aissa) (Source: Authors, 2021)

Results and Discussion

Assess Urban Vulnerability by AHP

The vulnerability of urban environments to the natural risks associated with landslides depends mainly on the degradation of the components of the urban fabric. Urban vulnerability reflects the tolerance of the city's general framework and its ability to cope with landslide damage. This concept of urban vulnerability can be formulated with the following equation:

$$\text{Urban vulnerability} = \text{urban element} + \text{damage to the element} \quad (5)$$

In this application marked by the complexity of urban vulnerability, the AHP aims to simplify this fragility by identifying the areas at risk of landslides, we will start by selecting the urban components (Figure 6).

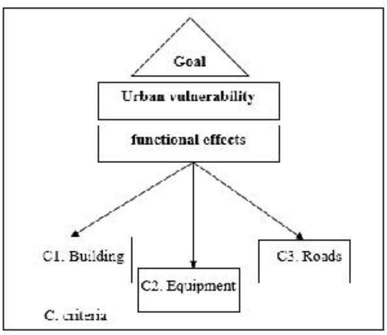

Fig. 6. Hierarchy of the problem studied (Source: Authors, 2021)

The first step of the hierarchy analytic process led to the identification of the main purpose. The urban elements of the municipality of Djebahia are hierarchical. The elements named C1; C2; and C3, respectively, are residential buildings, equipment, and roads, in particular the national road 25 and the highway, represent the urban criteria. These urban elements were selected based on their importance in the study area for the preparation of the comparison matrix (Table 3).

Tab. 3. Values of random coherences according to the order of the matrix

	Dwellings	Equipment	Residential Roads	Highway	NR25
Dwellings	**1**	3	5	7	5
Equipment	1/3	**1**	4	7	5
Residential Roads	1/5	1/4	**1**	5	3
Highway	1/7	1/5	1/3	**1**	1/2
NR25	1/5	1/7	1/5	2	**1**

Evaluate the order of priorities of the urban criteria and the weights

Once the comparison matrix by pair is established, we proceed to the calculation of the respective weighting criteria obtained for the characteristics (criteria) considered essential for the development of the sliding probability map. the priorities of the urban criteria represented in the named matrix (V1) were calculated by multiplying all the values of the matrix and dividing the result by the total number of criteria.

Priority (Houses) = 3.34695488
Priority (Devices) = 1.67875665
Priority (Res. Roads) = 0.98717524
Priority (RN18) = 0.49111861
Priority (Highway) = 0.38385195

Sum = 6.88785734

The results express weights that are automatically integrated into the database previously created in the Arc Map software, following the use of the spatial analysis function (raster calculator). This application indicates that the values must correspond to each urban element. The results are expressed in degraded colours, ranging from dark to light, according to the value of importance (judgements) given previously in the matrix v. (Experience of the researchers). Weights were calculated using the following formula:

Weight = priority i; j… / total priority… (6)

The consistency of the response was then verified through the calculation of the Consistency Index (CI) and the Consistency Ratio (CR). The latter must imperatively be less than 0.1, as recommended by Saaty (1990). The results show that the consistency ratio (CR) value is equal to 0.09. Since these values are less than 0.1, they are therefore acceptable.

Tab. 4. Values of λ max, index consistency, and consistency ratio

λ max	***Consistancy index***	***Consistance ratio***
5,45	0.117	0.09

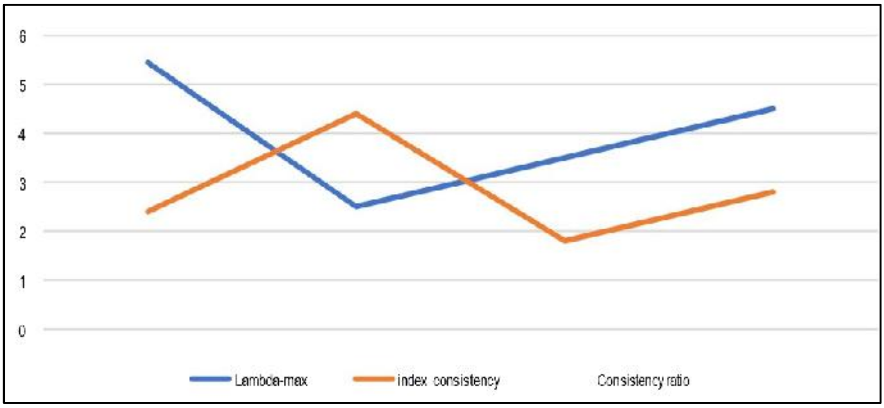

Fig. 7. Graphic representation of the values (λ max; IC. RC) (Source: Authors, 2021)

Using the AHP method, the urban landslide vulnerability values were calculated using equation 1. Calculations as well as the merging of the results obtained in the study area database have shown that urban fragility in the Djebahia is marked by the presence of three levels of vulnerability: strong, medium, and low (Figure 8). Overall, these results significantly expose the high degree of damage recorded in the study area. The elements in red show areas (buildings, equipment, roads) with a high vulnerability. Most of these buildings are dwellings (49%) and equipment (24%). Examples include the residential area of sector 15, subdivision 3 and equipment (Djemaa Omar vocational training centre). Levels 2 and 3, respectively, symbolize medium (yellow) and low (green) vulnerability. As for road networks, the recorded values vary from 6% for the East-West motorway, 7% for National Road 25 and (14%) for residential roads.

Fig. 8. Map of the vulnerability of Djebahia communal capital to landslides (Source: Authors, 2021)

In order to have more precision in the comparison, we superimposed two maps: that of urban vulnerability to landslides (Figure 8) and the map of urban components of the study area. The comparative map shows precisely the degree of vulnerability of each urban component to landslides (Figure 9). Indeed, the bottom of this card expresses that the following facilities: the Naçer bey slimane high school (13); the Djemaa Omar training center (14), as well as the two types of habitat (collective, individual), the highway is -west, national road 25 and residential roads are elements that belong to the first level (high vulnerability in red), except for a few places where we recorded low vulnerability in green: the highway (1), (2); the national road 25 (3), (4), the residential roads (6), (7), (9), (10), (11) the Mosque (7) ; the communal stadium (9), the "Djebri Messaoud" primary school (11), the November 1 housing estate (12), the 30 LPA housing units, the "Derouaze Abd El Kader" primary school (8), belong to the second level which shows the average vulnerability in yellow. As for the zones of future extension (10), it belongs to the low vulnerability level, which means that this area is very suitable for moving equipment such as the health centre and schools that are affected by landslides. We have tried to detect the causes that are at the origin of this vulnerability. We have tried to identify the causes of this vulnerability. The theory indicates that physical characteristics such as the geological nature of the soil, topography and hydrology are major causes in the process of landslide release. These factors automatically increase vulnerability, damage and risk consequences on urban planning in general. Anthropogenic causes are also considered among the important causal risk factors.

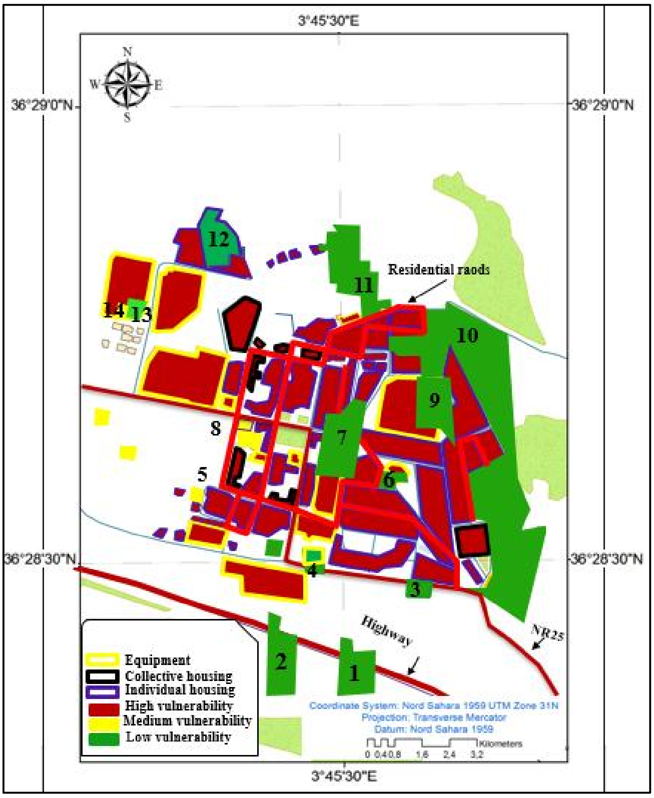

Fig. 9. Map of the vulnerability of urban components to landslides (Source: Authors, 2021)

In the study area, human causes play a major role in urban fragility. In fact, the construction of the propulsion station directly near the East-West Highway has led to changes in the physical conditions surrounding the areas where housing and equipment are located. This has resulted in reduced shear resistance to building materials and unstable soil layers. A variation of the degree of vulnerability has been recorded at the level of individual dwellings, and the response of some of them is high because most of these constructions are very old houses such is the case of the house N°02 located along the street Djebri Issa (Figure 10). There are other single dwellings that have medium to low fragility. This is due to the quality of their construction materials, durability and strength.

Fig. 10. A house affected by landslides (Source: Authors, 2021)

Conclusion

This research demonstrates the potential of spatial analysis techniques in landslide risk assessment. The process of analytical prioritization was applied to create an urban vulnerability map to landslides for the communal capital of Djebahia. To achieve this objective, three vulnerability induction elements were taken into consideration, namely housing, equipment and roads. These elements act as a detector of weaknesses in the urban system in the study area. By applying the AHP method, values of urban vulnerability to landslides were calculated. The urban vulnerability map was subsequently derived under AHM-GIS integration. Three levels of vulnerability were detected and had shown the significant degree of damage recorded in the majority of the territory of the study area. The physical characteristics of the soil, in particular the topography of the terrain, as well as the large-scale digging work carried out for the construction of the payment station near the East-West highway had had adverse consequences on the shear resistance of the material on the slope. as well as the stability of the soil layers.

Conflicts of Interest: The authors declare no conflict of interest.

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