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ASSESSING LANDSLIDE SUSCEPTIBILITY, ANALYZING AND RANKING CAUSES. CASE STUDY OF THE NORTHEASTERN REGION OF BOUIRA-DJEBAHIA, ALGERIA

Abstract: This study aims to use Sig-Ahm integration to assess the susceptibility to landslide risk in the municipality of Djebahia, located in the northwest of the province of Bouira (central Algeria). Using spatial data, this work is also intended to study the main factors that cause the risk of landslides in the study area. Five factors were considered in this research: slope, appearance, altitude, land use and vegetation cover, and drainage. These factors are weighted and ranked using the AHP method to generate a final map that represents the susceptibility of the study area to landslides. The map shows results at four levels, from very low to very high susceptibility.

Key words: susceptibility, landslides, AHM method, GIS, spatial data, Djebahia

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Introduction

In this third millennium, the world is confronted with extremely difficult climatic changes. These changes create environmental complexity that is accurately reflected in ecosystem issues. As a result, most of the natural risk is then caused by the combination of hazards and vulnerability under the influence of various factors, including climate change and land use (Ayala, 2008). A landslide is defined as the movement of a mass of rocks, debris, or earth materials towards a slope under the influence of gravity (Noorollahi et al., 2018). These are significant risks that often occur in mountainous areas (Saha et al., 2019). This concept of landslides has been confirmed by its characteristics (Zhou et al. 2013), which predict that the mountainous area is the special theatre of activation and manifestation of this type of phenomenon due to the often very rugged topography.

Landslides are defined in the same context as a massive movement of soil or rock caused by shear (Akgun & Bulut, 2007). These rapid and intermittent downward movements of a mass of earth along the surface are caused by gravity-induced rupture (Taleb, 2019). A landslide is a geophysical seismic hazard that causes a slope to move continuously or discontinuously (Payne et al., 2009). They can be considered a brake on the process of urbanization and reconstruction, with a very heavy impact on people's lives, property, and the general natural environment (Temesgen et al., 2001; Ayalew & Yamagishi, 2004; Ayenew & Barbieri, 2005; Woldearegay, 2005). Natural and anthropogenic factors can trigger landslides (Wilde et al., 2018).

Especially for landslides, which are parameters related to topography, geology, hydrology, and land cover, susceptibility is the concept that encompasses all the parameters that lead to the manifestation of a landslide. At this scale, it is important to clearly define the susceptibility of a terrain to landslide risk. Indeed, there are many methods and tools that process and help in the mapping of landslides, given the necessary data in the application process. For greater accuracy, landslides are described as a massive movement of ground or rock shear along one or more sliding surfaces (Akgun & Bulut, 2007). Algeria is one of the countries at risk of landslides, particularly in coastal and central regions (Dilmi & Boutabba, 2022).

This research aims to study the factors behind the risk of landslides in the commune of Djebahia, located northwest of the department of Bouira in Algeria. Similarly, the site hosting the East-West Road toll booth project is also affected by subsidence. Other sites in this region are also affected by this problem and also show a strong weakness, such as the municipalities of Buharon and Aomar. In parallel, several newspaper articles were published to highlight the threat of landslides and describe the suffering of citizens in this region. In addition, civil society has also sent numerous letters of complaint to local and state authorities, urging them to intervene and find a solution to their situation.

Fig. 1. Effects of landslides on the study area (roads and installations) (source: prepared by authors with cam program, 2022)

Fig. 2. Effects of landslides on the sidewalk (source: Prepared by Authors with cam program, 2022)

At this scale, it is important to define the susceptibility to the risk of landslides. Susceptibility is the concept that encompasses all the parameters that lead to the manifestation of a landslide. Several methods can measure it. Qualitative methods are based on expert knowledge to identify key triggers. They determine the weight of natural and anthropogenic factors as they determine landslide-sensitive areas (Aditian et al., 2018). As for methods that depend on quantity, we can mention the hierarchical analytical process for decision-making that is widely used in several other areas (Adimi et al., 2018; Nourani et al., 2016).

This method is marked by the presence of the hierarchy. It is based on the decomposition of the complex problem, comparative judgment, the calculation of priorities, and the measurement of the weights of each criterion and sub-criterion. These depend on the expert's judgment, so the resulting map is compatible with the AHP theory as soon as the judgments are more accurate. The methodology adopted in this study aims to analyse and clarify the real causes of landslide risk in the study area, indicating the main or predominant cause that greatly affects the onset of risk. This methodology is based on the hierarchical analysis process (AHP) and the use of the geographic information system (GIS) as a tool to model and map the vulnerability of the study area to landslide risk.

Study Area

The municipality of Djebahia is located in the northwest part of the wilaya of Bouira in Algeria, between 36° 28' 35" north latitude and 3° 45' 28" east longitude (see Figure 3). Due to its geographical location on its regional territory, Djebahia is influenced by an arid Mediterranean climate, characterized by a warm summer and a cold winter. To be more precise, July is the warmest month of the year, with an average temperature of 26.2 °C. The coldest month is January, where the average temperature can drop to 7.3 °C. The average annual temperature is around 18.9 °C (PRR. 2018. Plan for rehabilitation and reconstruction).

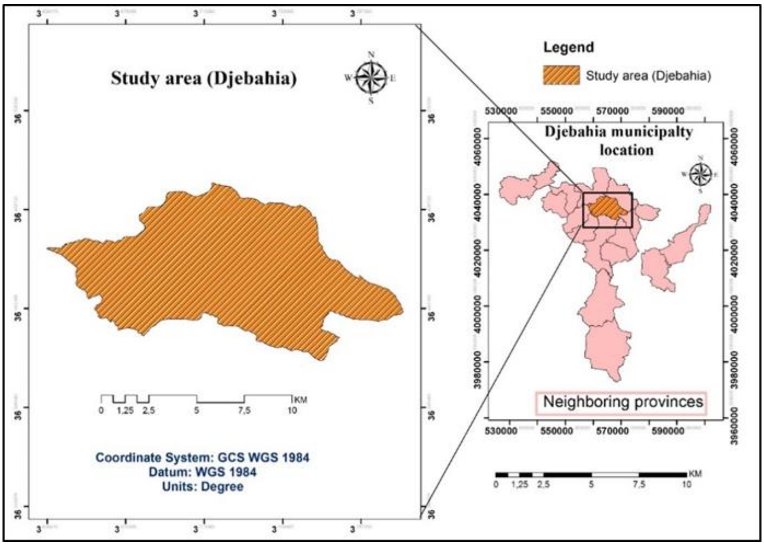

Fig. 3. Djebahia municipality location (source: prepared by authors, ArcGis 10.3.1)

Materials and methods

Input Data

The data used in the analytical process of this research are from remote sensing and field observations. They are thus considered the main pillars of this work. They were collected from satellite images from the Algerian Space Agency (ASAL) as well as the digital elevation model (DEM). The above data were used to apply the Gis 10.3.1 Arc spatial analysis tools. Thematic maps of the study area were produced using the 30-meter resolution digital terrain model. This study used six layers with input data to produce a landslide susceptibility map, taking into account slope, slope direction (Aspect), altitude, drainage, land use, plant cover, and lithology (see Fig. 2). All these data are processed using the following coordinate systems: WGS 1984 UTM Zone 31, projection, transverse Mercator, and Datum WGS 84 (See Table 1).

Tab. 1. Data collection and sources.

Data	Description	Source
Satellite image: ALSAT-2DIMAP	Type: Alsat 2 Scene Level 2A Layer: Scene A2 2019-07-26 Format: Dimap	Algerian Space Agency (ASA)
DEM	Raster: Geotiff	
Slope/Aspect/Elevation/Flow Direction/Flow Accumulation/Basin	ASTER Global Digital Elevation Model V003/Resolution 30m	(USGS) U.S. Geological Survey
LULC	Derived from DEM	
Geological Data	Derived from ALSAT-2DIMAP	ArcGIS 10.3.1 program
	Extracted from Africa Geological Data	Sentinel-2/10m

Geology

Numerous studies have shown that lithology is a very important factor in creating the landslide susceptibility map (Yalcin, 2007). This parameter is considered a major causal factor that triggers the risk of slope instability due to the complexity of this factor itself and its variation in the type of rock that constitutes the soil (Abay et al., 2019). Based on the character of the subsoil, this science aims to describe and understand the depths of the ground layers. The geological rocks forming the study area date from the Upper Marine Cretaceous, with kimberlite rocks and kersantite, according to an extract from a geological map of northern Algeria. It is a constituent of sandstone and brittle sand linked to high-porosity calcite, which has led the rocks to store water underground.

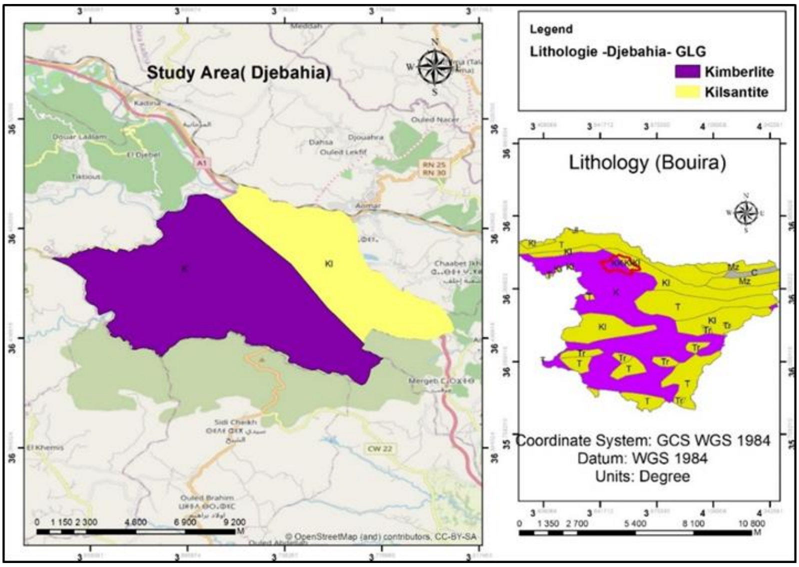

Figure 4. maps of the nature of the soil (source: prepared by authors, ArcGis 10.3.1)

Slope

Many researchers have confirmed, following the use of experimental methods, that slope angle is considered the most important parameter in soil stability studies. (Dai et al., 2001; Lee & Min, 2001; Lee, 2005; Woldearegay, 2005; Long et al., 2011). Indeed, this is an important causal factor. It is used to map the sensitivity of soils to landslides. (Chen et al., 2017); slope is directly related to its use in preparing landslide risk maps (Clerici et al., 2002; Cevik & Topal, 2003; Ercanoglu & Gokceoglu, 2004; Lee & al., 2004; Lee, 2005); In this research, a numerical terrain model (DEM) was used with a resolution of 30 m. This cartography summarizes the information concerning the terrain, the nature and structure of the surface, as well as the process of determining altitudes and level curves. The topographical analysis has made it possible to extract various curves of level as well as particular inclinations. It has also made it possible to determine the topographical structure, which is represented in the figure below (see Figure 5).

Aspect

The aspect generally refers to the orientation towards which a mountain slope is oriented (Abay et al., 2019). This is the direction a mountain slope faces (Pourghasemi et al., 2012).

Another climate parameter on which this factor can have a very important influence is the amount of precipitation (Dai & Lee, 2002). Slope direction is a causal factor for landslides. The topography of this study area is very complex because the values of the angles vary from place to place to very different and difficult degrees and are distributed throughout this study area (see Figure 5).

Altitude

The difference in elevation can be related to various environmental characteristics, such as vegetation cover types and precipitation (Catani et al., 2013). Geologists and geomorphologists have found that the altitude parameter is an important factor and have included it among the conditions for the occurrence of a landslide. (Dai & Lee, 2002; Ayalew & Yamagishi, 2004). The Arcgis 10.3.1 spatial analysis program was used to prepare the altitudes produced in this study, as shown in Figure 5.

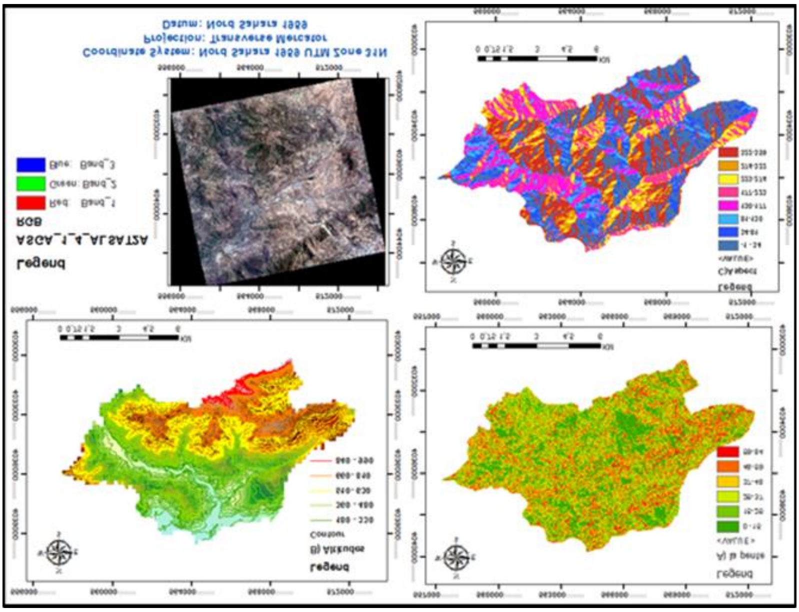

Fig. 5. Topography maps (source: prepared by the authors, ArcGis 10.3.1)

Drainage

Rivers can affect slope stability by eroding slopes or saturating the bottom of the material (Dai et al., 2001). This is mainly related to precipitation accumulating in streams (Ayenew & Barbieri, 2005). The distance and direction of these streams are considered to be one of the primary factors in the stability controller (Yalcin 2011). The study area is characterized by the main river, called Wadi Djemaa. It begins in the middle of the central slope of the town of Djebahia, towards the north side (1); as we find other secondary valleys (2, 3, 4, 5, 6) (see Figure 6). The proximity of residential communities to watercourses is also noted; these streams meet and extend to the depths of the soil, forming watersheds. The tectonic morphology of the study area is strongly altered by incisions in streams, which may ultimately affect slope stability by accentuating the lower sections of the slopes (Abay et al., 2019).

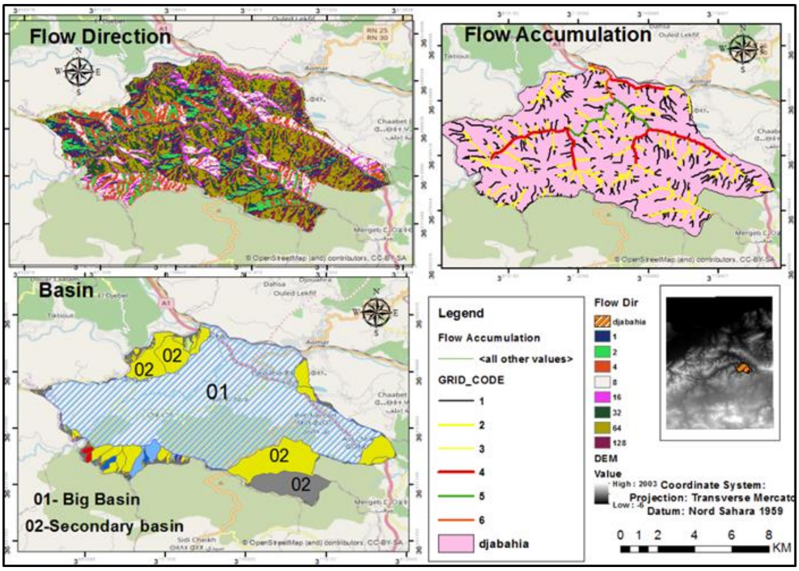

Fig. 6. Hydrology maps (source: prepared by the authors, ArcGis 10.3.1)

Land Use and land Cover (LuLc)

Land use patterns have a strong influence on landslides because they are linked to anthropogenic interference on the slopes of hills (Pradhan et al., 2010). Therefore, the Alsat2 images of the ASAL (Algerian Space Agency) as well as the field observations are data used to prepare a map of land use in the study area (Fig 4). The study of this imagery revealed three types of land use in the study area: urbanized land, agricultural activities, and natural vegetation. This index is marked by the presence of four classes: (-0.21.0.21); (0.21.0.29); (0.29.0.35); (0.35.0.63). The importance of vegetation and land use is very clear in the processes of land instability and degradation that contribute to landslides in the study area. The relationship between vegetation cover and the agricultural activities of the population is direct because high-elevation areas are characterized by a higher index than low-elevation areas. This explains the process of deforestation and the reason for construction in higher areas.

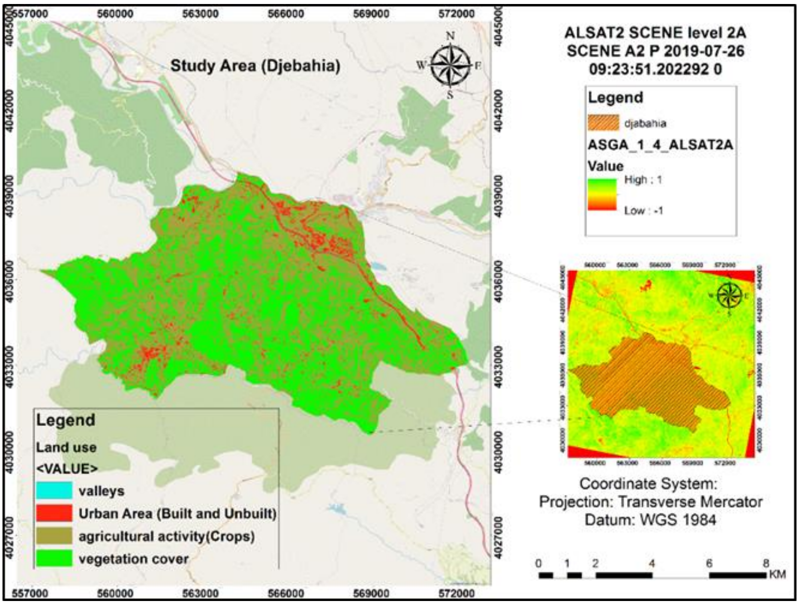

Fig. 7. Map of land use (source: prepared by the authors, ArcGis 10.3.1)

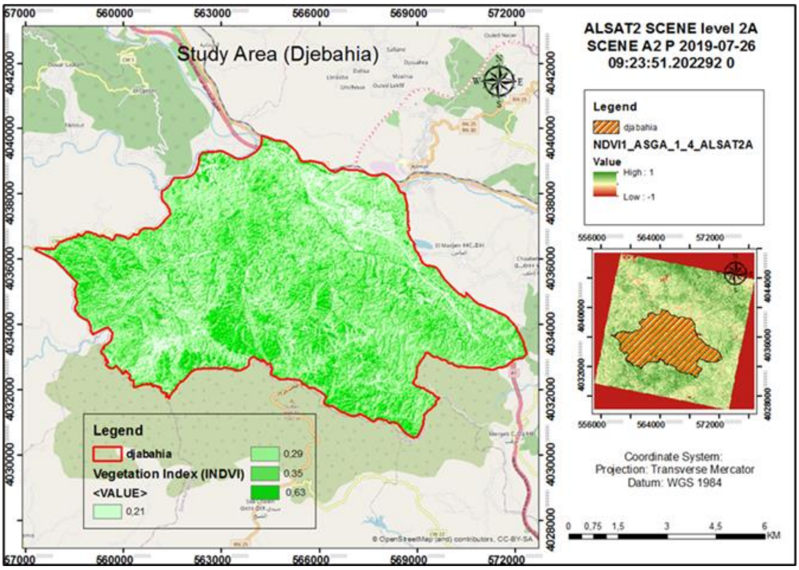

Fig. 8. Map of land cover (source: prepared by the authors, ArcGis 10.3.1)

The approach methodology (AHP)

In 1990, Thomas Laurie Saaty presented the hierarchical analysis method in a structured framework. It is very unique and is used to treat cases that have complex histories. (Mezughi et al., 2012). According to Pourghasemi et al. (2012), the AHP has three main steps: The first step is the generation of the parity comparison matrix. The second is the calculation of criteria weights, while the third phase is the estimation of the consistency ratio. To establish the comparison matrix, the AHP method uses a scale from 0 to 9.

The goal is to evaluate the relative preferences of two criteria (Bachri, 2019). The steps and methodological procedures used to weight the factors behind landslides are summarized in three phases, the first of which is to construct the hierarchical structure of the multifactorial problem studied. The next step is to construct a pair comparison in the form of a judgment matrix. The main purpose of this phase is to compare the various elements of the hierarchy that was created earlier. The input data for the problem consists of comparison tables for each pair of level elements that contribute to the objectives of the next higher level (Abay et al., 2019).

Tab. 2. Judgment scale (1 to 9)

Importance	**Explications**
1	Two elements are equally important
3	One element is slightly more important than the other
5	One element is more important than the other
7	One factor is far more important than the other
9	One element is absolutely more important than the other
2, 4, 6, 8	Values associated with intermediate judgments

Source : El Jazouli et al.2019

While the third phase depends mainly on the calculation of weights and the consistency of comparisons to evaluate the value of each criterion, it is essential to calculate the specific vector of the comparison matrix (weight) for each selected criterion. Then divide all the values in each column by the sum of that column to arrive at a simplified matrix that helps to compare the elements of the problem under study. This method has a very important property that allows one to verify the accuracy of the results presented by the calculation of the consistency index according to equation (1).

$$\mathrm{IC} = \frac{(\lambda \max - n)}{n-1} \quad (1)$$

Where λ max: (T. w);
T = the vector;
w = the sum of the columns of the comparison table;
n is the number of criteria in the comparison table.

Finally, and as a final phase, simply calculate the RC consistency ratio according to equation (2).

$$\mathrm{RC}=\mathrm{IC}/\mathrm{CA}..........\leq 0.10...... \quad (2)$$

The matrix is acceptable.

Tab. 3. Values of the random consistency index (CA)

N	1	2	3	4	5	6	7	8	9	10
CA	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Kayastha et al.2013

Result and Discussion

The methodology adopted in this study aims to investigate the real causes of landslide risk in the Djebahia study area. This methodology is based on AHP as an analytical method as well as the use of geographic information systems (GIS) as a modelling tool. A landslide is a complex process caused by some internal and external factors. Inherent factors include slope stability, geological factors, soil class, groundwater condition, slope geometry (slope, aspect, elevation, and curvature), and changes in land use and land cover. From a methodological point of view, it should be noted that this work was carried out in coordination between three main elements, the first of which depends on taking notes when signing the locations of landslides. The second element by which we simplify the complex subject of the study is hierarchical analysis (Ahp). Therefore, with this method, the factors causing the landslide can be prioritized by the expert. The third element is based on the geographic information tool (ArcGis 10.3.1). This software allows users to receive and store spatial data and has a huge capacity to process this data from different sources. In the same context, six factors that cause landslides in the study area were selected based on their magnitude of impact. Applying the principles of hierarchical analysis, a pair comparison matrix was created for landslides in the commune of Djebahia. Topographical (slope, slope direction, level curves), hydrological (watersheds, streams, flow direction), and geological factors, as well as land use (urban fabric, vegetation, and grain activities), were placed in the comparison matrix. The comparison matrix was created based on judgments ranging from 1 to 9, so that each factor receives a corresponding value and each factor receives an approval value. We note here that these provisions are derived from field observation (the researcher's scientific experience).

This work aims to balance individual relative factors. Although all of the factors chosen result in the appearance of a landslide risk, each factor is made up of sub-factors, or what is referred to in the alternative hierarchical analysis. The division of each factor was done automatically using the Natural Break (Jenks) function. Next, the extraction stage of the primary and dominant alternatives and sub-factors that affect the stability of the study area will be organized according to their degree of impact. In the same context, partial comparison matrices were created for each factor individually (see Table 4), and then priorities, weights, and λ_{max} were calculated using the relationship above. Once the or λ_{max} is calculated, the validity of the matrix is checked by the CI consistency index and the CR consistency ratio, where the latter must be less than 0.10 for the matrix to be considered acceptable.

Tab. 4. Pair comparison matrix (causes of landslides)

Criteria	(A)	(B)	(C)	(D)	Weight	Ranking
(A) GEOLOGY	1	2	3	5	0,47	1
(B) HYDROLOGY	1/2	1	3	3	0,30	2
(C) TOPOGRAPHY	1/3	1/3	1	5	0,16	3
(D) LuLc/NDVI	1/5	1/3	1/5	1	0,07	4

Source: prepared by authors. 2022

Tab. 5. Pair comparison matrix (sub-criteria, Alternatives)

Criteria	Alternatives	Category	Weight	Ranking
Topography	Slope	0-15 15-26 26-37 37-48 48-59 59-84	0,104 0,158 0,355 0,236 0,100 0,048	4 3 1 2 5 6
	Aspect	F-N-NE (34) NE-E (34-81) E-SE (81-130) SE-S (130-177) S-SW (177-223) SW-W (223-274) W-NW (274-322) NW-N (322-359)	0,115 0,215 0,228 0,127 0,072 0,058 0,056 0,120	5 2 1 3 6 7 8 4
	Altitudes	180-330 360-480 510-630 660-810 840-990	0,22 0,20 0,42 0,11 0,05	2 3 1 4 5
Hydrology	Drainage	Bassins versant Cours d'eau Sens d'eau	0.200 0.290 0.810	3 2 1
Land use	Built and non-built Vegetation Index Cereals and other	Urban area Vegetation Other Activity	0.648 0.258 0.105	1 2 3

The results of Table 4 show that the geological factor (0.47/47%) is the main cause of landslides in the study area, followed by hydrology (0.30/30%). In this case study, geological and hydrological links can be reported because of their close relationship with each other, so that what is above the earth's surface is a representation of what is below. Indeed, this was proved by the spatial analysis of the previous data, where it was found that the study area consists of rocks like kimberlite and kirsantite, which are very rich in water. This characteristic was also confirmed by the hydrological analysis, where the study area was found to be located on a major watershed and other secondary watersheds. Increased pore water pressure reduces shear resistance on a slope and promotes water flow. Materials that descend the topography slope (0.16/16%) and land use (0.07/7%) rank third and fourth, respectively (Figure 9).

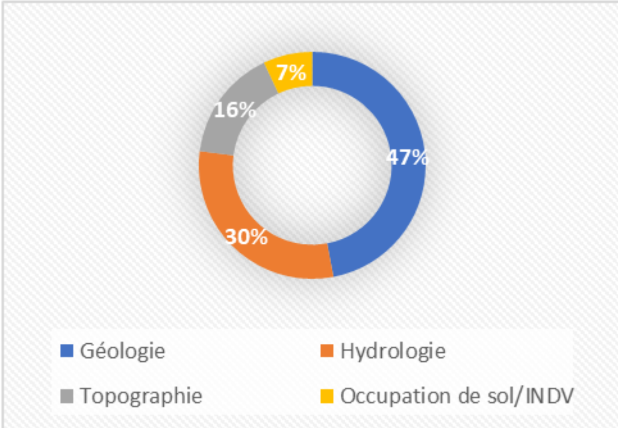

Fig. 9. Nature of landslide causes

Tab. 6. Evaluation of consistency of preferences used to evaluate vectors and categories

	N	Λ max	RI	CA	CR
General Matrix	4	4.21	0.07	0.9	0.07
Slope	8	8.12	0.02	1.41	0.01
Aspect	6	6.18	0.04	1.24	0.03
Altitudes	5	5.06	0.02	1.12	0.01
Flow direction	3	3.61	0.03	0.58	0.05
Land Use/NDVI	3	3.08	0.01	0.58	0.02

Finally, the indicators of all the above factors are combined to produce a final indicator. Then, using the ArcGIS 10.3.1 matrix calculation function, which aims to extract a complete vulnerability map, we were able to establish an accurate map of the study area at risk of landslides. The total susceptibility index is calculated as: (0.47 geology + 0.30 hydrology + 0.16 topography + 0.07 land use/INDV).

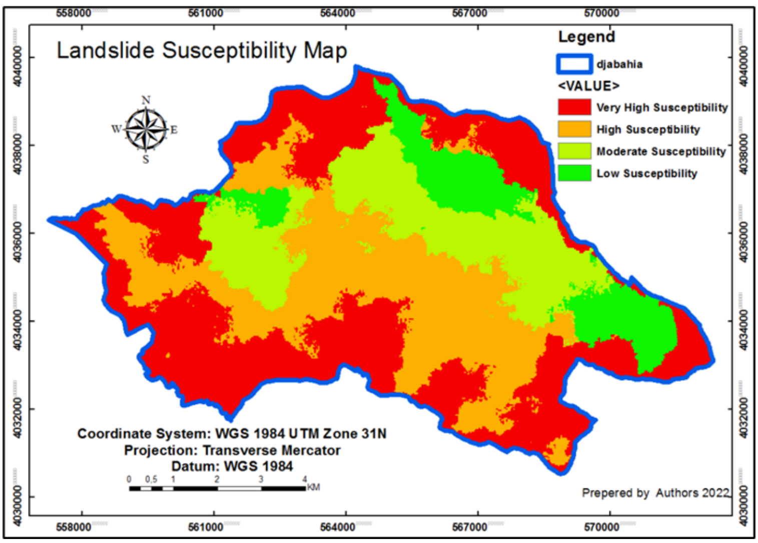

Figure 10. Landslide susceptibility map (source: prepared by the authors, ArcGis 10.3.1)

Conclusion

Landslides are a potential natural threat to society and the individual in general. This risk must therefore be assessed in order to determine the most important actions to be taken if it occurs. In the same regard, the causes of landslides are determined with the utmost care. It can be argued that, in the case of a meeting for more than one reason, the seriousness of the risk and its impact on its surroundings are more important.

The main objectives of this article were to simplify the problem of landslides, dismantle their access, and structure and detail the main causes of danger. This procedure was created using a hierarchical analytical pathway based on a variety of natural factors such as the topography, hydrology, and geology of the study area as the primary causes of landslides. Using the Geographic Information System, the results obtained through the application of the AHP were modeled to obtain a landslide risk sensitivity map. Using the Sig-AHP interconnection, the risk of landslides and the extraction of risk areas were assessed, and four susceptibility levels were inferred: very high, high, medium, and low. It is important to note here that these levels of susceptibility represent the varying degrees of involvement of the above elements responsible for the occurrence of risks.

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

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