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Application of the Qualitative Method to the Study of Landslides in the Wilaya of Mila North-East Algeria

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Abstract

The wilaya of Mila is experiencing multiple landslides endangering several structures, road infrastructures and several constructions. The combination of several natural and anthropic factors is at the origin of the triggering of landslides. This study aims to map potential landslide areas in order to prevent damage. The methodological approach used in this work is the qualitative method, which is based on the multi-criteria analysis of the different factors in the GIS. It defines all the factors that interact in the triggering of gravity phenomena and that explain the susceptibility to landslides.

The results showed that the surface formations of a clay and clayey-marly nature with low geotechnical characteristics were geotechnical characteristics. We conclude that the method used in this study gives a good accuracy in the prediction of landslides in the Mila region of landslides in the Mila region. The produced susceptibility map can be used for future planning and can be considered as a powerful tool to solve the spatial distribution of landslide risk.

Key words: Susceptibility, Multi-criteria analysis, GIS, Landslides, Mila, Algeria.

INTRODUCTION

The wilaya of Mila is one of the regions most exposed for several decades to the risk of progressive ground movements due to geomorphological, hydrogeological, climatic, seismic and anthropic characteristics geological, climatic, seismic and anthropic characteristics. These movements, which are causing significant damage to buildings in several sites,and today they seriously threaten other sites in urban and rural areas with precarious stability.

They are more worrying because of their location in densely populated urban areas, their large extension and the extent of the damage to buildings. The history of landslides in the Neogene basin of Mila goes back to the quaternary period, polygenic forms with a varied inherited typology are divided into rotational landslides and landslides with complex morphology.

Its forms continue to evolve to the final stage of badlands, now very recent forms of instability, which further weaken the soil texture. Landslide risk management and mitigation can be done in several ways.

One possible approach is to assess and map the hazard within potentially unstable areas, using geographic information systems as an indispensable tool for efficient spatial management.

PRESENTATION OF LANDSLIDES IN THE STUDY AREA

Geographical Location

The wilaya of Mila covers an area of 9,373 km^2 with an average altitude of 500 m. This geographical area is divided into 13 daïras and 32 communes.

Administratively, it is bordered to the North by the wilaya of Jijel and Skikda, to the South by the wilaya of Batna and the wilaya of Oum Bouaghi, to the East by the wilaya of Constantine and to the West by the wilaya of Sétif (Fig. 1).

The region is part of the large Neogene basin of Constantine, limited to the North by the tellian chain and to the South by the high plains.

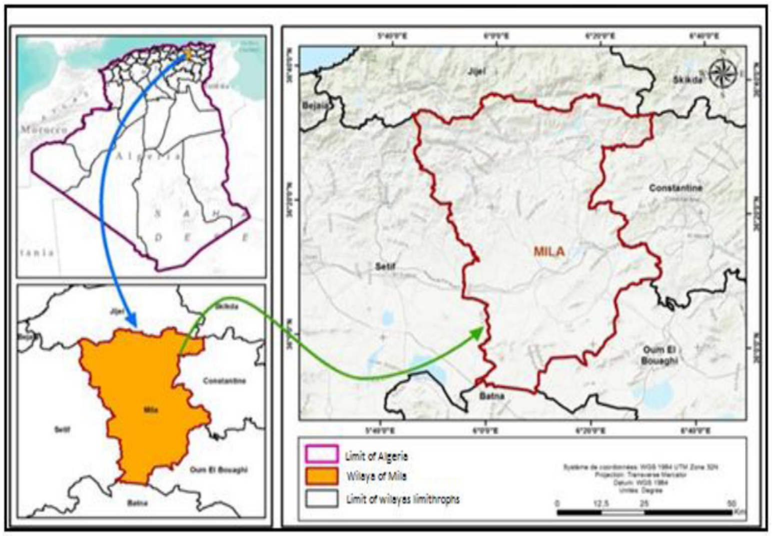

Figure 1. Location map of the wilaya of Mila.

Mapping of Landslides in the Study Area

Landslide inventories are the basis for assessing landslide susceptibility, hazard and risk (Soeters and Van Westen, 1996; Aleotti and Chowdury, 1999; Ardizzone et al., 2002; Dai and Lee, 2008; Van Westen et al., 2008). They are essential for susceptibility models that predict landslides based on past conditions.

The region is characterised by low to steep slopes, shows evidence of ancient landslides in its extent, justified by a very gullied morphology.The area is characterised by low to steep slopes, shows evidence of ancient landslides justified by a very gullied morphology. A series of earthquakes of moderate to strong magnitude have caused the reactivation and acceleration of several landslides.These landslides are very varied, both in rural and urban areas, of which we distinguish :

Sibari Landslides

The village of Sibari is located on formations represented essentially by quaternary red clays, clayey marls with a gypsum layer and conglomerates with a sandy layer. According to the geotechnical data of the site, three main landslide axes mark the locality of Sibari and which are from North to South The first axis of landslides to the north, located along a major tectonic fault corridor oriented East-West, is particularly active and presents a series of nested pullouts.

This landslide presents spectacular instability phenomena, linked on the one hand to the earthworks of the various platforms which were built without any particular precaution during the construction of the dam and to the existence of water sources. The second axis of the landslide develops to the south in parallel to the first axis, the triggering of this landslide was during the construction of the Beni Haroun dam.

This landslide presents a series of niches nested in each other, the axis of which corresponds to a major tectonic accident in the East-West direction. The third slip axis located to the south of the second slip, this movement shows characteristics of a rotational slip, this area shows the most critical movements of the Sibari worm.

The first movements started in the lower part of the slope where several houses were displaced and tilted during the rainy periods in December 1998. The upper part of the slope did not experience any movement until 2003. The origin of the aggravation of the situation is linked to the stabilisation works carried out on the national road RN nº27, which contributed to the destabilisation of the area by creating additional overloads on the land that slipped. The landslide caused the collapse of part of the RN n°27, accompanied by the sinking of several buildings and the tilting of some trees and electricity poles.

Landslide Near the Technical Landfill of Mila

Along the secondary road leading to ouled Bouhama, several sections are affected by important and active disorders, which occupy large surfaces on both sides of the road, the most important of which is located near the technical landfill centre at about 1 km from the Mila-Sid Khlifa intersection.

It is a flat landslide with an extension of 80m long and 40m wide, always in greyish clays of the Mio-Pliocene, causing cracks in different directions which show a strong instability of the ground.

In the light of this analysis, it appears that the numerous instability phenomena observed in various points are the result of a combination of natural and anthropic factors, including: the clayey nature of the land, climatic conditions and the nature of precipitation, slopes with a natural medium to steep gradient, often greater than 10°, which constitutes the limit of stability for clayey soils, earthworks carried out during the construction of the road, which often accentuated the slopes, thus accelerating the erosive phenomenon by causing multiple landslides.

El Kherba Landslides

The city is located on the northern slope of the El Kherba hill at an average altitude of 650 and 450 metres respectively, and on a slope of around 15°,the northern slope of the El Kherba hill is the site of major soil movements which occupy two thirds of the city's area,triggered after the earthquake of 07/08/2020 of magnitude (Mw=4.9), which caused significant damage to the upstream part of El Kherba and caused the degradation and collapse of 1040 buildings, making hundreds of people homeless.(Photos nº1-2)

The terrain is devoid of vegetation, its soil consists of marly clays (with gypsum interactions) from the Miocene, covered in places by Quaternary deposits in the form of tuffaceous soil (calcareous crusts) or muddy palaeoclays.It is worth noting the presence of traditional wells and many resurgent springs at the foot of these paleo-boulder flows, thus forming marshy areas in the flats.

Photo 1. Collapse of buildings in El Kherba due to the earthquake (7/8/2020)

Photo 2. Earthquake damage (7/8/2020) in El Kherba Mila

METHODOLOGY

We have adopted for this work the qualitative method, which is carried out by combining, by approaches based on simple map algebra operations, maps of factors controlling the stability of the slopes of a region. The qualitative (or direct) approach favours the expert's opinion and knowledge of the phenomena and the terrain, and two methods can be distinguished : the first, known as the expert method, in which the scientist intuitively and directly evaluates the relationships between the observed land movements and the various predisposing factors (YANNICK.T et al., 2008).

L'approche qualitative (ou directe) privilégie l'avis de l'expert et sa connaissance des phénomènes et du terrain, et on peut distinguer deux méthodes : la première, dite méthode experte, dans laquelle le scientifique évalue intuitivement et directement les relations entre les mouvements de terrain observés et les différents facteurs prédisposants (YANNICK.T et al., 2008).

a-First step : identification and elaboration of occurrence parameters (creation of thematic maps) This phase consists in selecting the factors of susceptibility to instability movement.

b-Second step : determination of the weights (weighting), we have attributed to each factor a weight representing the contribution of this factor to a potential instability.each factor map includes several levels translated by index values. Thus, the study area is subdivided into zones with different indices according to their level.

c-Third step : evaluation of the «landslide susceptibility» phenomenon,the factor maps are combined and the indices summed up respecting the weights of the different factors, hazard levels are defined according to the final index values.

Factors Predisposing to Instability

The approach to assess the susceptibility of landslides in the wilaya is based on simple cartographic algebra operations, which requires, in the first place, the selection of maps of the factors influencing the stability of the slopes in the wilaya.

In this work seven predisposing factors were mapped to assess susceptibility: degree of slope, exposure and hypsometry, lithology, rainfall, drainage density and vegetation. A description of each putative determinant is given below. The selection of factors was based on the scientific literature

The Geomorphological Context

Surface topography is a permanent predisposing factor for worm instability, can condition the spatial distribution of movements.On the morphological level, the wilaya of Mila is characterised by a varied relief, essentially made up of: a mountainous zone essentially made up of a succession of mountainous massifs (tellian massifs) limiting the wilaya in its northern part (Djebel Tamezguida 1600m, Djebel Zouara 1300m, Djebel M'Sid Aicha 1300m).

Altitude

Altitude is another parameter frequently used for landslide susceptibility studies. It is stated that landslides are more likely to occur at higher altitudes (Ercanoglu et al.2004). The hypsometry map was derived from DTM[1] in table 1, it can be seen that the class (650-850) m is the most dominant with a percentage of 34.22% of the study area.

Table 1. Surface areas of the elevation classes in the wilaya of Mila

Classes	Surfaces aeras (Km^2)	Surfaces aeras (%)
(0-200) m	41,23	1,18
(200-450) m	432,09	12,32
(450-650) m	451,46	12,87
(650-850) m	1200,04	34,22
(850-1000) m	1045,15	29,8
(1000-1200) m	318,11	9,07
>1200 m	18,72	0,53

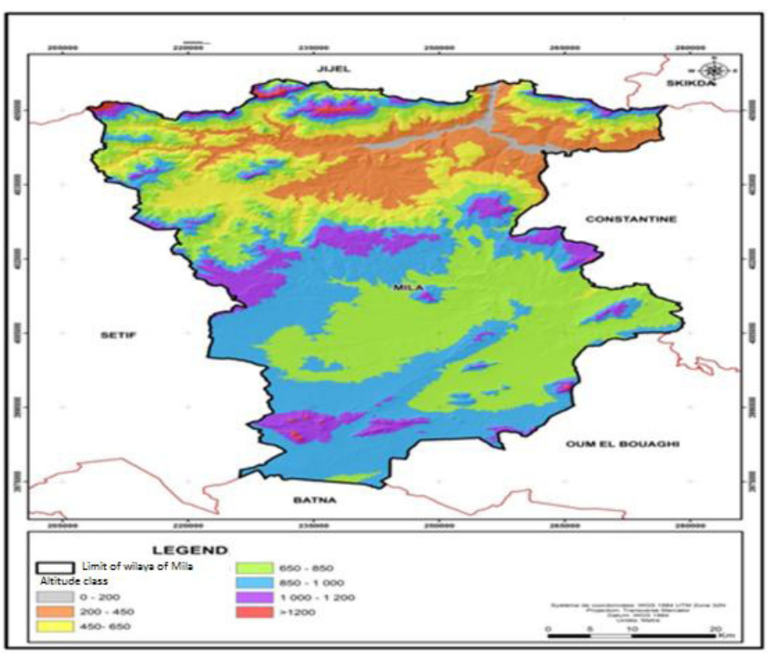

Figure 2. Altimetric map of the wilaya of Mila

[1]:www.earthexplorer.usgs.gos

Slope

The presence of a slope favours formations susceptible to instability, in particular the clay and marl formations of the Neogene, which can cause, locally, a slow creep of the slope and the formation of clay domes.

Within the framework of this work, we drew up several maps using digital terrain models (DTM) with a resolution of 30 m under Arc-Gis 10.5, which show the relief and elevation of the various zones of the wilaya of Mila.

The slope map shows a moderate relief on almost 90% of the surface of the wilaya of Mila, only 10% of the surface represents the piedmonts and mountains of the region, this structure. This structure favours the accumulation of rainwater and allows the clay and marl formations to soak. The analysis of the data extracted from the slope map indicates that the slopes between [0-10°] are dominant, with a percentage of 71.03%, followed by the classes, [10-20°], [20-30°], [30-40°] [>40°] successively as presented in tablen°2.

Table 2. Surface areas of the slope classes in the wilaya of Mila

Classes	Surface areas (Km²)	Surface areas (%)
0°-10°	2490,85	71,03
10°-20°	814,58	23,22
20°-30°	176,62	5,03
30°- 40°	23,06	0,65
>40°	1,56	0,65

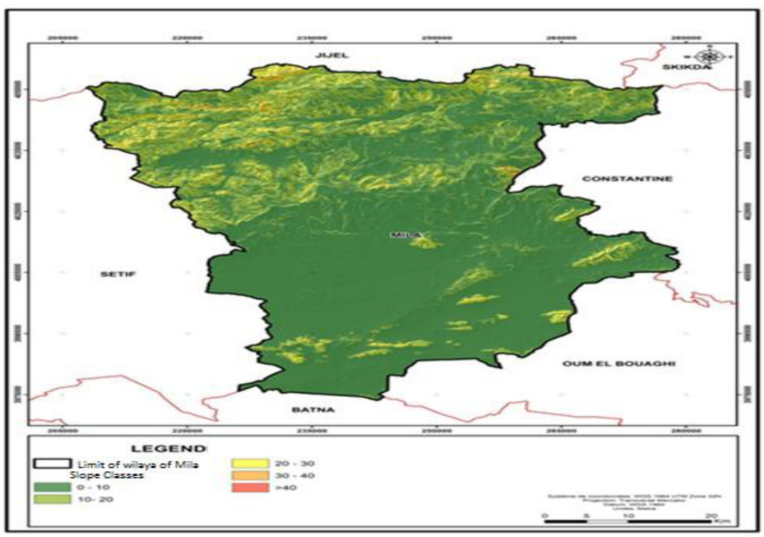

Figure 3. Map of the dance slopes in the wilaya of Mila

Slope exposure

The exposure of a slope is its orientation with respect to the North. It is determined by measuring the angle between North and the horizontal projection of the line of maximum slope of a slope, moving in a clockwise direction.

The change in the exposure of the slopes is equivalent to a great variability in the obliquity to the sun's rays, the duration of sunshine on the slopes, as well as unequal energy inputs (wind, temperature...).

This makes the predisposition of slopes to slope movements very different.Indeed the intensity of light exposure, the type and extent of vegetation cover and the supply of surface water vary considerably depending on the aspect of the slope, the temperature difference between day and night on a sunny slope is also greater than on a shaded slope and the dry-wet cycle is also faster, which reduces the strength and stability of the rock mass and soil on the sunny slope, in turn increasing the likelihood of landslides.The slope aspect map was also prepared from a DTM under nine classes from Table 3, it can be seen that the South-East and South classes are the most dominant classes followed by the North-East, East and North classes.

Table 3. Areas of exposure classes in the wilaya of Mila

Classes	Surface areas (Km²)	Surface areas (%)
Flat	44,24	1,26
North	426,28	12,16
North-East	430,93	12,29
East	429,7	12,25
South-East	498,07	14,20
South	508,15	14,49
South-West	399,05	11,38
West	353,88	10,09
North-West	416,25	11,87

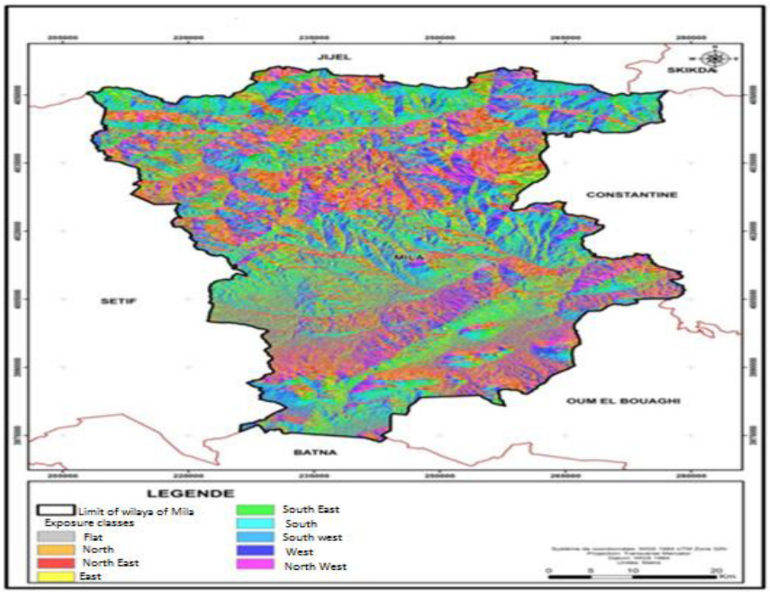

Figure 4. Aspect of the slopes of the wilaya of Mila

Lithology

The Mila region is part of the Mila basin, a sub-basin of the large Neogene Constantinois basin, which belongs to the Tellian domain that constitutes the outer zones of the alpine chain of North-Eastern Algeria.

The formations present in the Mila region are essentially transgressive continental and marine deposits (Mio-Pliocene detrital and evaporite deposits).

One of the geological characteristics of the Mila basin is the predominance of clay deposits leading to numerous terrain instabilities.This area belongs to the external domain of the Alpine chain of North East Algeria.

The elements that influence the susceptibility to landslides are first of all the lithology of the formation, which is a predominant predisposing factor in the instability of the slopes. The lithological characteristics of the deposits are the result of a synthesis based on recent geological work by coiffait (1992) and observations of the terrain collected at different sites.

The geotechnical characteristics of the soils in the region show that the majority of unstable ground consists of fine soils. These soils often lose their tenacity in the presence of water and move under their own weight.

According to the analysis of the distribution of lithological units, the most dominant unit in the wilaya of Mila is alluvium with a percentage of 50.40%, followed by clays with 21.49%, while Kaolin clays, Dolomites and marly limestones represent 1.45%, 1.61% and 0.34% of the total surface respectively (Table n°4).

Table 4. Surface areas of rock formations in the wilaya of Mila

Classes	Surfaces areas (Km²)	Surfaces areas (%)
Recent Quaternary alluvium	1767,51	50,40
Clay	753,72	21,49
Kaolin clay	50,75	1,45
Limestone	76,54	2,18
Marly limestone	12,04	0,34
Flint limestone	227,08	6,48
Dolomites	56,36	1,61
Sandstone and quartzite	173,79	4,96
Gypsum	71,82	2,05
Marls and marly limestones	317,27	9,05

Proximity to Water Systems

At the level of the site studied, the hydrographic network is well developed from upstream to downstream by the junction of two main oueds : oued El Kebir which extends the North-Eastern limit and oued Endja at the North-Western limit. Hydrographic and hydrogeological conditions play an important role in the triggering of movements, as the large quantity of infiltration water rapidly saturates the clay cover and lubricates the contact surface between the quaternary clays and the more impermeable underlying layers of clay and marl, which favours the appearance of landslide surfaces. On the other hand, the circulation of seepage water along the tectonic fault corridors weakens the Neogene formations.

Indeed, the circulation of water along the zones of weakness causes the dissolution of soluble rocks (carbonates, gypsum and salt) and an intense extraction of very fine solid particles (clays),leading to the disassociation of detrital elements in the case of conglomerate formations and to the creation of voids in the case of gypsiferous clay and marl formations which leads to collapses and/or subsidence at depth, accompanied at the surface by mass movements if the topography is favourable. In addition, surface runoff, especially in the event of heavy flooding, attacks the foot of the slopes and consequently triggers their instability.

The city of Mila is delimited on the East side by oued Makraoued and oued Bordjia which delimits the rest of the city in its eastern part. In addition, the city is crossed by watercourses of very low flow with seasonal flow in winter period one distinguishes oued Mila which separates the old city from the colonial village and from the industrial zone and oued El Kherba which crosses the two slopes occupied by the Boulmerka housing estate and the El Kherba district and the university site. The realisation of the drainage density map was possible thanks to the command «line density» under Arcgis 10.5.

Table 5. Surface areas of the classes of distance to water courses in the wilaya of Mila

Classes	Surfaces areas(Km²)	Surfaces areas (%)
High	658,82	18,79
Medium	1216,49	34,69
Low	1631,57	46,52

Precipitation

Precipitation plays a primordial role in the acceleration of land movements. This precipitation water infiltrates into the subsoil and reaches the clays and gypsum marls, reducing their mechanical characteristics.Indeed, the effect of water in ground instabilities is remarkable, the enormous quantities of water that infiltrate during exceptional rainfall play an essential role in setting unstable ground in motion. The map of the spatial distribution of rainfall in the study area was developed by interpolating the annual rainfall from the website over the 30 year series (1990-2020). We note that the hydro-climatological characteristics show that the region has a temperate climate where the northern and central part of the wilaya of Mila is located in a zone where the average inter-annual rainfall is between (500-582) mm/year, while the southern part of the wilaya only records averages of less than 560mm/year.

The Vegetation

Vegetation has a significant role to play in water exchange (evapotranspiration) and in the cohesion and fixation of the soil due to the roots. On the other hand, when the vegetation cover is very dense, the weight is greater, which increases the driving forces that cause the instability of the slope. The soil cover has an effect on the resistance of slope materials against sliding and the control of the water content of the slope. It absorbs water from the soil and reduces the potential for landslides [Moradi et al., 2012].

We used the normalized vegetation index NDVI[2], for the detection of active vegetation, which is very strongly correlated to the chlorophyll activity of the leaves which is very strongly correlated to the chlorophyll activity of the leaves, as chlorophyll pigments absorb strongly in the red and leaves reflect strongly in the near infrared.

Determination of the Model

The analysis method adopted enabled us to prioritise and then classify the factors.Indeed, after identifying the seven landslide susceptibility factors, we proceeded to assess the relative importance of each factor.

This evaluation will be done through the calculation of the weights of the different factors and classes, we have established a database on the predisposing factors, these data have been obtained, processed and mapped using Arc Gis 10.5,to obtain the maps of the predisposition parameters once the variables were georeferenced, integrated and organised in the GIS, the overlay of information could be used to assess the susceptibility

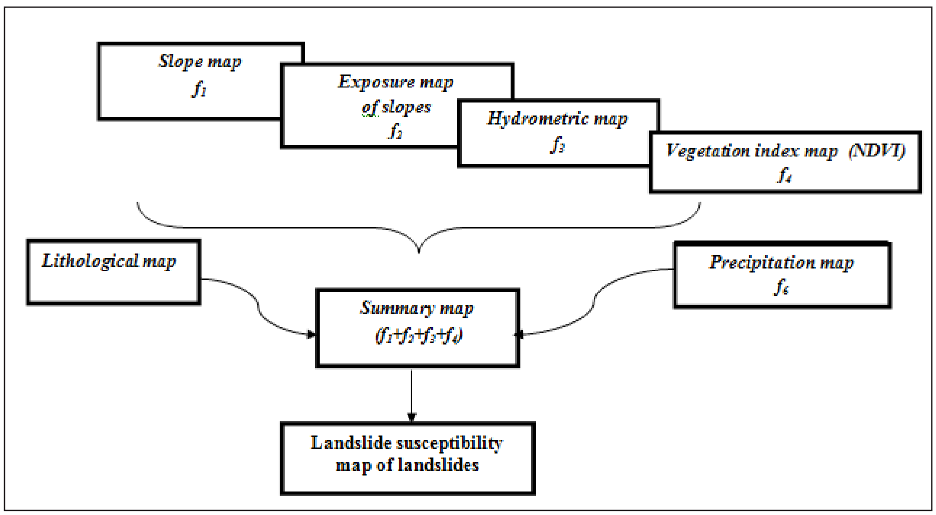

Figure 5. The hierarchical structure of the model

RESULTS AND DISCUSSION

The results show that slopes varying from 5° to 15° and above have a direct effect on the landslides, this shows a high concentration of landslides and a high susceptibility of the slopes,which confirms that the occurrence of landslides increases with the steeper the slope.The results also show that the high susceptibility to landslides is focused in the North and North-West facing slopes.

The number of landslides decreases with increasing altitude.The particularity of the study area is the lithological nature of the formations involved in the landslides landslides of a clayey and marly clayey nature this feature is an important factor in the factor in the occurrence of landslides, the impermeability of this formation leads to the leads to the circulation of water on the surface and the development of a hydrographic network whichfavours the phenomenon of erosion. The use of Geographic Information Systems allows the calculation of indices used to simplify and map complex phenomena from the insertion of data. The summed values were reclassified into three classes of base slide susceptibility which can be easily interpreted: low, moderate, high. According to the results of the analyses of the distribution and extent of the different zones presented in Table 5 and figure 6.

High and moderate susceptibility represent 1278.25 km^2 (36.45%) and 2036.80 km^2 (58.09%) of the total study area respectively The low sensitivity area represents 191.40 km^2 (5.46%) of the total study area.

[2]NDVI is constructed from the red (R) and near infrared (PIR) channels

We can summarize some information on landslides in the wilaya of Mila, nearly 94.54% of the total area is classified in zones of high and medium susceptibility. The qualitative method is often very subjective as it relies on expert judgement on several occasions.

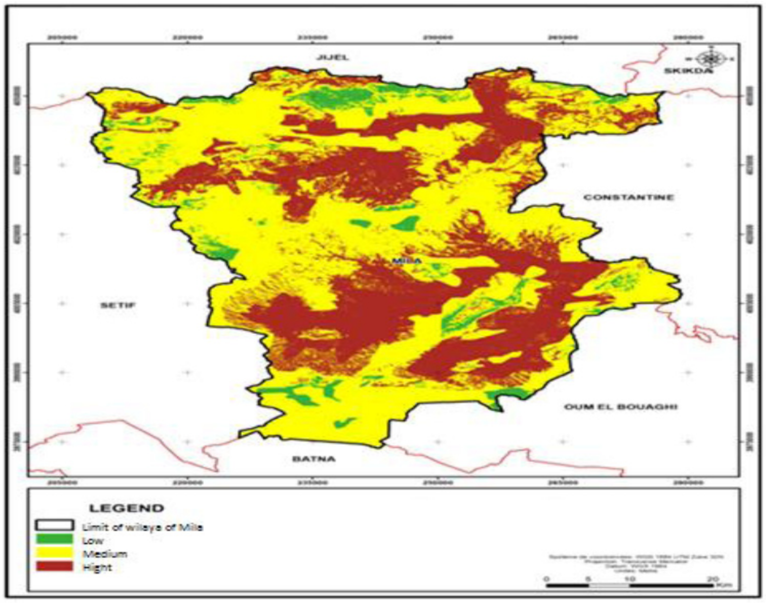

Figure 6. Landslide susceptibility map of the wilaya of Mila

Table 6. Landslide areas for the different susceptibility zones

Classes	Surfaces areas (Km^2)	Surfaces areas (%)
High	1278,25	36,45
Medium	2036,80	58,09
Low	191,40	5,46
Total area	3506,45	100

CONCLUSION AND RECOMMENDATIONS

The numerous instability phenomena observed in different areas are the result of a combination of a combination of natural and man-made factors, the pace of urban expansion the expansion of the city on the western side and a cause amplifying the gravity movements. The relationship between the importance of landslides and the effect of each factor shows that lithology, rainfall, slope and aspect of slopes are the triggering factors for movements in the wilaya of Mila. As well as the earthquakes that have shaken the region have led to spectacular landslides of several hectares. The landslide susceptibility map presented in this study can be a good source for decision makers,planners and engineers. It can be used by the relevant authorities in disaster management planning for landslides.

All the results obtained need to be improved by other studies, in particular on the vulnerability of the issues at stake. In the interests of prevention and forecasting, it is imperative to undertake a thorough investigation of the phenomenon and to ensure rigorous monitoring of all vulnerable sites. For some landslides, a drainage system is necessary, reforestation of unstable slopes to stabilise the land and control rainwater, the installation of a network of piezometers and inclinometers in areas considered to be at risk,avoiding the construction of roads in areas deemed unstable through the correct choice of routes and proper shaping of embankments during earthworks.

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