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Using GIS Combined with AHP for Mapping landslide Susceptibility in Mila, in Algeria

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ABSTRACT

Due to the complexity of its structure and morphology, the soil in the Mila area has experienced numerous landslides; damaging the road network and other supporting infrastructure. First, the most important landslide types were inventoried and mapped using existing data. The objective of this study is to develop a model based on the AHP analytical hierarchy process and integrate cartographic data into a GIS geographic information system for identifying and mapping regional landslide susceptibility. The approach uses factors such as slope, lithology, land use, road location, fault, flow and drainage network density as the main criteria to control the occurrence of selected landslides. The results showed that 15% of ground movement occurred in areas of high to very high susceptibility, 55% in areas of moderate susceptibility, and 30% in areas of very low to low susceptibility. The resulting map is subsequently validated by comparing the location of the mapped landslides with the susceptibility classes. The analysis of the results of this study shows that the landslide vulnerability map is a powerful decision support tool for local community development plans in the Algerian municipality of Mila.

1. INTRODUCTION

Mapping the susceptibility of slopes to ground instabilities is a very important component of assessing the risks associated with large-scale landslides. Because zoning based on the degree of land movement can help managers and decision makers with development efforts and reduce the impact on people, the environment and infrastructure.

Due to its geomorphological and climatic complexity, the region of Mila, like all of northeastern Algeria, was characterized by a high rate of land instability. This threat can cause casualties and damage to homes, hydroelectric installations, and various networks. Currently, due to the exodus of the rural population, Mila is facing demographic pressures. All the stable and easily buildable areas surrounding the city were filled in. The development of the city has led and will lead to an influx of urban development on the adjacent slopes and platforms.

To assess the risks associated with land movements, scientists have produced maps describing the spatial distribution of land instability phenomena, using methods based on geographic information systems (GIS). Among these is the heuristic approach, which is a multi-criteria spatial method applicable to a regional scale. Being a semi-quantitative approach, the weight of each layer depends on the expert's judgment, so the more accurate this judgment is, the more consistent the map produced will be [1]. AHP is a theory of measurement and decision-making developed by Saaty [2]. Thus, AHP makes it possible to quantitatively solve a large number of decision-making problems by developing a decision support model, which is represented in the form of a hierarchy that allows comparison of measurable and intangible criteria [3]. In the case of landslide susceptibility mapping, each data layer used is divided into sub criteria (classes) and weighted according to their importance, and these layers are then combined to create the final map. This approach is based on three principles: decomposition, comparative judgment, and synthesis of priorities [4].

This research aims to use a combination of the hierarchical multi-criteria analysis method [5] and geographic information systems [5] to determine susceptibility to landslides [6].

To validate the results obtained, we performed a correlation analysis of the ground motions and the calculated sensitivity levels that have been inventoried and validated in the field.

The obtained landslide susceptibility map is a powerful decision tool in land use planning, such as the construction of projects under the local development program [7]. Indeed, it is a necessary step to assess the landslide risk in the region in general [8].

2. MATERIALS AND METHODS

Initially, the data collected were: inventory, characterization, and mapping of ground movements from maps, aerial photos, satellite images, and on-site reconnaissance. This allows the development of a database of factors conducive to the land movement in the study area from the synthesis of these bibliographic data.

Then use the analytical hierarchy process to organize and assign weights associated with the different susceptibility parameters. Finally, a regional landslide susceptibility map [9] was developed by combining indicator maps [10].

2.1 Study area

The study area is located in the eastern part of the Mila region. The town of Mila constitutes a small tributary of Rhumel, dominated by the mountains of Marchau, 53 km west of Constantine, at latitude 36º27'00 "N and longitude 6º16'00" E, with an average altitude of 464m; a minimum of 155 m; a maximum of 1040 m above sea level (Figure 1).

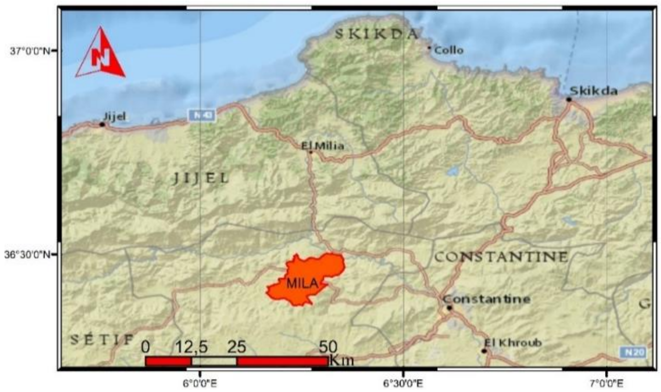


Figure 1. Location of the study area

The local climate is semi-arid, with mild winters surrounded by a cool sub-humid climate typical of mountainous terrain. In general, rainfall occurs between October and February. The annual average is about 600 mm per year.

The region has a long dry season (March to September). Land use in the region is mainly devoted to food crops or wild grasses. This sparse vegetation promotes land degradation and instability through soil erosion.

2.2 Data sources

The image data source used in this study is Landsat 8, with a spatial resolution of 30 m. Landsat images were downloaded from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). We selected images from the July period to reduce the likelihood of an environmental condition. The present study includes topographic and geologic maps of Constantine, Redjas El Ferada, Sidi Merouane, and Sidi Dris, produced and high-resolution Google Earth images. The data were used to digitize the landslide inventory, lithology, land use, distance to faults, roads, and rivers. To extract topographic (slope) and hydrogeological (drainage density) data, digital elevation model (DEM) data provided by NASA's open-source Shuttle Radar Topography Mission (SRTM) software, with a resolution of 30m, were used.

2.3 Inventory of ground movements

The landslide process occurs under the influence of several factors, including gravity, earthquakes, seepage pressure, soil quality, relief, and various natural loads [11].

Following the landslide caused by the latest earthquake of magnitude 4.9 on the Richter scale that occurred in Mila on August 7, 2020, the National Laboratory of Housing and Construction LNHC launched a study including drone surveys and geotechnical and geophysical tests to determine the causes and assess the condition of damaged sites.

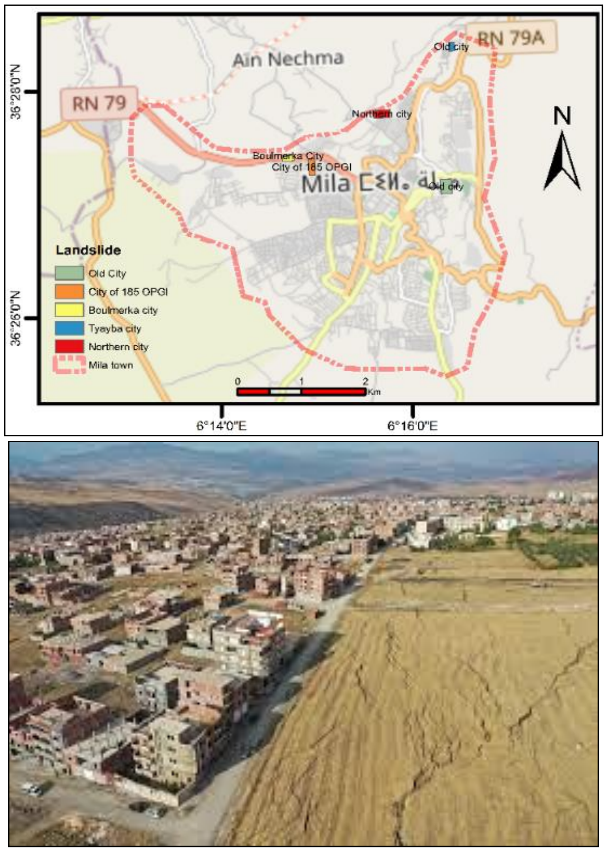


Figure 2. Inventory of ground movements. Overview (top). Zoom on the landslide of the city of El-Kherba (bottom). Source:(LNHC, geotechnical monitoring 185 Mila social housing units, 2006)

Other localities have also experienced land movements before, such as the Boulmerka housing estate, the 185 housing units (R+4) for residential use, the old town to the east, the Tyayba housing estate, and the housing estate to the north-east of the city of Mila (Figure 2).

2.4 Predisposing factors

The causative factors of ground instabilities are classified into two categories, namely predictors and triggers. The predictor that we have taken into consideration are: lithology, land use, fracturing, slope angle, distance to roads, distance to rivers and drainage density. The triggers variables are: earthquakes, precipitation, and human intervention. Since we are interested in the spatial components of the study, only the predictors are mapped. If we are interested in the temporal component, triggers will be considered.

The identification and spatialization of the predictors of ground movement in the region of Mila require the consultation and synthesis of the available bibliographic data.

The developed multi-source and multi-scale database of predisposition parameters (lithology, land use, fracturing, slope, density of the hydrological network, distance to roads, and distance to rivers) will allow the variables to be crossed, superimposed on each other, and used to model and update them according to the new data obtained [12]. The database will be mainly used to develop landslide susceptibility maps in the Mila region.

2.4.1 Slope

The rate of landslide collapse increases with slope steepness [13]. Due to the relatively low instability, very steep slopes seem to be the most prone to landslides and rockfalls. Therefore, for the calculation of slope instability risk, six slope levels (1: (0°-5°); 2: (5°-10°); 3: (10°-15°); 4: (15° - 25°) 5: (> 25) derived from the DTM corresponding to five instability indices from 5° to 30°, based on the statistical comparison between the density of the landslide area and the slopes (Figure 3A).

2.4.2 Lithology

The occurrence and spatial distribution of the landslides we identified and mapped indicate that a large number of landslides develop on different outcrops. For the extraction of lithological information at the regional scale, the part covered by geological maps, satellite data, and professional Google Earth software was used.

The elaborated map (Figure 3B) shows a lithological variation of the outcrops which can be grouped into eight classes: 1- middle pudding, 2- pudding, 3-mio_pliocene, 4-marl, 5-black marl, 6-limestone, 7-pudding, 8-old pudding, and 8-recent pudding. The marls are characterized by their poor mechanical aspect and their sensitivity to variations in water content [14].

2.4.3 Proximity distance to the river

The position and alignment of the river that divides the municipality into two main parts, East and West, were extracted from the hydrogeological study, verified on the topographic map, and the google earth image. Six zones parallel to the main river were created using Euclidean distance (Figure 3C). The zones range from the smallest distance (50m) to the largest distance (>300m). The action of the river could cause the destabilization of the soil and thus participate in the occurrence of landslides.

2.4.4 Fracturing

The digitization of the fault was made from the geological maps of the Mila region. The fracturing is directed in the South-East - North-East (SE-NE) direction. This allowed us to establish a fracture density map (Figure 3D), which takes into account the length of the fault. The faults are related to the distribution of seismic activity in the region. In the field, ground motions are localized along the fault, (shears and/or dislocations) formed by weakened materials. This parameter requires the introduction of the notion of distance of ground movements from the faults [15].

The fault allows water to infiltrate, which increases the pore pressures and reduces the shear strength of the soil [16]. When this reaches saturation, mass movements will start with the formation of the deep shear surface.

2.4.5 Distance to roads

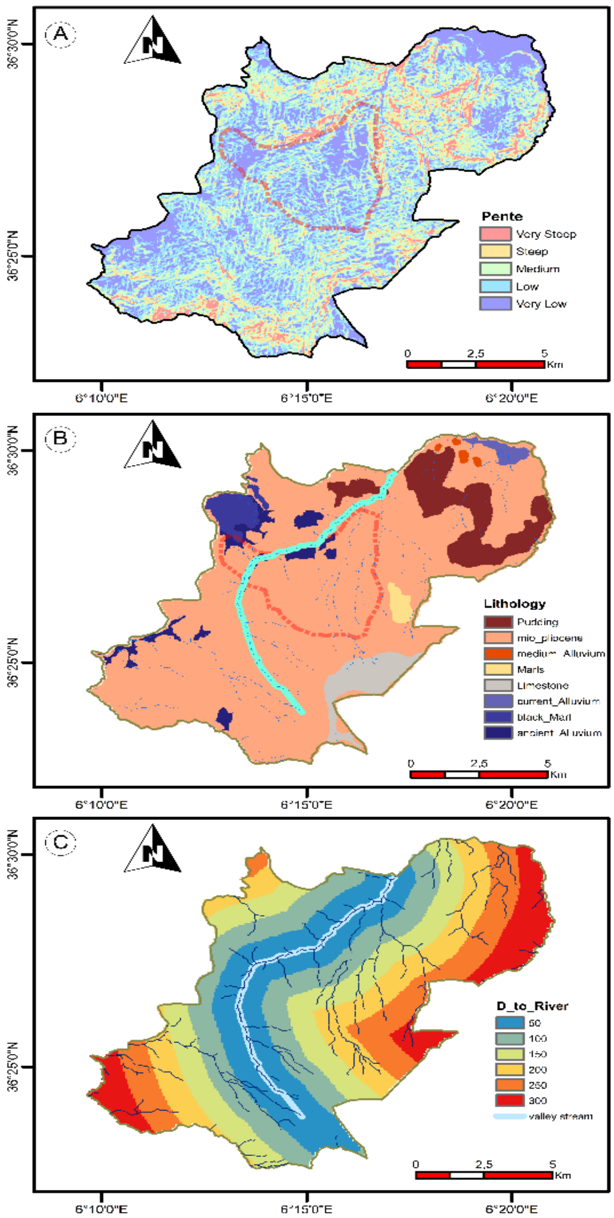
The road network was digitized from the road maps of the National Institute of Cartography in Algeria. Six zones parallel to the initial roads were created using the concept of Euclidean distance (Figure 3E). These zones range from the smallest distance (5m) to the largest distance (>30m). The action of the road network can cause destabilization of the terrain and thus contribute to the occurrence of landslides.

2.4.6 Draining

The hydrographic network was created from the digital terrain model and then verified on the topographic maps. The map density was constructed with six classes (Figure 3F). The erosive action of the hydrographic network can cause the destabilization of the terrain and thus strongly contribute to the occurrence of landslides. Several mapped land instabilities are reactivated along the river, especially during flood periods.

2.4.7 Land use land cover

The vegetation cover of the Mila area has stabilized the slopes with clay or rock matrix. This effect is manifested by the improvement of the physical quality of the soil through the root structure, in particular by the attachment of the altered mantle which slides easily relative to the substrate. Years of drought, forest fires, and the increase in the frequency in particular of human clearing activities across the territory, the accelerated development of various networks (roads, railways, etc.), have reinforced various forms of erosion. surface and deep sofas, making the soil more adaptable to the emergence of ground movements. An applied maximum likelihood classification was applied to a combination of two bands of Landsat 8 data, followed by verification of the resulting map by several checks on the Google Earth images. The land use/land cover map (Figure 3G) has been classified into 4 classes: 1: water bodies - 2: bare land - 3: shrubs - 4: vegetation.



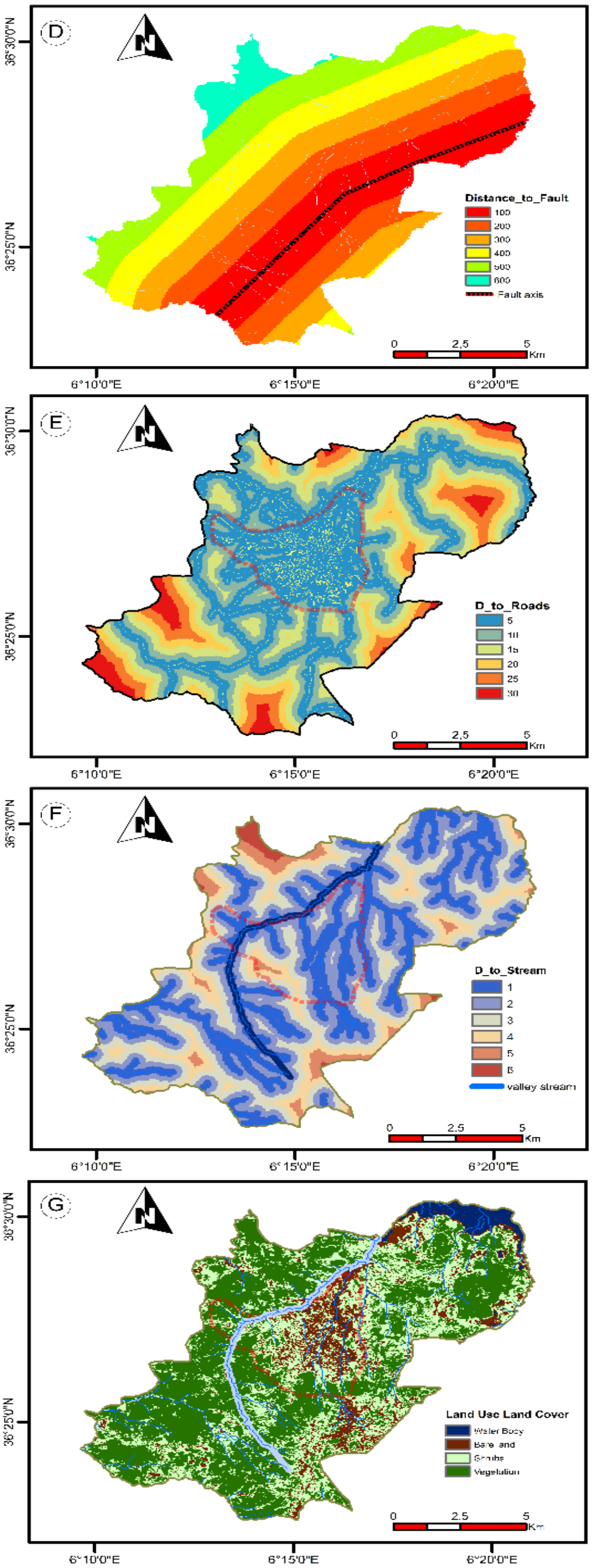


Figure 3. Predisposing factors Maps (A) Slope (B) Lithology (C) Proximity distances to river (D) Fracture density (E) Distances to roads (F) Drainage density (G) Land use/Landcover

2.5 AHP analytical hierarchy process

To prepare a landslide susceptibility map, various methods can be used, such as fuzzy logic, statistical methods, and the AHP analytical hierarchy process. AHP is an indirect qualitative heuristic method frequently used by almost all researchers in the world.

The AHP method involves pairwise matrix comparisons of the influence of each factor. Saaty [3] provides a detailed description of the AHP method. To compare the importance of things about each other, the relationship between each factor and other landslide susceptibility factors is assessed by assigning a relative dominant value between 1 and 9. These values and descriptions of the different scale levels are listed in Table 1.

Table 1. Fundamental scale for pair-wise comparisons [17]

Importance	Definition of Scale
1	Equal Importance
3	Moderate prevalence of one over another
5	Strong or essential prevalence
7	Very strong or demonstrated prevalence
9	Extremely high prevalence
2,4,6,8	Intermediate values

To construct a pairwise comparison matrix (C), the factors and weights of each level are expressed as $c_1, c_2, \ldots, c_n$ and $w_1, w_2, \ldots, w_n$. The relative importance of ci and cj is shown as cij. The pairwise comparison matrix of $c_1, c_2, \ldots, c_n$ of the form C=[cij] is expressed as Eq. (1) [18]:

$$C = \begin{bmatrix} 1 & c_{12} & \cdots & c_{1n} \\ 1/c_{12} & 1 & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/c_{1n} & 1/c_{2n} & & 1 \end{bmatrix} \quad (1)$$

In this matrix, the element, $c_{ij} = 1/c_{ji}$, and thus, when i=j, $c_{ij}=1$.

In AHP, to check the consistency of the matrix, we use the consistency ratio, which depends on the number of parameters. The consistency ratio (CR) is obtained by comparing the consistency index (CI) and the average random consistency index (A.R.I.). The consistency ratio is defined as follows:

$$CR = \frac{CI}{ARI} \quad (2)$$

The consistency index of a comparison matrix is given by the consistency index (CI).

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

The average random coherence index (ARI) is derived from a sample of the reciprocal matrix randomly generated using the scales 1/9, 1/8, ... 8, and 9 (see Table 2).

Table 2. Average random consistency index (A.R.I.)

Number of factors	1	2	3	4	5
A.R.I.	0.00	0.00	0.52	0.89	1.11
Number of factors	**6**	**7**	**8**	**9**	**10**
A.R.I.	1.25	1.35	1.40	1.45	1.49

For these matrices, the consistency ratio (CR) must be less than 0.10 [18].

2.6 Landslide susceptibility mapping using the AHP method

Susceptibility refers to the tendency of an area to be affected by certain hazardous events within an uncertain period. The trend of these phenomena is used for evaluation, regardless of the recovery period or the possibility of recurrence [19].

The combination of maps used in this work is used to construct the soil instability susceptibility map, which was originally proposed by Carrara et al and has been widely used in the literature [20].

It must prioritize the selected susceptibility parameters: slope, lithology, distance from rivers, distance from faults, distance from roads, drainage density, and land use [21]. The model adopted to produce the map of susceptibility to landslides is shown in Figure 4.

Once the hierarchy is created, the relative importance of all resolved items is inferred by binary comparison, which is used to create a ratio matrix. Binary comparisons are determined between the main criteria and sub-criteria within the hierarchical level [22].

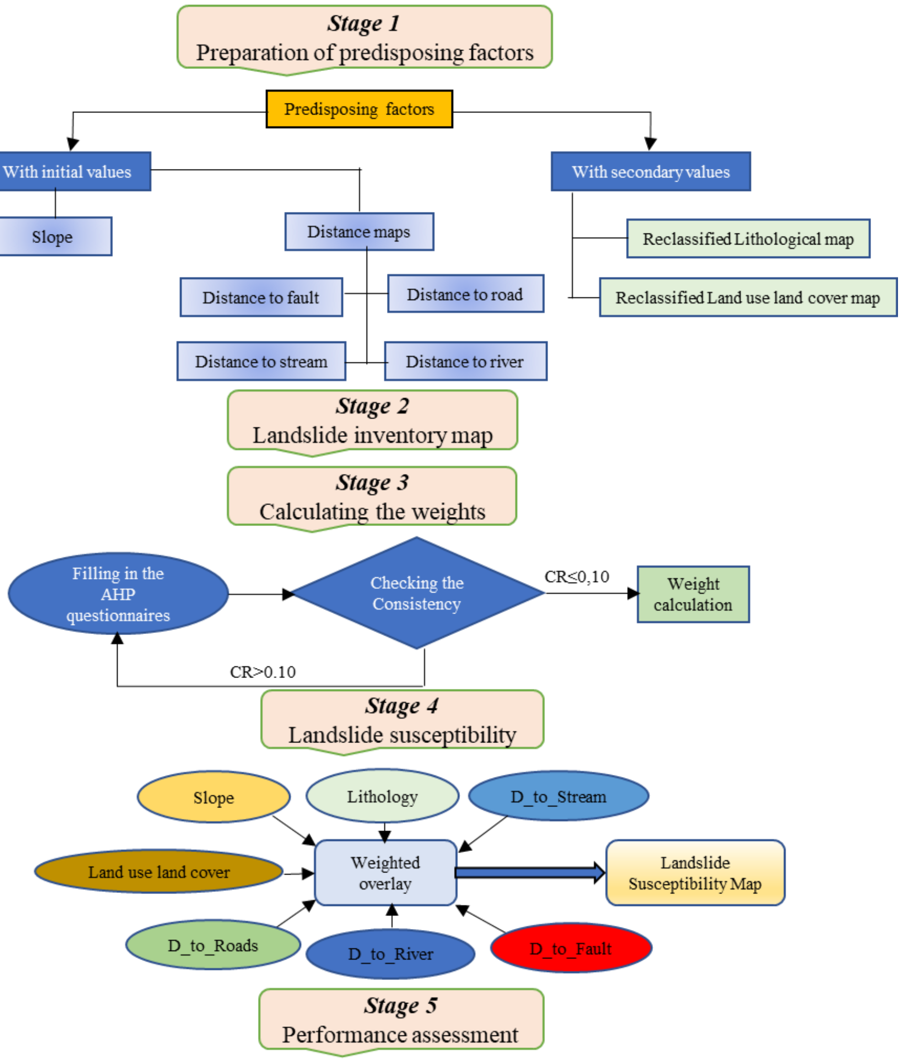


Figure 4. The model adopted for the landslide susceptibility map

Table 3. AHP weights matrix

Parameter	Slope	Lithology	Distance to River	Distance to_Fault	Distance to Roads	Distance to_Stream	LULC	W_i	Rank
Slope	1	2	3	4	5	6	7	0.35	1
Lithology		1	2	3	4	5	6	0.24	2
Distance to River			1	2	3	4	5	0.16	3
Distance to_Fault				1	2	3	4	0.10	4
Distance to Roads					1	2	3	0.07	5
Distance to_Stream						1	2	0.05	6
LULC*							1	0.03	7

Parameters values : n=7, λ_{max}=7.162, CI=0.027, RI=1.35 CR=2%

* Land Use Land Cover

The value of the relative weights assigned is based on our understanding of the geodynamic environment that leads to the development of soil instability in the Constantine region. To generate the AHP matrix, seven predisposing factors were used in the pairwise comparison (Carrara, Catalano, and Sorriso-Valvo 1978). These factors are first normalized and ranked (MJ, AB, and GA, 2019). We also assign weights to each type of predictor based on expert opinions (Maleki, 2009) (Table 3).

3. RESULTS AND DISCUSSION

The original Analytical Hierarchy Process (AHP), allows for problem modeling, pairwise comparisons, judgment scales, derivation methods, consistency indices, weight synthesis, and sensitivity analysis. The obtained consistency ratio (CR=0.02) is acceptable as it is less than (10%) of Saaty's values [23], the weights of different parameters influencing the slip are carried over in Table 3.

The landslide susceptibility map (Figure 5 and Table 4) obtained by the AHP method shows 5 levels: very low, low, moderate, high, and very high. The resulting landslide susceptibility map was cross-referenced with the identified landslides to test and validate the proposed model. The results show that 15% of the landslides are located in areas of high susceptibility, 55% in areas of moderate susceptibility, and 30% in areas of very low to low susceptibility.

The last point can be explained by the occurrence of landslides around the main urban centers of the Mila region and along with the road network that has been or is being built. This document is a contribution to the management and development of the city's territory and is part of the State Development Plan for the Mila District.

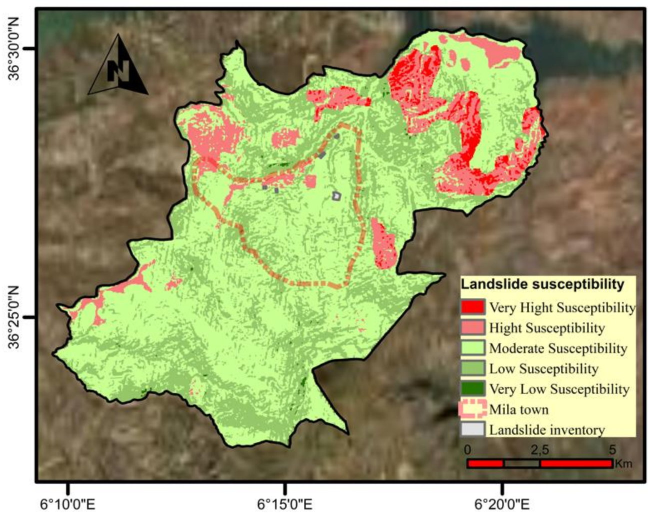


Figure 5. Landslide susceptibility map

Table 4. Classification of landslides according to severity

Susceptibility	Landslide (km²)	%	Rank
very high	4	3	4
High	16	12	3
Medium	71	55	1
Low	36	28	2
Very low	3	32	5

4. CONCLUSIONS

Due to its topography, climate, seismic conditions, geology, and geomorphology, this area is known to be more prone to landslides. In this limited study area, seven layers of lithology, land use, fracturing, slope, hydrologic network density, distance to a river, and distance to the road are considered using a combination of existing literature, satellite imagery, and landslide data.

To test and verify the results, the susceptibility map was compared to the landslides affecting the area. Despite the strong correlation of the landslides inventoried with the susceptibility map, it is clear that some of the observed shapes are more reliable than others.

It can be stated that the highly sensitive and extremely sensitive landslide areas determined by the analytical hierarchy process can predict the potential landslide areas in reality.

This research shows that when the terrain conditions are skillfully determined, the results obtained are a very satisfactory verification of the landslide susceptibility map established and the analytical hierarchy model used.

The resulting landslide susceptibility map provides useful and effective information on the current instability and its possible future evolution, which constitutes a powerful decision-making tool for land use planning within the framework of the government's local development plan for the city of Mila, Algeria.

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REFERENCES

[1] Moradi, M., Bazyar, M.H., Mohammadi, Z. (2012). GIS-based landslide susceptibility mapping by AHP method, a case study, Dena City, Iran. Journal of Basic and Applied Scientific Research, 2(7): 6715-6723.

[2] Saaty, T.L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1): 83-98.

[3] Vargas Jr, E.A., Velloso, R.C., De Campos, T.M.P., Costa Filho, L.M. (1990). Saturated-unsaturated analysis of water flow in slopes of Rio de Janeiro, Brazil. Computers and Geotechnics, 10(3): 247-261. https://doi.org/10.1016/0266-352X(90)90038-W

[4] Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. John Wiley & Sons.

[5] Harker, P.T., Vargas, L.G. (1987). The theory of ratio scale estimation: Saaty's analytic hierarchy process. Management Science, 33(11): 1383-1403. https://doi.org/10.1287/mnsc.33.11.1383

[6] Kayastha, P., Dhital, M.R., De Smedt, F. (2013). Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping: A case study from the Tinau watershed, west Nepal. Computers & Geosciences, 52: 398-408. https://doi.org/10.1016/j.cageo.2012.11.003

[7] Li, R., Wang, N. (2019). Landslide susceptibility

mapping for the Muchuan county (China): A comparison between bivariate statistical models (woe, ebf, and ioe) and their ensembles with logistic regression. Symmetry, 11(6): 762. https://doi.org/10.3390/sym11060762

[8] Perrone, A., Canora, F., Calamita, G., et al. (2021). A multidisciplinary approach for landslide residual risk assessment: the Pomarico landslide (Basilicata Region, Southern Italy) case study. Landslides, 18(1): 353-365. https://doi.org/10.1007/s10346-020-01526

[9] Saha, A.K., Gupta, R.P., Arora, M.K. (2002). GIS-based landslide hazard zonation in the Bhagirathi (Ganga) valley, Himalayas. International Journal of Remote Sensing, 23(2): 357-369. https://doi.org/10.1080/01431160010014260

[10] Dehimi, S. (2021). The use of new techniques in spatial modeling and analysis of urban quality of life: multiple-criteria decision analysis and GIS. Geo Journal of Tourism and Geosites, 35(2): 355-363. https://doi.org/10.30892/gtg.35213-659

[11] Pozdysheva, O., Taldykina, V., Polezhaeva, E. (2021). Methods of regional zoning of territories by zones with the risk of landslides. Technium, 3(1): 84-87.

[12] Thiery, Y., Malet, J.P., Sterlacchini, S., Puissant, A., Maquaire, O. (2005). Spatial analysis of slope susceptibility to landslides. International Journal of Geomatics, 15(12): 227-245.

[13] Bougdal, R., Larriere, A., Pincent, B., Panet, M., Bentabet, A. (2013). The landslides in Belouizdad district, Constantine, Algeria. Bulletin of Engineering Geology and the Environment, 72(12): 189-202.

[14] Alonso, E., Loudière, D., Morlier, P. (1987). Study of the marly materials used for the construction of the Montbel dam. French Geotechnical Review, 38(9): 33-49.

[15] Bray, J.D., Seed, R.B., Cluff, L.S., Seed, H.B. (1994). Earthquake fault rupture propagation through soil. Journal of Geotechnical Engineering, 120(3): 543-561. https://doi.org/10.1061/(ASCE)0733-9410(1994)120:3(543)

[16] Ng, C.W.W., Shi, Q. (1998). A numerical investigation of the stability of unsaturated soil slopes subjected to transient seepage. Computers and geotechnics, 22(1): 1-28. https://doi.org/10.1016/S0266-352X(97)00036-0

[17] Dehimi, S.A.L.I.M., Hadjab, M. (2019). Evaluating the quality of life in urban area by using the Delphi method. A case study of M’sila city/Algeria. Romanian Journal of Geography, 2(63): 193-202. https://www.researchgate.net/publication/353105216_EVALUATING_THE_QUALITY_OF_LIFE_IN_URBAN_AREA_BY_USING_THE_DELPHI_METHOD_A_CASE_STUDY_OF_M'SILA_CITYALGERIA.

[18] Saaty, T.L. (1977). A scaling method for priorities in hierarchical structures. Journal of mathematical psychology, 15(3): 234-281. https://doi.org/10.1016/0022-2496(77)90033-5

[19] Mezhoud, L., Benazzouz, M.T. (2018). Evaluation de la susceptibilité à l’aléa « glissement de terrain » par l’utilisation de l’outil SIG: Application à la ville de Constantine (Algérie). Science & Technology. D, Earth Sciences, 91-103. http://revue.umc.edu.dz/index.php/d/article/view/2949.

[20] Carrara, A., Catalano, E., Sorriso-Valvo, M., et al. (1978). Digital terrain analysis for land evaluation. Geologia Applicata e Idrogeologia, 13: 69-127.

[21] Belloula, M., Dridi, H., Kalla, M. (2020). Spatialization of water erosion using analytic hierarchy process (AHP) method in the high valley of the Medjerda, eastern Algeria. Journal of Water and Land Development, 38(1): 33-44. https://doi.org/10.24425/jwld.2019.127041

[22] Aladejana, O.O., Anifowose, A.Y.B., Fagbohun, B. J. (2016). Testing the ability of an empirical hydrological model to verify a knowledge-based groundwater potential zone mapping methodology. Modeling Earth Systems and Environment, 2(4): 1-17. https://doi.org/10.1007/s40808-016-0234-3

[23] Shokati, B., Feizizadeh, B. (2019). Sensitivity and uncertainty analysis of agro-ecological modeling for saffron plant cultivation using GIS spatial decision-making methods. Journal of Environmental Planning and Management, 62(3): 517-533. https://doi.org/10.1080/09640568.2018.1427561

NOMENCLATURE

ci, cj	dimensionless factors of each level
wi, wj	dimensionless weights of each level
C=[cij]	dimensionless pairwise comparison matrix
CR	dimensionless Consistency Ratio
CI	dimensionless Consistency index
ARI	Average Random Consistency Index
N	Number of parameters
LULC	Land Use Land Cover

Greek symbols

λmax	dimensionless largest eigenvalue of decision matrix