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Risk assessment of several hazards along railway network using AHP incorporated into GIS

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Abstract. Located in northeastern Algeria, the region of Constantinois is undoubtedly among the regions most affected by various risks related to rail networks. These phenomena are one of the major development issues and a major and permanent threat to the population and existing facilities. The risks associated with rail field transport are associated with several parameters such as soft geological formations, steep slopes, hydrographic network, seismic frame and mainly problems linked to human accident, suicide and stones thrown. In this context, the objective of this paper is the identification of risk-prone areas in the rail network linking Constantine to Skikda (Algeria). This in order to highlight the relations that exist between several parameters: geological conditions, local topography, flow hydrographic network, vegetation...etc., and hazard treat on railway network such as settlement or landslide risk anthropic risk (risk of stone thrown and suicide accident). The methodology used is based on a GIS approach to identify areas susceptible, it is based on the interpretation of satellite map, topographic, geological and other data. The GIS project developed will allow to superimpose and analyze the effect of several factors on railway network integrity, these factors and their respective weights are then calibrated with statistical tool by adopting the method "Analytical Hierarchy Process" AHP. The resulting susceptibility maps distinguishes several degrees of susceptibility of areas that may be affected by collapse or accident problems of rail platforms. The comparison with the inventory map of several accidents that have already been recorded by railways services shows that the results obtained from the spatial modeling are very satisfactory.

Keywords. Railway network, Rail collapse, Susceptibility, GIS, AHP

1. Introduction

The geography of transport is defined by the knowledge of transport systems and the perception of the movement needs of people and goods in a given space (Cascetta, 2013). Therefore, this definition assumes that the means of transport and communication are a privileged tool for spatial study. Transport is a key sector for the development of a given territory (Skorobogatova, et al. 2017). Indeed, in a modern economy, it plays a preponderant role because it not only facilitates exchanges between economic agents, but also improves the circulation of people, goods, ideas and services, as well as the strengthening of ties of friendship,

and brotherhood among peoples. The study of transport networks would require the analysis of visible networks (rail, road, air, sea, pipes) but also perceptible data such as constraints, hazards or potential risks, the approach to which is much more complex. Subsequently, the role of transport management is not only to circumscribe the space or to enumerate the various physical and human constraints, such as distance, time, and administrative divisions, but rather to foresee the risks which can affect the sustainability of the network itself and can cause human and material losses as a result but is achieve the goal (Andrić et al. 2019; Saaty and Vargas, 2013).

In addition, the geography of railway transportation includes all useful information for carrying out several studies such as the plot plan, municipalities and departments crossed, situation of crossed forests, land use, and underground networks. It also makes possible to identify the linear assets of the railway network, in order to manage the equipment. So, the solution is interfaced with the Geographic Information System (GIS), and many topics such as natural environments, land use, hydraulic resources, fauna and flora, and the data of technical infrastructure (Plakhotnik et al. 2005; Mitra et al. 2021).

In Algeria, after independence, the state inherited a heterogeneous but relatively extensive colonial rail network for an underdeveloped country (Belkacemi, 1984; Makki, 2015). Since then, several investments have been made to cope with the rise of the economy, which has revealed bottlenecks represented by the insufficiency of networks and means of transporting goods. Since 1997, the railway network has been organized into 4 regions Algiers, Oran, Constantinois and Annaba, each having jurisdiction over their respective territory, land transport is organized accordingly within the framework of a national transport plan and transport plans of wilaya (county) and urban ditricht, these plans constitute instruments for the orientation and development of land transport in the medium and long term but remain insufficient to ensure the sustainability of the network itself (Bavoux, 2000; Kouzmine. 2008; Madani 2012).

So the purpose of this paper is to carry out a spatial modeling in order to obtain a susceptibility map to assess to the risk of collapse or subsidence of the rails of the Constantinois rail network. The proposed methodology is based on a qualitative analysis of the determining factors of the problem of collapse and derailment of the railway platforms. This work should be a part of a broader process of continuous improvement of the management of natural risks in order to improve the safety and regularity railway. This approach consists to capitalize on and to develop historical know-how of the local railway company in terms of taking into account several treats. The resulting map will be used as a basic document linked to the regional rail transport plan.

2. Historical overview

The concretization of the railway projects in Algeria (Figure 1), started on April 8, 1857, by a decree of the French government which authorizes the construction of 1,357 km of railways in its colony of Algeria. The first construction site began on December 12, 1859, it concerned the construction of the line from Algiers to Blida. Its management is entrusted to the private company called Compagnie des chemins de fer algériens.

Construction work was also undertaken to link Oran to Saint-Denis-du-Sig as well as a link between the port of Philippeville (today Skikda) and Constantine, but financial problems forced the company to interrupt the work and develop the line from Algiers to Blida, which will be opened on September 8, 1862. On July 18, 1879, a new investment campaign is launched at the national level to strengthen the lines "of general interest" with the objective of add 1,747 km to the existing network. The construction of these so-called "local interest" lines is left to

private investors and local authorities. In the thirty years that followed, 2,035 km of railway lines were added, constituting the Algerian railway network. Between 1907 and 1946 a third investment campaign added 1,614 km to the network. At the end of the Second World War, the Algerian rail network extended over 5,015 km. On June 30, 1959, the French State and the OCFA signed an agreement creating the National Company of French Railways in Algeria (SNCFA). The National Company of French Railways in Algeria becomes the National Company of Algerian Railways (keeping the same acronym SNCFA). On May 16, 1963, the French equipment was kept but, quickly, orders for locomotives and cars, coming from the countries of the Soviet bloc, completed the fleet.

On March 31, 1976, at the end of the concession from the French State, the Algerian State divided the SNCFA into three separate bodies, the National Railway Transport Company (SNTF), the national company for studies and achievements of the railway infrastructure (SNERIF) and the railway infrastructure engineering and construction company (SIF). A new investment program allows the construction of 203 km of new lines, the doubling of 200 km of track on the northern ring road and the renewal of 1,400 km of track and ballast. At the end of the 1990s, the SNTF operated a 3,500 km network. The development project proposed during the study of the land use plan study and the initial state of the district to assess the expected evolution of the latter and improve the project by identifying insufficiently treated targets. In 2005, the national agency for the study and monitoring of the realization of railway investments (ANESRIF) was created to manage a new public investment program with the objective of increasing the network to 12,500 km in 2025. In 2010, 315 km of new tracks are open (Bordj Bou Arreridj to M'Sila, Ain Touta to M'Sila, new Béchar line), the suburban lines of Algiers have been electrified. In 2015 out of a program of 2,300 km of new lines, 1,324 km are under construction, most of which concerns the western part of the high plateau loop. Currently, the total length of the rail network is 4,439.53 km, including 3,854 km of operated lines, 449 km of double-track lines and 323.15 km of electrified lines” (Hammadache and Boudjemil 2020; Amin, 2021 Aissat and Metsaha, 2018).

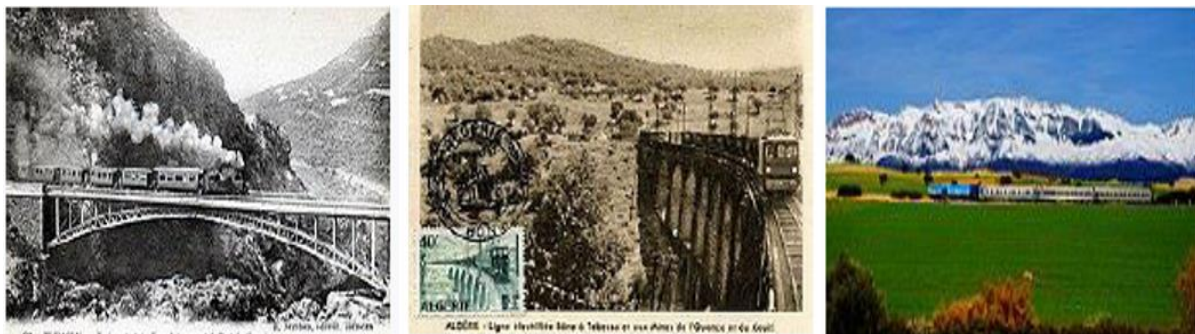


Figure 1: a) Train in Tlmeccen 1905; b) Electrical line Tebessa 1940; and c) new Algerian line (present day)

3. Description of Study Area

3.1 Geographical location

The study area (Figure 2) is located between latitude $36^{\circ}52'0.49''N$ and longitude $6^{\circ}54'0.02''E$ up to latitude $36^{\circ}13'57.74''N$ and longitude $6^{\circ}56'38.65''E$, in the geographical area between the Tellian Atlas and the Mediterranean coast.

The studied network crosses 2 wilayas (Constantine, and Skikda) is intersected by seven national roads, 21 county roads of the wilaya and a multitude of province roads. The length of the railway over the Constantine and Skikda wilayas is 97 km. It is reinforced by track doubling over length of 50 km between the town of Ouled Rahmoune and Ramdane Djamel (wilaya of Skikda). The network of the study area appeared at the end of the 19th century. It is used to transport people and goods. The ambition of the public authorities is to connect the majority of the municipalities of the willaya of Skikda and the willaya of Constantine: (Skikda, Hammadi Krouma, and Hadaik, emdjez edchich, Ramdane Djamel, Salah Bouchaour, el harouch, Ain Bouziane, zighoud Youcef , didouche ramadan , Hamma Bouziane , Constantine , el Khroub , Ouled Rahmoun) linked together by the rail network.

3.2 Geological context

The geological context of the study area (Figure 3) concerns in the Maghreb chain (Durand Delga M., 1980). The Maghrébides form a chain with southern vergence, extending from Gibraltar to Sicily, over more than 2,000 km. This chain results from the structuring of the Maghreb basin and its margins. The latter was located between the African and European continental margins (Bouillin J.P., 1986). The layers where the structures constituting this chain have a southern vergence and come from three paleogeographic domains: 1) The internal domain; 2) The Flyschs domain and 3) The external domain.

For the internal domain, it is the Kabyle base bordered to the south by the Kabyle ridge. The Kabyle basement includes the outcrop of a metamorphic basement characterized by Cambrian formations (granulite, phyllite, gneiss) and a sedimentary cover from the Paleozoic to the Tertiary, while the Kabyle ridge represents a narrow band of secondary and Tertiary sedimentary formations. For the Flysch domain, it corresponds to a deep and mobile marine sector of the Middle Jurassic, and rests with various structural modalities on the internal zones and occupies an allochthonous position with respect to the external zones. The Numidian nappe corresponds to the less tormented formations.

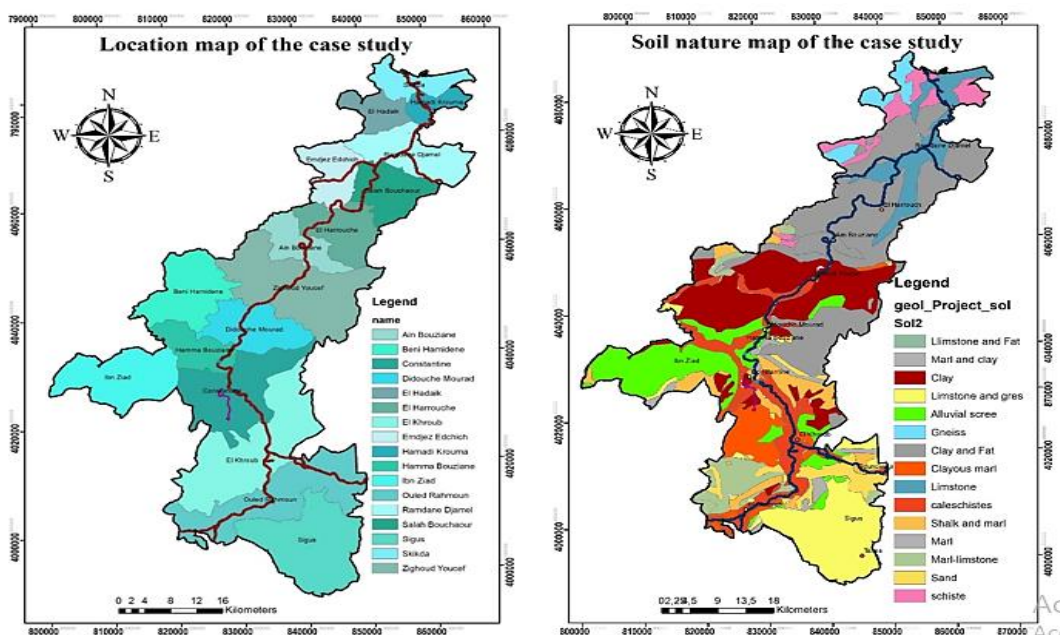


Figure 2: Location map of the case study **Figure 3:** Geological overview

The following units and domains can be successively consider from East to West: a. Constantine neritic unit; b. south unit – Sétifiennes; vs. Sellaoua unit; d. the autochthonous para; e. the autochthonous north – aurésien. The Constantine neritic series form isolated massifs, of variable size, the most important outcrops correspond to the reliefs of the Tadjenanet, Oued athmania Constantine and Ain Mlila (Dj Grouz), the rock of Constantine and Dj khaneg. These neritic series are characterized mainly by carbonate formations, from the Upper Jurassic to the transgressive Senonian. The examination of the geological maps made by Vila, 1980 allowed us to produce the following geological map which represents the lithology of the geological facies at the level of the case study.

3.2 Inventory of detected accidents

Before producing the susceptibility map of the railway platforms of the Constantinois network, an inventory of the accidents that have occurred in this area must be carried out by consulting the railway authority database. This step is also very important to validate the final modeling. There are several railway accidents (Figure 4) detected in the case study. They are dependent of their nature, the most recurrent accident is the derailment or collision, and stones thrown near urban location. The sliding and flooding cause also serious damage to the network. In this context the inventory map of Figure 5 is dressed.

This map is crucial in order to validate the spatial analysis of susceptibility map.



Figure 4 Several railway accidents **Figure 5** Inventory map of accidents

4. Method and Materials

4.1 Analytical Hierarchy Process (AHP)

The production of the susceptibility map is a main component in risk management. Susceptibility expresses the spatial probability that a type of phenomenon will occur in a territory for different local environmental conditions of predisposition factors (Flentj et al., 2007). The railway network of Constantinois is potentially susceptible to problems related to soil subsidence because of the clayey nature of certain areas which promotes the phenomenon of swelling-shrinkage depending on the fluctuation of the water content in these soils. In order to analyze spatially these accidents, it is necessary to use the expert method "Analytical Hierarchy Process known as AHP".

The AHP is a mathematical method of multi-criteria analysis aimed at resolving decision support problems. The AHP is a quantitative method for classifying decision-making alternatives by developing a numerical score to rank each decision based on how well each alternative meets the decision maker's criteria.

In addition, AHP is a decision-making approach developed by Saaty in 1980 (Pérez, 1995). The process helps to solving complex multi-criteria problems in a number of areas of application. The three basic steps for considering AHP decision problems are: 1) Construction of a structural hierarchy; 2) Establishment of comparative judgments; and 3) Summary of priorities. This method was applied in the first stage to produce the land settlement susceptibility map by superimposing six thematic maps which correspond to the factors of: slope, proximity to the hydrographic network (drainage), vegetation cover (NDVI: Normalized difference vegetation index), land use, and soil nature (Figure 6).

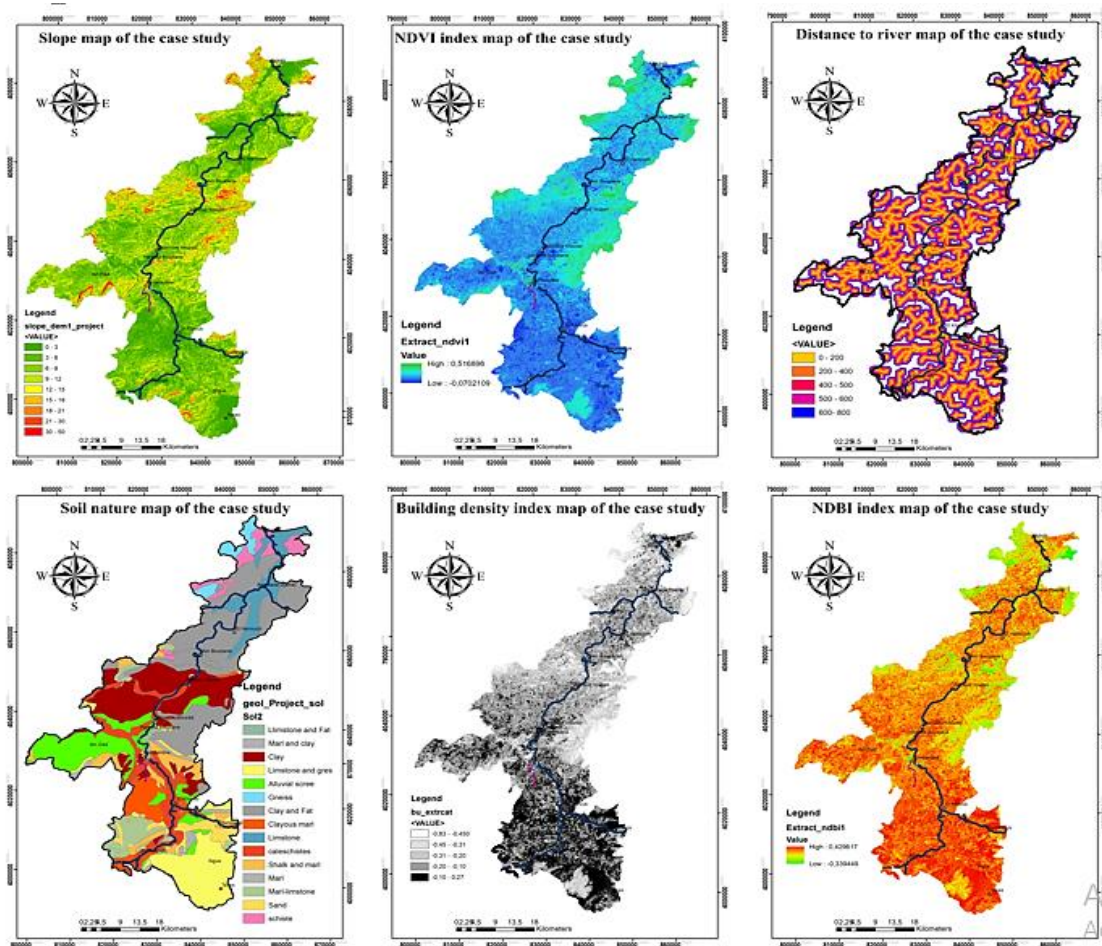


Figure 6 Several factors used in the spatial analysis

There are a second stage, it is conducted in order to highlight the importance of the phenomenon of landslide and stability. It is important to notice that the parameters are the same, but the weighting changes in relation to the settlement or landslide risks. The 3rd variant consists of establishing a map for anthropic risks such as several car accident or person suicide and susceptible area to train stone thrown, by integrating the land use component and proximity to urban areas.

The results are expressed in term of weighting of several used factors are expressed in the following Table 1.

Table 1. Results of calculation of weights by the AHP method

	Slope	Distance to river	NDVI	Distance to Road	Soil nature	Land Occupation
Var 1	25%	33%	7%	-	35%	-
Var 2	35%	25%	7%	3%	30%	-
Var 3	10%	-	20%	30%		40%

4.2 Approach for producing several susceptibility maps

The following figure 7 summarizes the approach adopted. The production of the land settlement susceptibility map involves calculating the value of the Land Subsidence Susceptibility Index

(LSI: Landslide Subsidence Index) for each pixel considered. This step consists to calculate the sum of the weights multiplied by the classes (raster image) for this pixel as shown in the following equation Eq.1:

$$LSI = \sum (W_i \times R_i) \text{ (Eq.1)}$$

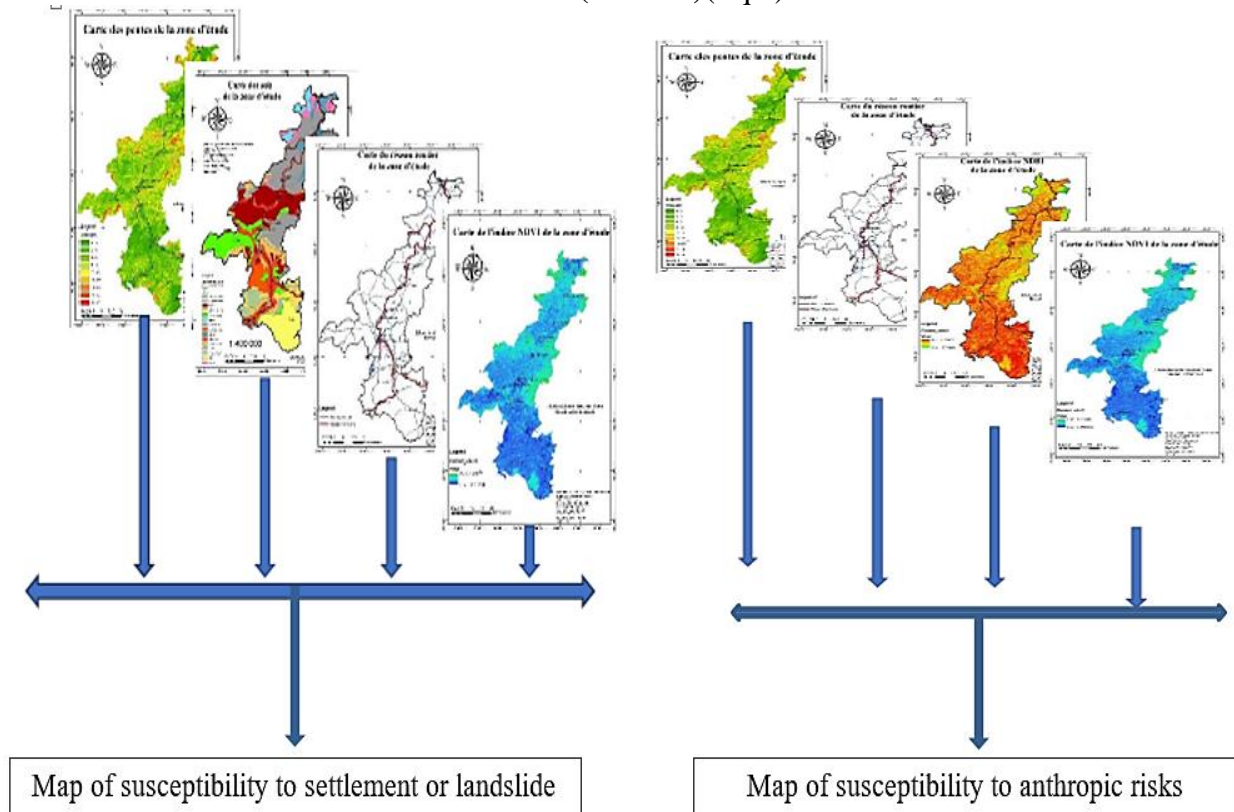


Figure 7. Approach followed for the map of susceptibility

Where LSI is the susceptibility index for a given pixel; R_i and W_i are respectively the weight of the class (rating value) and weight of the factor. Thus, all the LSI values would be separated into 4 categories of zones susceptible to subsidence (Land Subsidence Susceptibility Zone: LSZ) of the region studied and which can be named: zone of very high susceptibility (VHS), zone of high susceptibility (HS), zone of medium susceptibility (MS), and finally zone of low susceptibility (LS).

Practically, the used factors are in the form of maps obtained by various processes (digitalization and extraction), and using different algorithms contained in the used software (ArcGIS). Therefore, each map corresponds to a factor with a class weight and the output map will be a thematic layers that have a relationship with the causal factors can be generated using the remote sensing tool, supplemented with inventory data and field surveys. The combined information includes: 1) the NDVI index (the vegetation index); 2) Land use in terms of roads); 3) lithology and geotechnics which are extracted from geological maps; 4) Topographic factors Slope and 5) approach to hydrographic networks.

For anthropic risks the same approach will be followed, only the factors and their weights are not the same. For anthropic risks such as the stone thrown of trains or suicide risks, the proximity of built-up areas or the road network can further amplify susceptibility.

5. Method and Materials

5.1 Swelling-shrinkage susceptibility Map

With the combination of the Four factors: NDVI, distance to the hydrographic network, the lithology and map of the slopes, it will be possible to obtain the final map of settlement hazard susceptibility with the application of the AHP method and using the LSI index as explained before.

The LSI represents the relative susceptibility of the occurrence of the settlement; therefore, the index is higher as the site is potentially unstable. The overall number of pixels was then reclassified into 4 classes, representing the different landslide susceptibility zones on the map; these are the zones of: low susceptibility (LS), moderate (MS), high (HS) and very high (VHS) (Figure 8). The relative percentages of the zones representing the different susceptibilities including the real detected settlement areas are presented in the table 3 below.

According to the data presented in this table Table 2), it is clearly mentioned that 19% of the total area is classified as VHS zones, 25% in HS and 29% as moderate (MS). In these three zones, there are 7 geolocated subsidence points which represent 87% of the total subsidence recorded. The other points of depression which represent 13% are located in the low LS (13%). These findings confirm and validates the modeling.

Table 2. Validation of spatial analysis

Susceptibility zone	count %	Number of real point
<i>Low (Ls)</i>	43.79	1 (13%)
<i>Moderate (Ms)</i>	27.88	1 (13%)
<i>High (HS)</i>	12.91	3 (37%)
<i>Very high (VHS)</i>	15.40	3 (37%)

5.2 Landslide susceptibility Map

The landslide hazard map is obtained by the combination of the five factors (NDVI, distance to the hydrographic and road network, the slopes map, and lithology). The susceptibility map is shown in the following figure (Figure 9). The relative percentages of the zones representing the different susceptibilities indicates that 42.85% of the total area is classified as moderate MS (33.47%); for high and very high represent 2.16 %. This mean that risk of landslide is low. This result was validated because there is no record of detected sliding area in railway network according to SNTF data.

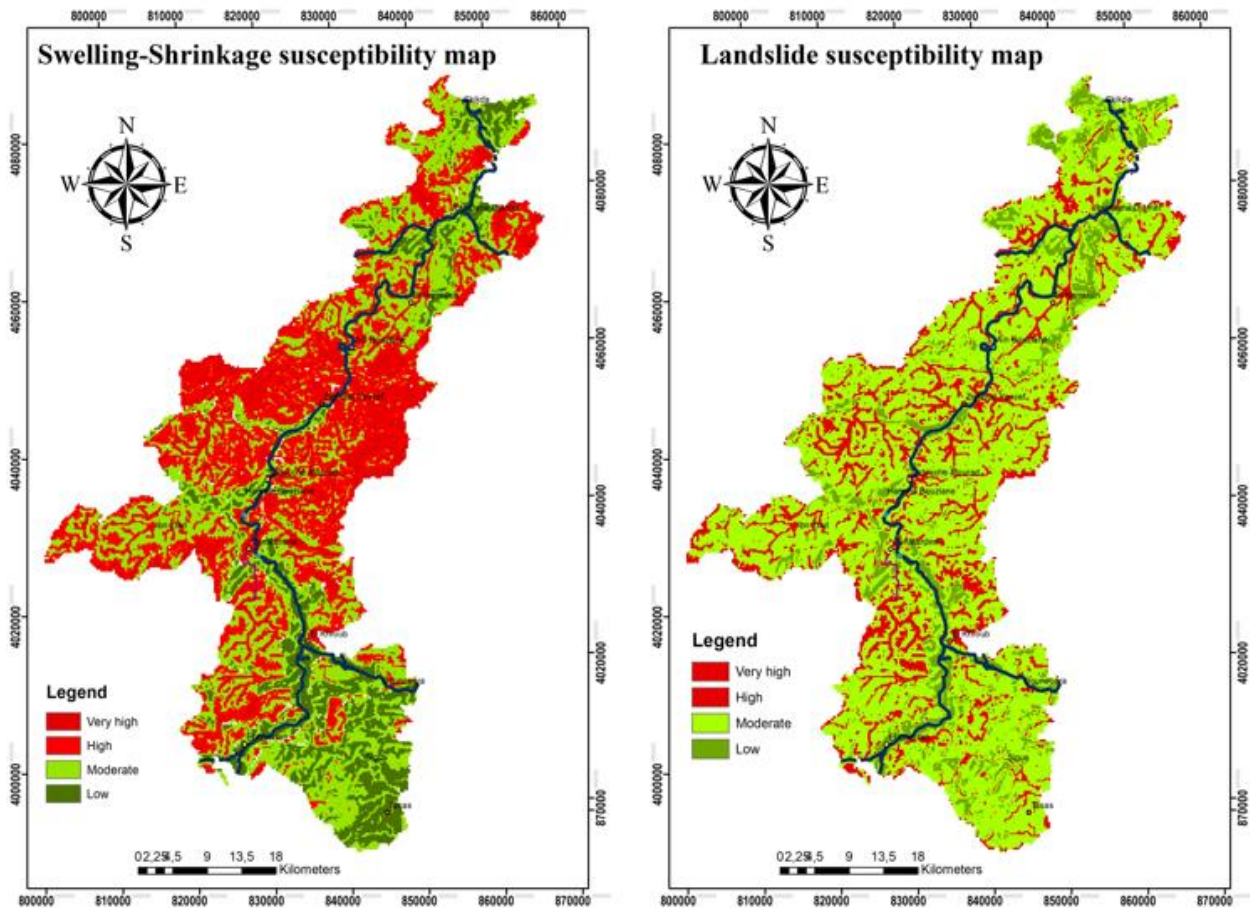


Figure 8 Susceptibility map for: a) Swelling-shrinkage, and b) Landslide

5.3 Anthropic accident susceptibility Map

The susceptibility map is shown in the following figure (Figure 9). The relative percentages of the zones representing the different susceptibilities are presented in the table below (table 3).

Table 3. Validation of anthropic hazards

Susceptibility zone	count %	Number of real point
Low (Ls)	22.36	1 (6%)
Moderate (Ms)	47.16	5 (31%)
High (HS)	28.9	7 (44%)
Very high (VHS)	2.15	3 (19%)

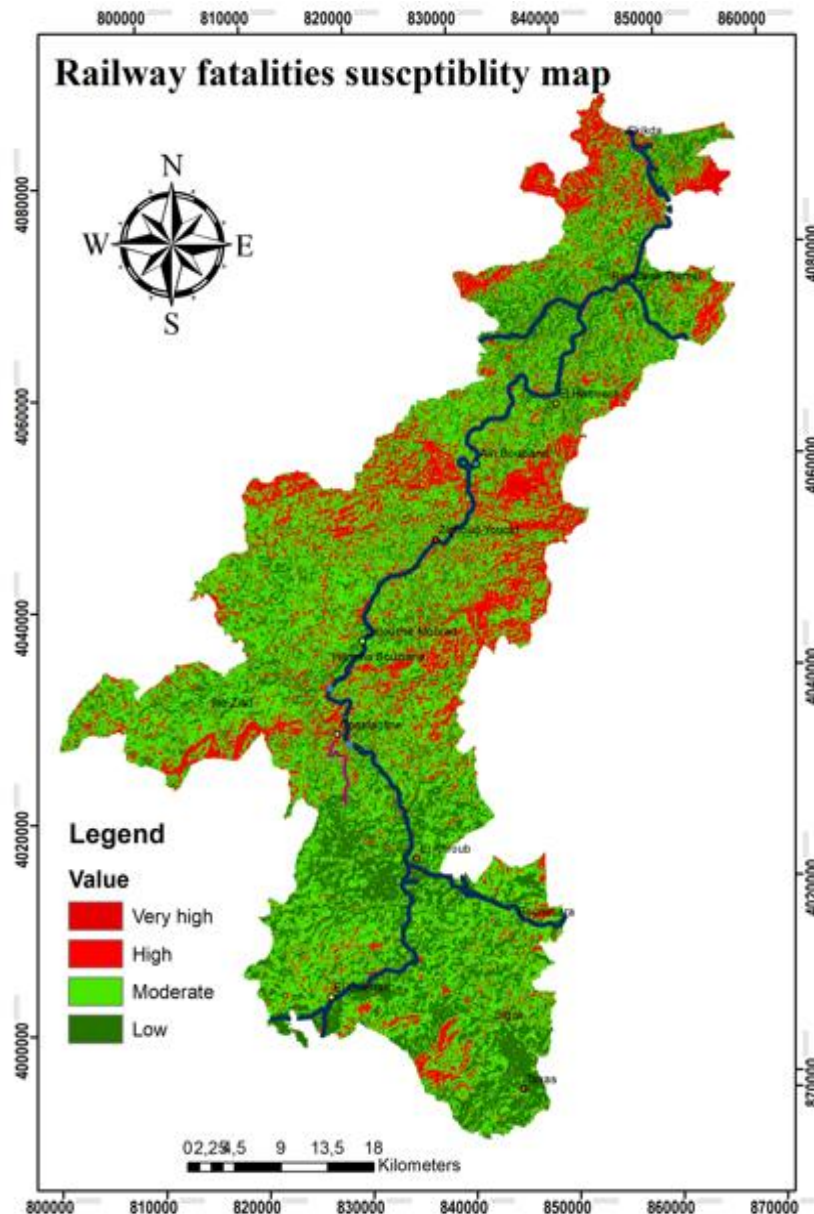


Figure 9 *Anthropic accident susceptibility Map*

According to the data presented in this Table 3), it is clearly mentioned that 2.15% of the total area is classified as TFS zones, 28.9% in FS and 47% as moderate. In the TFS and FS and MS zone, there are 15 geolocated accident points which represent 94% of the total accident recorded. The other points of depression which represent 16% are located in the low fS (16%) and very low susceptibility zone TfS (0%). These findings confirm also and validates the modeling.

The results of this part show the interest of using GIS technology in the assessment of risk susceptibility. The method used made it possible to identify areas exposed to risk in the study area. The results obtained show that the areas exposed to medium and high risk cover the total area of the study area. The extent of these areas deserves monitoring and surveillance in order to secure the populations and socio-economic infrastructure of the region.

6. Conclusion

This study made possible to draw up some maps of the risk susceptibility linked to the railway network at the level of the Constantinois network. It is necessary to underline the difficulty of the task, because the mapping of the zones exposed to risk in the study area is quite delicate, it required the collection of important information and a very good knowledge of the site. So in an attempt to develop a finer cartographic representation of the hazard of risks, it was necessary to combine four parameters judged to be the primary causes of the appearance of risks, which are as follows: - The geomorphology of the site, - the rate of plant cover, - the distance to the road network and hydrographic network. In addition, to highlight the interest of soil nature, the fifth parameter was added which is the soil lithology. In the case of the anthropic accident hazard map it is necessary to use the land use map in the spatial analysis.

The combination method used is based on multi-criteria analysis with the usage of the geographic information system. The result of this approach is the development of a risk susceptibility map at the level of the study area, which is a useful document for easily identifying the exposed areas with the use of four levels of importance. (Low, medium, high and very high). In this sense, this mapping constitutes a decision support approach for managers and planners of the area. On the other hand, it has been found that the use of a GIS has a double advantage, namely the possibility of using multi-source data and grouping them into different layers of information. This same technology makes it possible to update and later integrate additional data that can be very useful in assessing the level of hazard associated with the phenomena as well as that of the issues and vulnerability.

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