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INTEGRATION OF AN MCA-GIS APPROACH FOR THE MODELLING AND ASSESSMENT OF MASS MOVEMENT RISK. CASE OF AÏN EL HAMMAM, BASIN OF TIZI-OUZOU (ALGERIA)

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Abstract: This paper presents a three-step approach to evaluate and map mass movement risk. First, hazard and vulnerability, the two components of mass movement risk, are evaluated through the use of a Weighted Product Method (WPM) borrowed to the Multi-Attribute Utility Theory (MAUT). The model evaluates each potential action a $\in$ A (set of potential actions) according to a set of attributes, points of view and criteria i, i = 1, ..., n, from gi measurement scales. The criteria retained are environmental factors of susceptibility to landslides and surrounding elements at risk (stakes). In a second phase, the risk is estimated by the product of its two components. Finally, the spatial mass movement risk is determined by crossing the susceptibility (hazard) and consequences (vulnerability) maps. The method has been tested in the area of Aïn el Hammam in the basin of Tizi-Ouzou (Algerian Tell).

Key words: landslide, rock fall, multi-criteria analysis, modelling, GIS

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INTRODUCTION

Mass movement risk is related on the one hand to the presence of an event or hazard that is the manifestation of a geomorphological phenomenon and on the other hand to the existence of issues; that is, all the consequences that can hit a specific environment: the loss of life, damage to economic activity, natural environment and national heritage. These consequences depend on the exposed elements and their vulnerability, often expressed in terms of damage level. As it is often difficult to quantify a level of hazard, it is only the susceptibility of land to a geomorphogenic process that has been picked for analysis. These different concepts of risk have been defined by several authors (Aleotti and Chowdhury, 1999; Fell et al., 2005; Glade, 2003; Gokceoglu and Aksoy, 1996; Herman, 2009, 2010).

Mass movement risk assessment methods use have soared, these methods consider hazard as the probability of occurrence of a spatial phenomenon for several environmental predisposing

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factors, and vulnerability is evaluated by taking into account the number and the magnitude of potentially affected exposed elements (Bui et al., 2011; Guettouche, 2012; Kouli et al., 2013; Tazik et al., 2014; Xu et al., 2015; Bourenane et al, 2016).

This work presents a methodological mapping process of mass movement risk in a sloping area (Aïn El Hammam) using spatial analysis model, based on the MCA-GIS coupling (Multiple Criteria Analysis and Geographical Information System). The selected area is marked by several rock fall and landslide locations, the largest of which is ranked among the most potentially destructive in Northern Algeria.

METHODOLOGY

The applied methodology in this work includes three large parts; it is essentially based on the integration of the Utility Theory MAUT and GIS (figure 1):

- modelling of mass movement risk through the use of Utility Theory (MAUT) theory simulating the relationship between the two most crucial criteria, namely, hazard and vulnerability;
- appraisal and mapping of hazard and environment vulnerability through the identification of the key elements and the analysis of their potential effects using the GIS tool;
- appraisal and risk mapping through the overlay of hazard and vulnerability maps.

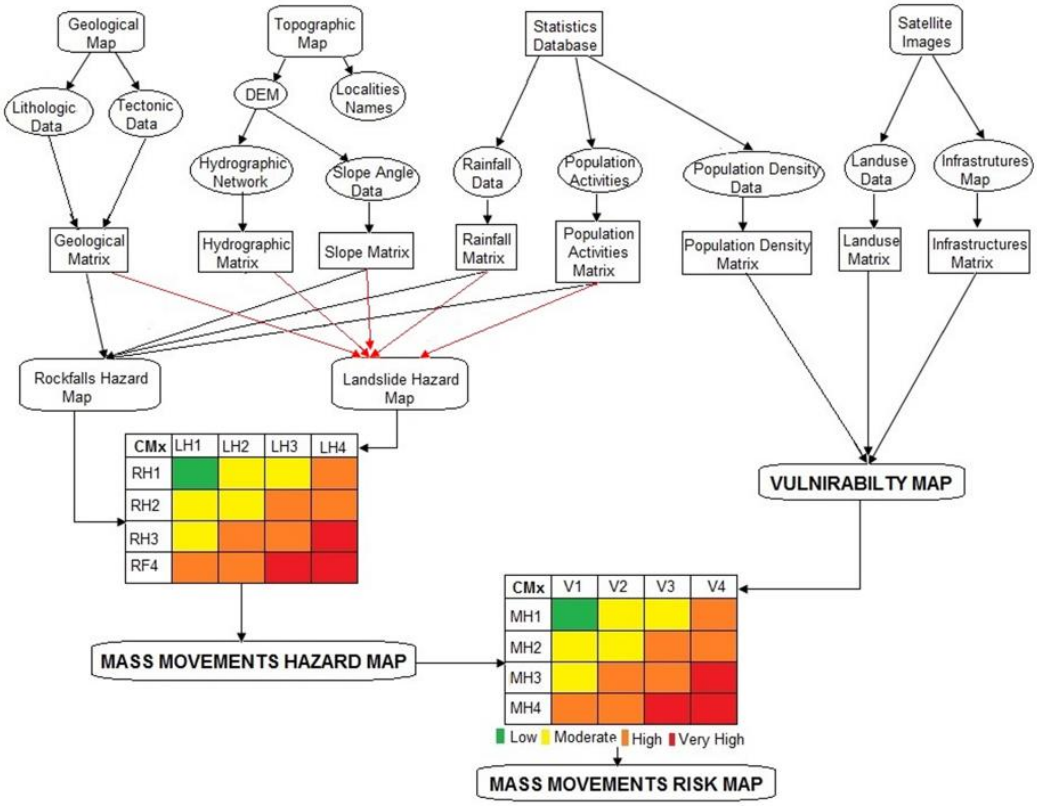

Figure 1. Methodology of mass movement risk mapping
(Source: Berchiche Razika)

To test our methodological approach, the “commune” (town hall district) of Aïn El Hammam in the Wilaya of Tizi-Ouzou was chosen as the study area (figure 3). This choice is all indicated due to the external geodynamic features and existing issues in the area.

Mass movement inventory map

The mass movements inventory maps are important for the study of the relationship between the distribution of these movements and conditioning factors. To produce detailed and reliable maps, thorough investigations and field observations were conducted in the study area. A total of 9 landslide and 5 rock fall locations have been identified and mapped in the study area (figure 2). The rupture types identified in the study area were determined according to the mass movement classification system proposed at the International Conference of Geomorphology (International Association of Geomorphologists).

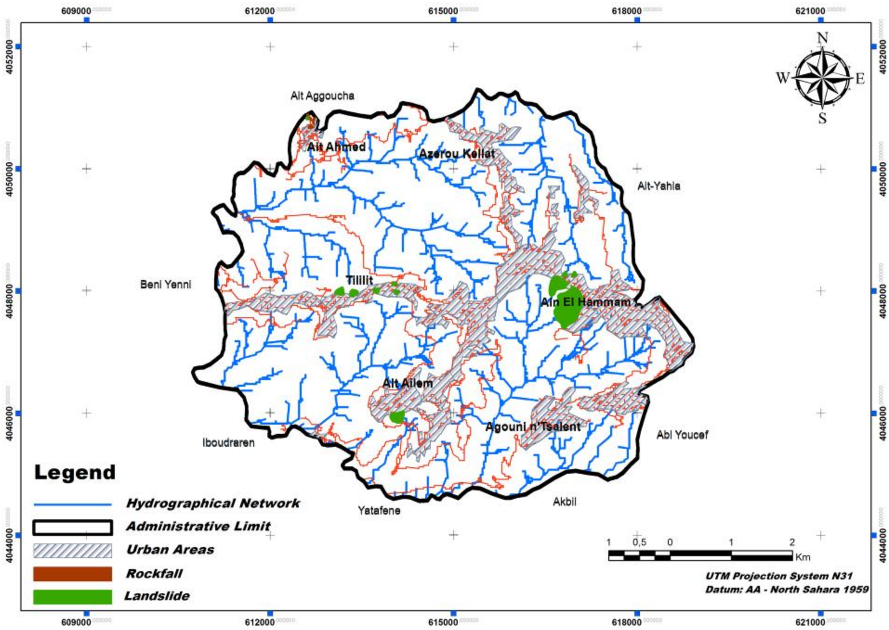

Figure 2. mass movement inventory map of study area
(Source: Berchiche Razika)

Mass movement risk modelling

Stemming from the definition of D. Bernoulli (in Guettouche, 2012) risk is considered to be the product of hazard and vulnerability (eq. 01):

$$R_{mt} = A_{mt} * V \qquad (01)$$

In our instance, mass movement hazard is the cumulative effect of two geomorphological processes, rock fall and landslides. This cumulative effect can be represented by equation (02):

$$A_{mt} = A_{eb} + A_{gl} \qquad (02)$$

Where:
R_{mt}: Mass movement risk. Amt: Mass movement hazard. V: Vulnerability.
A_{eb}: Rock fall hazard. A_{gl}: Landslide hazard.
A_n alternative approach based on the WPM method (Weight Product Model) is used to define either mass movement hazard or vulnerability, (eq. 3)

$$P(A_k) = \prod_{j=1}^{n} (a_{kj})^{\omega_j} \qquad (03)$$

Where:

$P_{(Ak)}$: Action defining the hazard or vulnerability. ωj: relative weight of importance of criterion C_i. a_{kj}: Value of the performance of the variant Ai when evaluated according to criterion C_i.

Identification of hazard and vulnerability criteria

Several authors reckon that a certain number of triggering factors may be responsible for the occurrence of mass movement in a region (Erener and Düzgün, 2008; Kanungo et al., 2009; Tazik et al., 2014; Yalcin et al., 2011) such as lithology, geomorphology, hydrology and entropic conditions; thus, the criteria adopted for the evaluation of landslide hazard and vulnerability are: lithology, slope, rainfall, river systems, vegetation, human activities, infrastructure and population density.

Indeed, the weight given to the chosen criteria are:

For landslide hazard (eq. 04)

$$A_{gl} = Pe^{0.3} * \mathrm{L}^{0.25} * \mathrm{Pl}^{0.2} * \mathrm{Rh}^{0.1} * \mathrm{Ah}^{0.15} \quad (4)$$

For rockslide hazard (eq. 05)

$$A_{eb} = Pe^{0.25} * \mathrm{L}^{0.35} * \mathrm{Pl}^{0.15} * \mathrm{Ah}^{0.25} \quad (5)$$

For environmental vulnerability (eq. 06)

$$V = D^{0.7} * \mathrm{Aa}^{0.2} * \mathrm{I}^{0.1} \qquad (6)$$

Where

A_{gl}: Landslide Hazard. A_{eb}: Rock Fall Hazard. V: Vulnerability. L: Lithology. Pe: Slope.

Pl: Rainfall. Rh: Hydrographic network. Ah: human activity. D: Population density (Np /m²). I: Amenities density represented by the line plots in a unit area (m/m).

Aa: agricultural stake evaluated through the ratio of farmland to the total area (ha/ha).

Construction of the spatial database

Through their capabilities of storage, management, analysis, modelling and display of spatial data, GIS are presented as the most suitable tool for the classification of the criteria used to model hazard and vulnerability in terms of their impact on unstable ground in our study area (Mashari et al., 2012; Bourenane et al., 2014; Magliulo et al., 2008; Pradhan and Youssef, 2009).

Based on a choice of criteria, a spatial database relying on categories of elements determining the hazard or vulnerability was built then weights were assigned to each element based on the objectives of the study and/or the socio-economic importance of the elements exposed in the study site. A linear combination allowed the evaluation of the susceptibility degree of the land or the potential damage for each stake. For details on the method please see Guettouche et al., (2011).

Hazard and vulnerability are translated into total risk classes in a double-entry matrix (Sorriso Valvo, 2005) implemented in a GIS tool (ArcGIS) for risk mapping.

Slope (Pe)

Considered the most relevant parameter in unstable hillslopes, the slope is an essential factor as well for the assessment to map mass movement. Therefore, the weight it has been assigned was high (Conforti et al., 2001; Erener et al., 2008; Yalcin et al., 2011; Hantz 2008). There for, the study area is a very rugged ground with slopes ranging from strong to very strong (from 45 to over 65%); this is epitomised by the location of the area, belonging to the Tizi Ouzou Neogene Basin.

Lithology (L)

Lithology plays often a fundamental role in the instability, evolution and the occurrence of mass movement. Undeniably, rock permeability, structure and hardness are parameters that affect the geological formations 'rheological character' (Kanungo et al., 2009; Xu et al., 2013; Tazik et al., 2014; Yalcin et al., 2011). Therefore, the geological nature of our study area appears to be very complex, showing a Paleozoic sedimentary cover that is hardly or not metamorphosed at all, part of the mainly carbonated Kabyle dorsal, dating from the Permo-Trias to the Oligocene with soft soils (Southern area) and hard ones (Northern area).

Rainfall (Pl)

As a general rule, rainfall is regarded as the main land slide triggering factor (Bui et al., 2011), thus, the Algerian Tell - in which the area studied is located- is a wet and rainy region (1000 to 1500 mm/y) making it very susceptible to landslides especially during the winter season.

Hydrographic Network (Rh)

The density of the hydrographic system plays an important role in the instability of hillslopes depending on its nature and its distribution (Bui et al., 2011; Mathew et al., 2007; Kouli et al., 2013; Kanungo et al., 2009). In our case, the study area chosen is a mountainous zone with broad, embedded and/or deep valleys and the classification was made according to the position of the talweg relative to the slope.

Human Activity (Ah)

Several authors (Maquaire et al., 2006; Mathew et al., 2007; Nathanail and Hudson, 1992; Ocakoglu et al., 2002) postulate that vegetation cover and human activity are important for the stability of slopes. For this study, the human activity map has been built relying on Landsat satellite imagery by supervised classification. In our case, human activity is mainly found in the Southern part of the region around the chief town of the district, due to the tender lithological characteristics, thus, facilitating crop growing.

Population Density (D)

The population density present in the study area is high (20,401 inhabitants/h), and is located in the Southern part. Even, the weight given to human life is the highest and the criterion has been segmented into three density classes.

Agricultural activity (Aa)

Economic and agricultural assets are all stakes that may be highly affected. This parameter is divided into four major classes.

Infrastructure (I)

The road network has been considered as the weakest factor for the vulnerability evaluation and has been segmented into classes depending on the importance and role of roads.

APPLICATION

Location of the study areas

Aïn El Hammam is a mountainous area with very steep slopes, located about 50 km southeast of the Wilaya capital of Tizi-Ouzou. It lies between longitude 4° 18' and 4°40' E and 36° 49' and latitude 36° 66' N. It is the county seat and is accessible through roads RN 15 and/or RN 71. It counts more than 20 401 inhabitants. Aïn El Hammam is one of the largest cities in the Wilaya of Tizi-Ouzou to have suffered significant economic and agricultural losses caused by landslides.

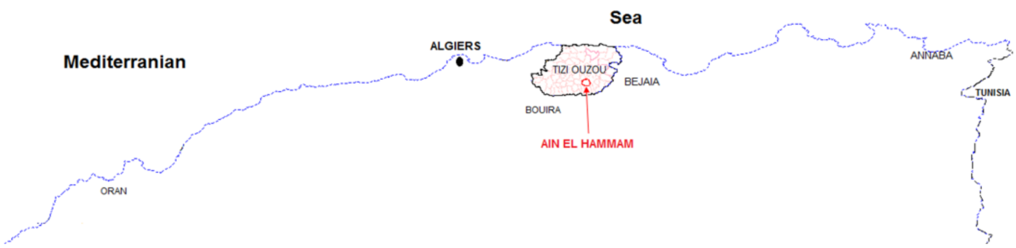

Figure 3. Location map of study area
(Source: Berchiche Razika)

Results

The main results obtained under the exposed WPM method are synthesized on the figures 4-8. The processing and analysis performed have led to a split of the communal space into four mass movement risk classes.

The analysis of different physical and human geography standards leading to mass movement (C_i) helped to determine the number of surface calculation units in the area and their optimal locations. Processing and combinatorial analysis of different matrices led to the spatial mass movement risk. This simulated spatialisation has been empirically validated by comparing the simulation map with the field observation results.

Landslide, Rockfall and mass movement hazard maps

Two hazard maps (landslide and rock fall) were completed (figures 4 - 5).

For the landslide hazard map (figure 4), locations (1, 2, 3) where the hazard is very strong, the lithology proved to be tender (micaceous shales), human activity very intense (urban area coupled to agriculture activities), dense hydrographic network, perpendicular to the slope, high rainfall (over 1000 mm/year) and slopes between 30 and 65%.

Furthermore, as for the rocks fall hazard map (figure 5), locations (1 and 2) are very susceptible (very high hazard) in contradiction with the physical and surface parameters (insignificant human activity, less than 50 inhabitantper km^2, forests and olive plantations), hard lithology (granuliticmica shales (gneis) and granuliticshales slopes between 30 and 65%, rainfall over 1000 mm/year^{-1}.

Overlapping the two maps (figures 4 - 5) produces the mass movement hazard map (figure 6), this latter shows four classes of land susceptibility to movement, of which the strong hazard is located in Aïn El Hammam, Tillilt, Agouni n'tsalent and Ait Ahmed.

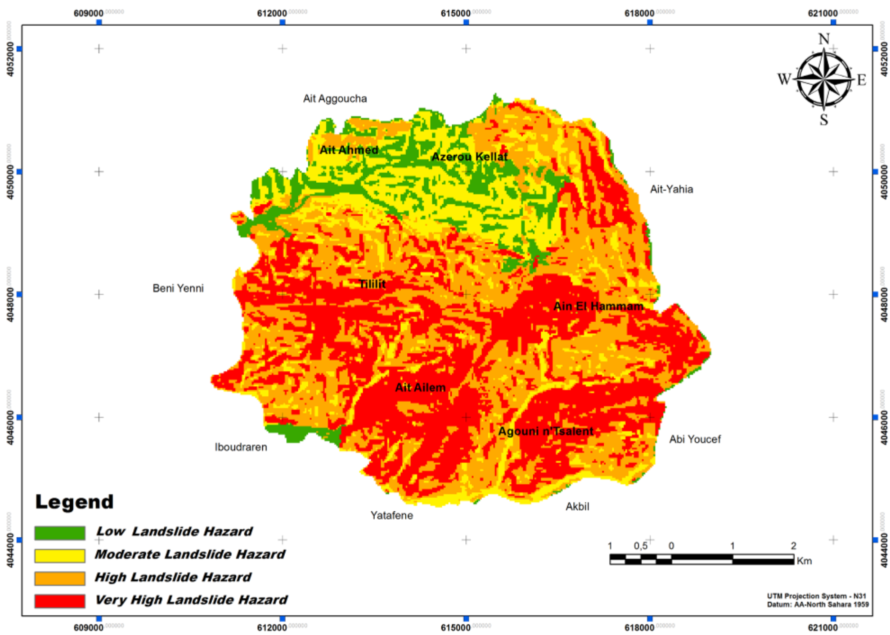

Figure 4. Landslide Hazard map of Aïn El Hammam area
(Source: Berchiche Razika)

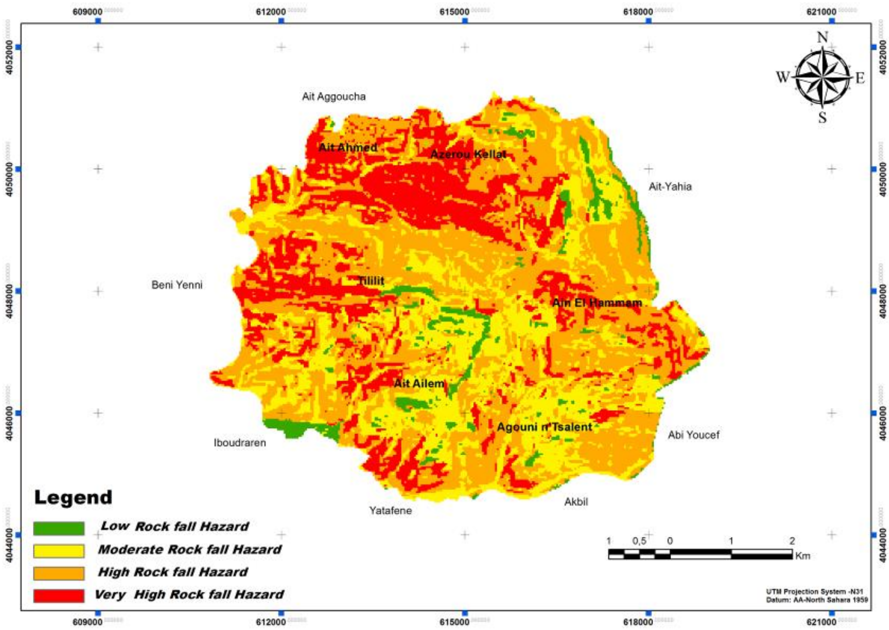

Figure 5. Rock fall Hazard map of Aïn El Hammam area
(Source: Berchiche Razika)

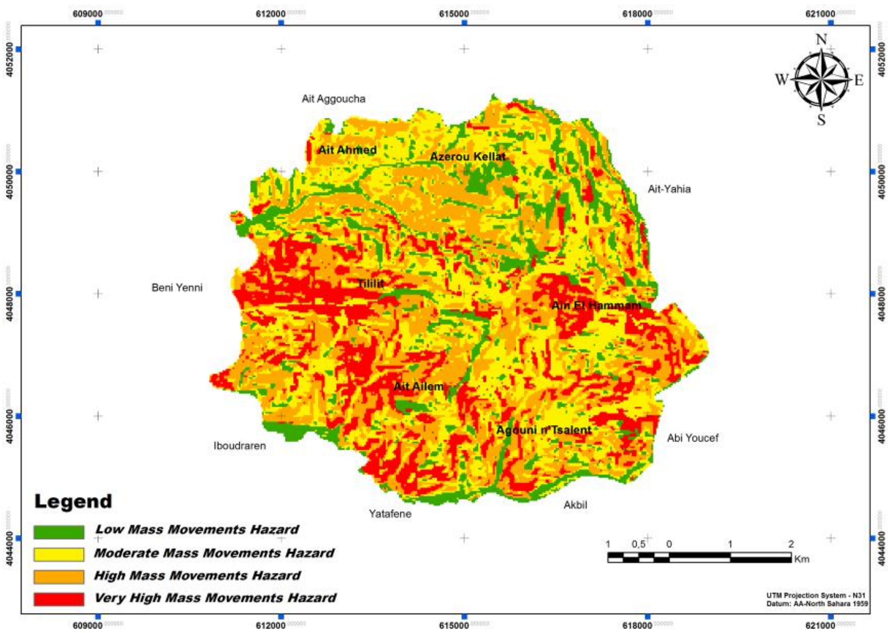

Figure 6. Mass Movements hazard map of Aïn El Hammam area
(Source: Berchiche Razika)

Vulnerability map

The figure 7 shows the total damage potential map (structural, functional and physical). Indeed, the town of Aïn El Hammam shows a significant vulnerability especially in locations 01, 02, 03 and 04 where the density of the population is high (1000 over 5000 inhabitants /ha) and human as well as agriculture activities are strong.

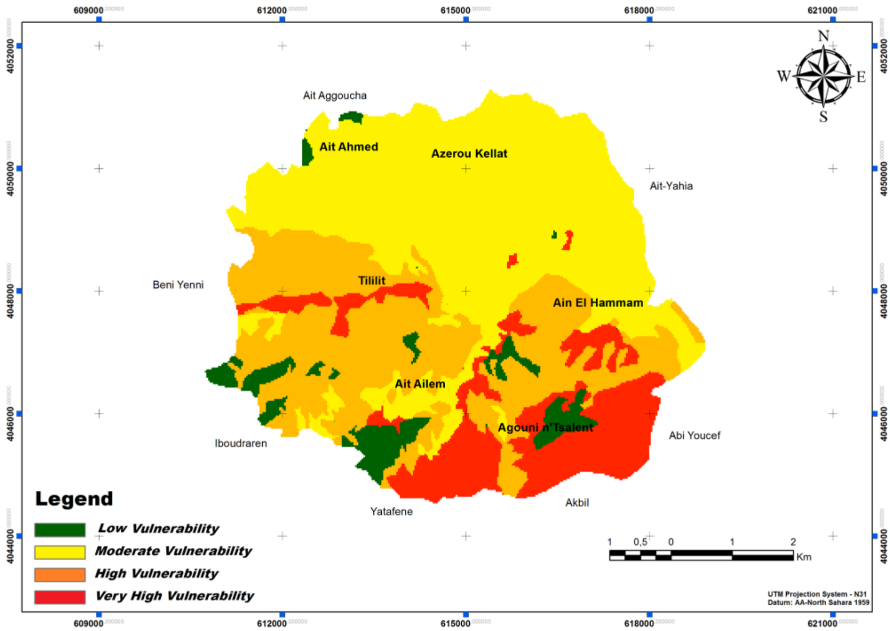

Figure 7. Vulnerability map of Aïn El Hammam area
(Source: Berchiche Razika)

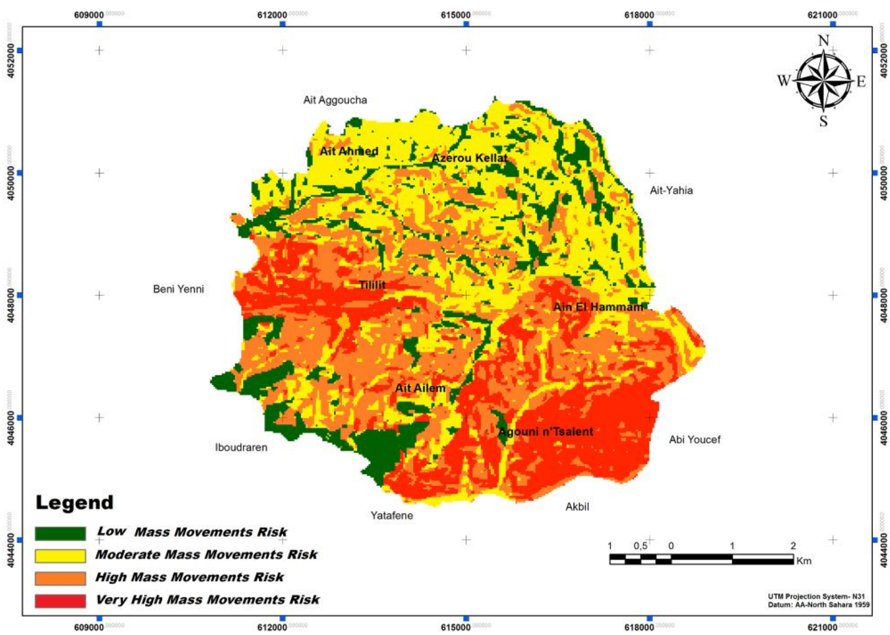

Figure 8. Mass Movements Risk map of Aïn El Hammam area
(Source: Berchiche Razika)

Mass movement Risk map

The combination of the mass movement hazard map (figure 6) and potential consequences map (figure 7) shows the mass movement risk levels in the region of Aïn El Hammam (figure 8).

The risk of mass movement map (figure 7) shows two distinct risk areas: the north area, which represents a low and medium risk, and the south area where the risk is graded strong to very strong.

Firstly, the very high risk - which represents 13.5% of the total land area- and the high risk are developed in areas consistent with sectors with high consequences (urbanized areas and/or agricultural) located on high susceptibility slopes (for example, soft or uneven fields) as in Aïn El Hammam, Tililit, Ait Ailem, and Agouni n'Tsalent.

Secondly, the north area which is graded as a low to medium risk, located in Azerou Kellat and Ait Ahmed, owing its low vulnerability to limited people mobility and agriculture due to the very rugged terrain (steep slopes> 65%) and its geological nature (hard ground: schist granulite, and micaschist granulite).

The comparison of the two maps (figure 8) with the one obtained through in situ mapping (figure 2) shows that the results provided by the model put to test are reliable and coincided with the information collected in the field, for example the infamous great landslide of Aïn el Hammam and is correctly shown and located in figure 8 provided by applying the model, as well as the communities of Ait Ahmed, Tililit and Ait Ailem.

Discussion

The results from the application of the MAUT theory can be dealt with in four points:

The analysis of the two maps elaborated shows that the allocation of the landslide hazard in the study area is mainly located in the Southern part, where the conditions are favourable. In contrast, the rockslide hazard is situated in the Northern part where the conditions are favourable to the occurrence of this latter. The breakdown of these two phenomena can be explained by the geographical situation of the study area which is part of the internal zone of the Kabyle territory; more precisely located between the flysch area to the South and the Kabyle spine to the North, which plainly crops out at Fort National. As a consequence, the maps of landslide and rockslide hazards seem to be very localizing.

The vulnerability map of the study area is represented by two very distinct areas, the northern part with medium vulnerability, and the southern with strong to very strong vulnerability. This can be explained by the strong distribution of the population in the southern part of the area as a result of the location of the county site of Aïn El Hammam and the nature of the soft ground (Schist and Micaschist) which makes for easy lands to exploit, favouring agriculture development.

On the other hand, it can be seen that the mass movement hazard map, shows four an homogeneous distribution of land susceptibility to movement.

Finally, the mass movement risk map, which does not show a homogeneous distribution of the risk, seems to be well localizing, this allocation is strongly influenced by the vulnerability of the environment; therefore, the risk assessment approach can be considered as a satisfactory result.

CONCLUSION

The results as stated illustrate four important topics:

- from a methodology angle, the choice to set up a risk modelling has helped to overcome the tedious and costly standards of accuracy of a conventional field investigation. So this will reduce the field investigations and the cost of studies;

- the inventory carried out, specifically oriented towards basic research through the study of the relationship between physical and human parameters, led to new inputs for risk management in the study area;

- natural hazard mapping set up in this work allowed to clearly distinguish two areas: one where the mass movement risk is high and requires short-term involvement and one where the mass movement is low. These movements are mainly related to lithological conditions, slope, human activity, hydrographic network and rainfall;

- in terms of spatial distribution, and on reading different maps issued from the application of utility theory (MAUT) models, we generally observed the same spatial distributions. In addition, through a fine map reading we noted that the WPM method is reliable and provides more details, and best prediction of the slope movement risk in the study area.

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