Spatial Distribution Analysis and Susceptibility Mapping of Mass Movements Using GIS-Based Logistic Regression: A Case Study of a Moderately Hilly Alpine Context (NW Morocco)

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Abstract— A quantitative mass movements susceptibility zonation map at a medium scale (1:50 000) of the Zoumi area (Central Rif – Morocco) was prepared using a probabilistic approach. Because, is considered as one of the most appropriate approaches for mass movements susceptibility mapping on this scale with datasets developed for application in a geographic information system (GIS). This paper presents a four-step procedure to map mass movements susceptibility in a moderately hilly context. First, mass movements inventory carried out through high remote sensing data interpretation and field surveys studies. Second, mapping predisposing parameters (geotechnical unities, fracturing density, slope angle, slope aspect, elevation, stream network density, earthquakes isodepths and land use) controlling the spatial occurrence of slope failure. Third, the strength of the eight predictor variables association was assessed and the logistic regression model was applied. Finally the degree of model fit of the susceptibility map was evaluated by calculating the cumulative percentage of mass movements area in each susceptibility class, accompanied by expert judgment.

Index Terms— Mass movements, Susceptibility, logistic regression (LR), GIS, Spatial analysis, Morocco.

1 Introduction

In recent years, researchers in geomorphology and other fields have become increasingly interested in using geographical information systems (GIS) in order to provide mass movements hazard maps. GIS is a powerful tool and has the facility to manage and assess mass movements' hazard on a large scale, where numerous calculations, data collection, and management are required. Thus the use of GIS has become an important aspect in assessing mass movements' hazard where the probability, location, and frequency of this phenomenon in the future can be predicted.

Mass movements hazard assessment defines the probability of a potentially damaging mass movements occurring within a certain period of time in a given area [1]. The "probability" of mass movements occurring can refer to: a) recurrence time; b) uncertainty of geo-mechanical parameters or geotechnical models; c) the frequency, intensity and duration of triggering agents [2]. Several different methods and techniques for mass movements' susceptibility mapping have been proposed and tested. A great variability in scale and mapping procedures exists: in fact, the choice of type and scale of the map depends on many factors, primarily on the requirements of the end user, and the ultimate purpose of the investigation [1], [3].

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A lot of research on mass movements' susceptibility mapping has been done over the last 30 years.

Broadly speaking, mass movements' susceptibility mapping may be qualitative or quantitative, and direct or indirect [4]. Qualitative methods are subjective, and they portray the hazard levels in descriptive terms. Geomorphological mapping is an example of a qualitative, direct method. Quantitative methods produce numerical estimates (probabilities) of the occurrence of mass movements' phenomena in any hazard zone. Direct susceptibility mapping involves mapping mass movements within a given region by means of field studies, aerial photographs interpretation or other methods. In direct mapping, the expert uses its knowledge and experience to map actual or potential mass movements' hazard. Indirect methods for landslide susceptibility mapping are essentially stepwise procedures. They require first the recognition and mapping of landslides over a target region or a training area. The identification and mapping of a group of physical factors are directly or indirectly correlated with slope instability. Indirect methods then involve an estimate of the relative contribution of instability factors in generating slope failures, and the classification of the land surface into domains of different hazard degree (or hazard zoning) [5]. In other words, indirect landslide mapping involves inferring the probability of land sliding through data on related properties. Despite the efforts, no agreement has yet been reached on the techniques and methods for mass movements' susceptibility mapping. This makes it difficult to compare results achieved by different au-

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thors. Overall, these conclusions encourage the continued investigation of the analyses of slope stability. Specifically, they indicate that research should concentrate on improving practice by exploring more explanatory variables and more powerful techniques [6], [7], in different areas. Nevertheless, the two groups of techniques are separated into qualitative and quantitative techniques [8]. They are often connected with the use of Geographical Information Systems (GIS) technology [9].

Mass movements are one of the natural risks which Morocco is confronted to, especially in the Rif regions. Those are more important in the corridor faults regions, where the recent reactivation of those may greatly contribute to the triggering of mass movements. The consequences of this phenomenon can be multiple: burial and destruction of homes (habitations), bridges, roads, and loss of human lives even if the latest case is rare. For information, in the current year 2010, about 53% of the total budget allocated to the DPTP (Provincial Directorate of Public Works) in the Rif was intended for reinforcement work, support and rehabilitation of roads following the occurrence of a big number of mass movements. Thus, the hazard assessment has become a topic of major interest to the authorities that manage regional planning of environmental protection and prevention from natural hazards. Consequently, Morocco is currently under an increasing need for susceptibility maps creation, describing and defining the areas susceptible to mass movements in the present and the future. Those maps will be a major contribution to the orientation and the choice of implementations in development sites, in urban extensions, as well as in the setting up of new roads and highways in the frame of the National Development Program of provinces in Northern Morocco.

Although several efforts have been made in the previous years to prevent mass movements in the Rif, but the number of movements doesn't stop from increasing and giving prejudice in areas supposedly already studied (low or null susceptibility) [10], [11], [12], [13]. This happens for the following reasons: - 1° Mass movements are not taken in their global geodynamic context within the dynamic of the watershed. Namely, taking into consideration seismicity, active tectonic and intense and irregular rainfall in the study area without forgetting the other environmental factors, - 2° The utilization of non adapted methods or usually based only on experience and experts opinion [14], - 3° Bad choice of work scale and the combination of factors that are considered causal of mass movements. The main objective of this study is to remedy to the previously mentioned gaps in order to establish mass movements susceptibility map using a logistic regression model (probabilistic approach = indirect and quantitative method) at the scale of 1/50 000 which is more credible and reliable. Finally, in order to validate the susceptibility map obtained by LR methodology, the degree of model fit was evaluated by calculating the cumulative percentage of mass movements area in each susceptibility class, accompanied by expert judgment.

2 Study area

The Moroccan Rif is a part of the Alpine thrust belt that extends from the Betics in southern Spain and curves through the Straits of Gibraltar into North Africa. The regional thrust sheet transport directions swing through a 180° arc. Thrusting is toward the North in Spain, toward the West around the Straits of Gibraltar and the Northwest Rif and toward the South in the eastern Rif and Tell mountains of Algeria and Tunisia. Many workers attribute the arched nature to a collision during the Tertiary period between a microplate (Alboran plate), the Iberian plate, and the North African plate [15]. The study area is located in the Northern edge of central Rif, North West of Morocco (Figure1). This thrust sheet occupies a tectonic position between the lower external thrust sheets to the West (Mesorif), and the higher Intrarif thrust sheets to the East. Overthrusting was directed toward the WSW. The Zoumi thrust sheet stratigraphy is made up of 0–100 m of white marine Eocene at the base, followed by the 1000–1500 m thick Upper early-Oligocene - mid-Miocene Zoumi Sandstone. Capping the sequence is about 50 m of Mid-Miocene olistostromes and thin-bedded turbidites [16]. About 95% of the Zoumi area is formed by sandstone thrust sheet (formerly the `internal Mesorif unit'. The three types of the external Rif units are presented in the Zoumi area:

- The Intra-Rif : Loukkos and external Tangier unities
- The Meso-Rif : Zoumi sandstones
- The Pre-Rif : Ouazzane sheet

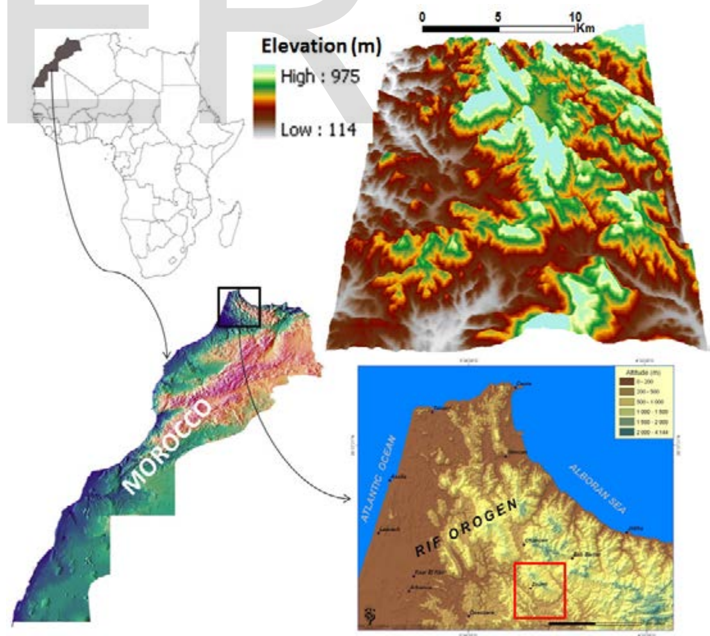

Fig. 1.Geographical location of the study area in Moroccan and African context.

3 Data preparation

The identification and mapping of a suitable set of parameters with a relationship to mass movements (dependent variable) require a prior knowledge of their main causes. The methodology applied in our study area is based on the

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well known principle of "The past and present are keys to the future'' [1]. The fundamental principle of this according to mass movements' susceptibility mapping is to use the characteristics of existing movements in order to evaluate the possible areas of future movements. For this reason, databases of mass movements and their triggering factors (independent variables) were established. To store the information of these parameter maps in a uniform thematic database, the size of each pixel for all the products was 25m × 25m.

3.1 Mass Movements Discription

Known as one of the most areas prone to mass movements (MM) in the NW of Morocco, the Zoumi sector was selected because of the frequency, distribution, and diversity of its active mass movements (Figure 2 & 3). We mapped and inventoried the various mass movements of the study area. The inventory data base was constructed using 1/17000 and 1/20000 scales aerial photographs, high resolution remote sensing data, and supported by the available geomorphological maps. In-situ, checking of the produced inventory was also performed during extensive field studies. A total of 286 mass movements were identified (Figure 2 & 3), which covered an area of 24 km², accounting for 0.04% of the study area (610 Km²). The minimum, mean and the maximum mass movement areas are 0.007, 0.082 and 0.578 km² respectively.

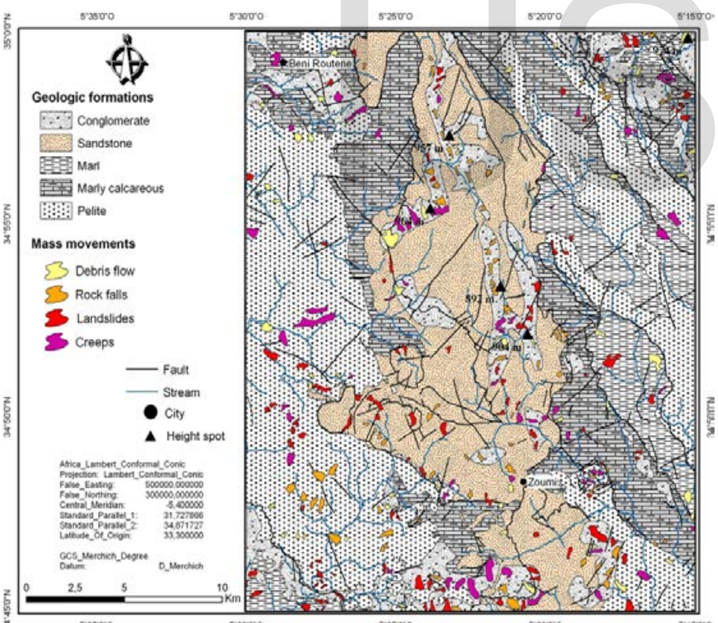

Fig. 2.Simplified geological map and inventoried mass movements location.

However, typical classification of mass movements in the Rif's area is not generally easy to establish for the great variability of materials, processes, and the morphological complexity that escalate with the size of mass movements [17]. Distinguishing between different types mass movements requires considerations of several parameters like: velocity and mechanism of movement; material; mode of deformation; geometry of the moving mass…etc [18]. For this reason, it is not surprising that there are many classifications in use and conflicts in applications of terms. The earliest widely used classification is that of [19] and most workers since then owe some debt to him for his pioneer effort. More recent classifications are those of [3], [18], [20], [21], [22], [23].

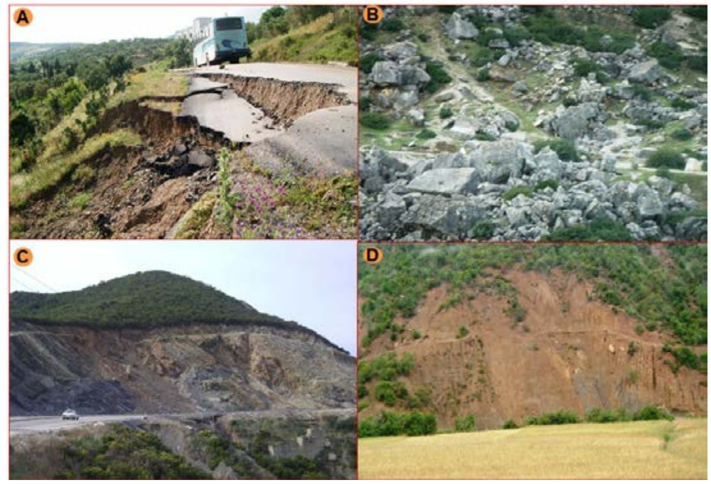

Fig. 3.Photos of typical mass movements in the study area. A: Landslide, B: Rock Falls, C: Rotational landslide, D: Debris flow.

According to the classification done by [18] which completes and combines between all the previous classifications, we classified our mass movements into four categories (Figure 2 & 3):

i- Rock falls that present 26.6 % (Figure 4) of the total number of recorded movements. They group a set of fast and rough phenomena which affect stiff and broken rocks such as limestones, clays or crystalline rocks. In the case of sedimentary rocks, the stratification increases the breakage of the rock and thus the predisposition of instability.

ii- Landslides which occupy 36 % (Figure 4) of the totality of movements. They correspond to slow movements of a coherent land mass, generally along of curved or flat discontinuity surface. According to their types, landslides may have very different characteristics and achieve very variable dimensions. Most of landslides which we met during the field studies have occurred in sandstone and marly formations or in marly calcareous intercalations.

iii- Debris flow constitutes 17.5 % (Figure 4) and are mainly encountered in conglomerate and politic terrains. They correspond to very fast and sudden movements that start in large-scale masses. Morphologically, debris flow has a lobule shape towards the downstream part.

iv- Creeps presents 19.9% (Figure 4) of the total number of movements. In contrast to debris flow, the creep occurs in rather slow movements, on hillsides saturated in water and which do not present a detectable discontinuity surface. The deformation of the soil is shallow with the rolls formation. The Figure 4 shows the number frequency and the area frequency of the mass movements occurring in the field of study.

The properties of the mass movements were recorded on a standard mass movements-inventory data sheet (shap file). A digitized map of MM boundaries was produced using ArcGis 10. A vector-to-raster conversion was performed to provide a raster layer of the MM areas.

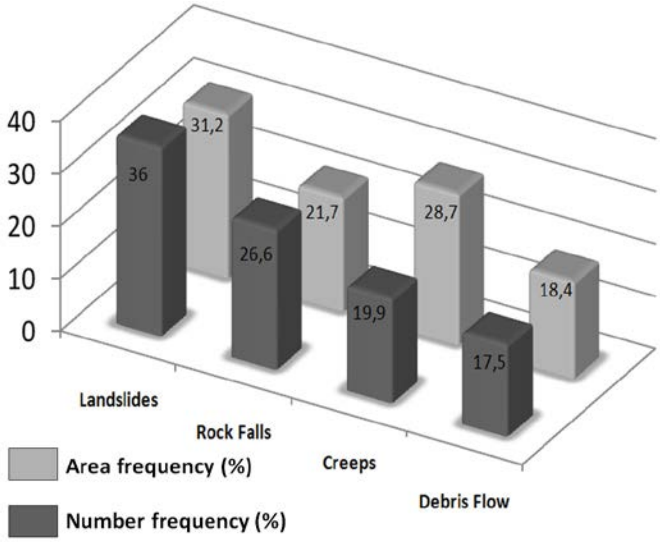

Fig. 4.Characteristics of identified mass movements.

3.1 Mass Movements Influencing Factors

The first dataset was the geological formations map. Geological paper map at 1:50 000 scale covering the study area was simplified and the geologic formations were identified and digitized (Figure 5a). The classification of geological formations is proposed by [24] and considered as standard. It is based on the landscape segmentation on geomorphological areas, closely associating lithology and forms. The identified lithology classes are pelite, sandstone, marl, marly calcareous and conglomerate formations.

The three largest datasets are topographical parameters (elevation, slope angle and slope aspect) (Figure 5b, c and d) that were obtained from the ASTER remote sensing data (DEM). Before extracting the topographic parameters we applied some filters allowing correcting artifacts' due to the nature of the ASTER sensor. Elevation in each raster cell was the raster cell value of the DEM. For this study, the slope angle was calculated for by the inclination computational method using eight neighboring cells (3 × 3 samples) and divided into six classes 0–5°, 5°–10°, 10°–15°, 15°–20°, 20°–25° and 25°–53°. Slope aspect was divided into four classes: north, including azimuths between 315° and 45°; east, including azimuths between 45° and 135°; south, including azimuths between 135° and 225°; west, including azimuths between 225° and 315°. These measures of slope orientation were calculated in compass degrees (from -1 to 360), based on the altitudes of the four neighboring cells. However, Recent and inherited tectonic activity can intervene, either by conditioning or triggering mass movements in the case of a seismic tremor in the fractured areas[25]. The fractures network may support the infiltration of water, involving the increase of interstitial pressure and the reduction of rocks shear strength. When the grounds are saturated the movement is started with formation of major shearing plan. Fracturing map (Figure 5e) was carried out through high remote sensing data, orthorectified aerial photographs interpretation, morphostructural analysis of digital elevation model (DEM), and field surveys. The drainage map (Figure 5f) was prepared by interpreting satellite images and ancillary information. The main drainage pattern of the area is generally dendritic. Up to the 5th order of drainage was found in the area. With this information, a fracturing and a drainage density map was prepared using a density factor computed as the total length of fracturing network and drainage network per a grid cell of 25×25 m. For the two maps, the density values were classified into five classes: very low, low, medium, high, and very high. The effects of land-use on mass movements' were also investigated in the study area. Land use plays an important role in land sliding in a hilly terrain. The land use–landslide relationship can be complex, depending on the nature and type of land use. Land use classes were mapped from the SPOT5 satellite images using supervised and unsupervised classification, visual interpretation and other auxiliary information, such as preexisting maps and field checks. Five land use classes were identified (Figure 5g): forests, natural vegetation, agricultural area, urban area, and naked area [26].The stability of a hillside is the report of stabilizing strengths/destabilizing strengths. Let us call back, that in case of earthquake, there is a broadcast of seismic waves or elastic waves of two types which propagate in the ground: the waves of volume said longitudinal and transverse waves and the surface waves said Love and Reyleigh waves. These seismic waves provoke an additional dynamic request [27]. The balance of the strengths is so modified that it can lead to mass movements. The destabilizations due to earthquakes can show in various ways. They can provoke at once landslides, debris flow, landslides, rock falls and significant deterioration of infrastructure due to the thixotropy of soils. In our study area, it does not engender directly mass movements. The earthquakes do not trigger mass movements directly. They have effects in the longer term, by increasing the cracking of geological formations and reducing their mechanical resistance. Furthermore, the cracks extended over the longer term tend to increase infiltration of water, promoting the breakdown of materials from the freeze-thaw cycles and thus result in a mass movement. However, in seismogenic zones, mass movements susceptibility induced by earthquakes is based on the intensity or magnitude of the earthquake and the nearness of the epicenters or the active faults [28], [29], [30]. A map of isodepths (Figure 5h) was established and it presents five classes, 0–10, 10 –20, 20–30, 30–50, and 50–95Km.

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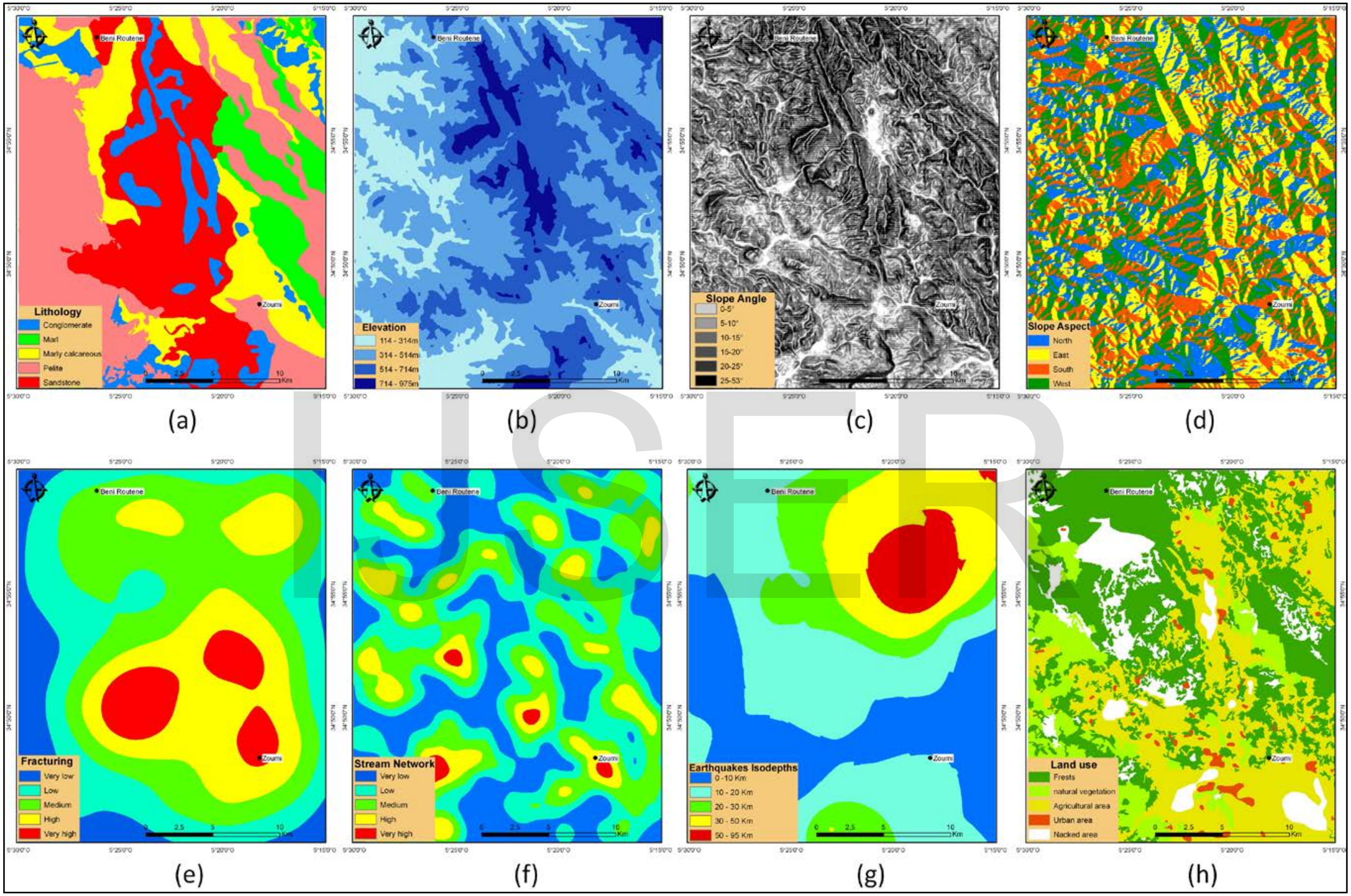

Fig. 5. Spatial distribution of influencing factors: (a): lithological map, (b): elevation map, (c): slope angle map, (d): slope aspect map, (e): fracturing density map, (f): stream network density map, (g): land use map, (h): earthquakes isodepths map.

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4 SPATIAL ANALYSIS OF MM DISTRIBUTION

We have classified all variables in field parameter maps and calculated their respective extent of impact, in order to calculate the mass movements' density. These maps were completed with histograms representing global density of grouped mass movements' for each class of variable (Figure 6 left), and sector diagrams showing the density of each mass movements' type for each class of variable (Figure 6 right). These variables are plotted in a lithological map, elevation map, slope angle map, slope aspect map, fracturing density map, drainage network density map, land use map, and earthquakes isodepths map (Figure 5, respectively a, b, c, d, e, f, g, and h).

The analysis of mass movements' activities and geological formations showed that two types of lithologies are most favorable for the mass movements' genesis: conglomerate and pelite (Figure 6a). Mass movements' are moderate in other lithologies (sandstone and marly calcareous) especially in the marl formation which covers a small part of the study area (Figure 3). The mass movements' density tended to increase with elevation until the maximum density (43%) was reached in the range of 314–514m (Figure 6b). Most of the mass movements occurred between 314 and 714m elevation, and decrease above this boundary below 314m and up 714m. Steeper slopes have greater mass movements frequency up to a slope angle of 5 – 20°. The highest density of mass movements both for number density and area density can be found on moderately steep terrain, ranging from 10° to 20° (Figure 6c) decreases with an increasing or decreasing slope angle. Inverse correlation between landslides events and slope steepness higher than 20°: their frequency decreases with an increasing of slope angle (limited infiltration). Very steep slope is immunized from MM activities because of the existence of resistant rocks (cf. sandstones). The slope aspect can influence soil strength and susceptibility to mass wasting because it affects moisture retention and vegetation cover. We used four (North, East, South, and West) aspects (Figure 5d). Figure 6d shows that the majority of mass movements' occurred on South (30.41%) and West (27.97%) facing slopes. The strong weathering and fracturing of the study area also increase the land sliding susceptibility [31]. The classes representing low, medium and high fracturing density have the highest mass movements' frequency with 28,11%; 24,34% and 23,8% respectively (Figure 6e). However, in the study area, faults guide the superficial drainage and permit the infiltration of water, involving the increase of interstitial pressure and the reduction of rocks shear strength. When the grounds are saturated, even locally, the movement starts with formation of major shearing-slipping planes. The correlation of mass movements' with stream network density shows that the highest frequency occurs for very low, low and medium stream network density classes (Figure 6f). The Figure 6f indicates clearly a decreasing of mass movements' frequency with the increasing stream network density because the high and very high classes cover very small part (12%) of total studying area. Five main types of land uses also favor mass movements' (Figure 6g): forested areas, natural vegetations, agricultural areas, urban areas and naked areas. Agricultural areas and forested (shrub) are the most exposed land uses to mass movements (32,48% and 33,44% respectively), favoring shallow infiltration of precipitation. Figure 6h shows clearly that mass movements' frequency increases with decreasing depth of earthquakes. It shows that most of mass movements' occurred in the two first earthquakes isodepths classes (0 to 10 and 10 to 20 Km) with 34,17% and 30,69% frequencies.

5 MASS MOVEMENTS SUSCEPTIBILITY MODELING

5.1 Logistic Regression Model

Logistic regression (LR) analysis is the most common statistical method used in earth sciences. It is useful when the dependent variable is categorical (traduced bay presence and absence, or 0 and 1, or true and false) and the independent variables (explanatory or causal factors) are categorical, numerical or both [32]. In the case of mass movement susceptibility mapping, the goal of LR would be to find the best fitting (yet reasonable) model to describe the relationship between the presence or absence of mass movements and a set of causal factors such as slope angle, aspect and lithology. LR generates the model statistics and coefficients of a formula useful to predict a logit transformation of the probability that the dependent variable is 1 (probability of occurrence of a mass movement event). It does not define susceptibility directly but an inference can be made using the probability. Generally. The logit model from LR model is expressed as a linear equation (Eq.1):

$$(1): \mathrm{logit}(y) = a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots\ldots e$$

Where "y" is the dependent variable, x1, x2, x3 are the causal or explanatory variables, a is a constant, b1, b2, b3 are the regression coefficients which measure the contribution of causal factors , and e is the error term. The logit of y is the natural logarithm of the odds (Eq.2):

$$(2): \log it(y) = \ln\ [p/(1-p)]$$

Where p is the probability of the occurrence of y, and p (1−p) is the odds. To convert logit(y) back to the probability p, Eq. (2) can be rewritten as (Eq.3):

$$(3): p = \exp\frac{(a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots)}{(1+\exp(a + b_1x_1 + b_2x_2 + b_3x_3 + \ldots)}$$

One of the most important advantages of LR is that, through the addition of an appropriate link function to the usual linear regression model, the variables may be either continuous or discrete, or any combination of both types, and they do not necessarily have normal distributions.

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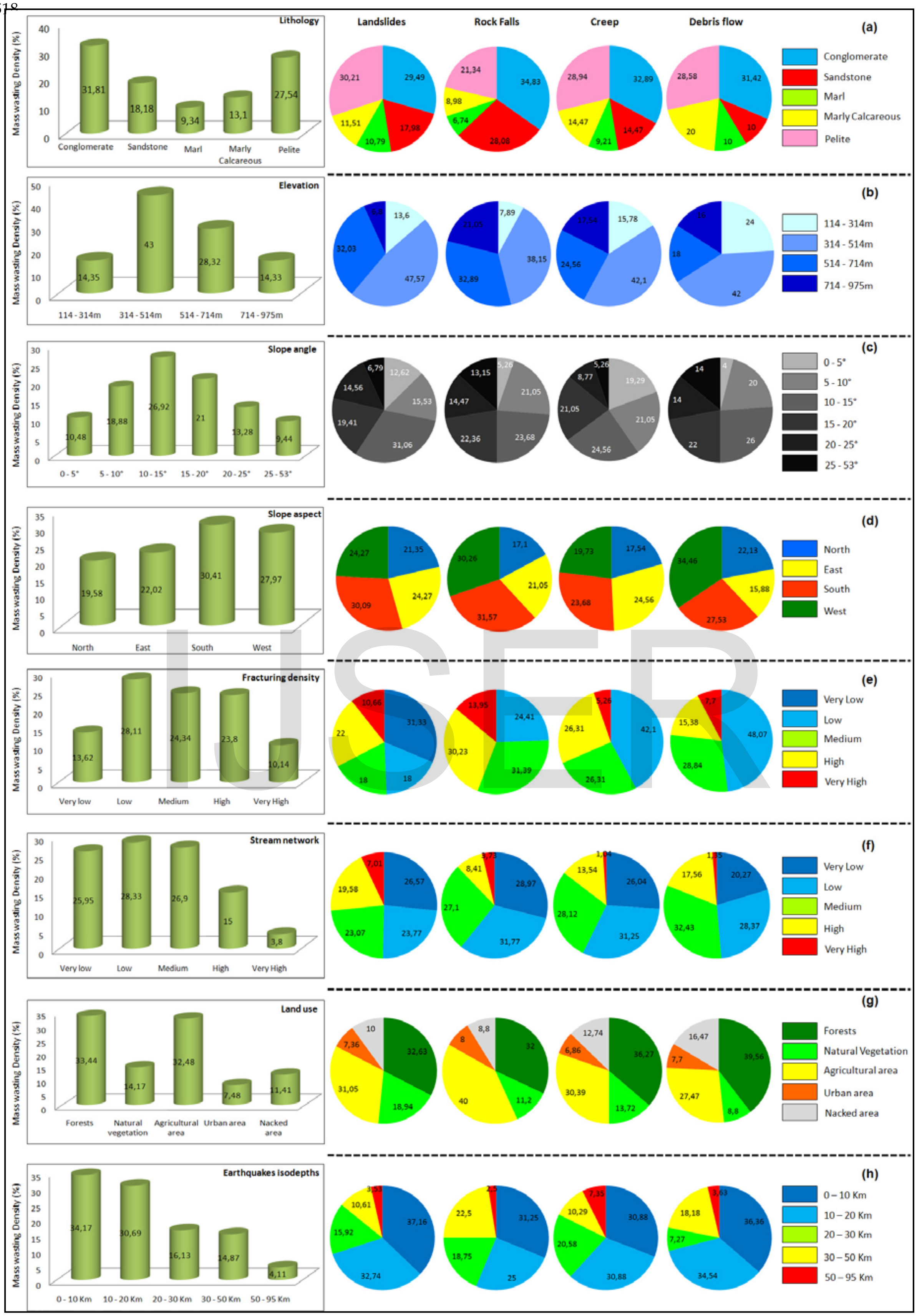

Fig. 6. MM frenquency digram (left): global density of grouped mass movements for each predictive variable class's. Sector diagrams (right) showing the density of each MM type for each predictive variable class's of: (a): lithology, (b): elevation, (c): slope angle, (d): slope aspect, (e): fracturing density, (f): stream network density, (g): land use, (h): earth-quakes isodepths.

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5.2 Test of Causal Factors Association

In studies using LR model we found no agreement on which causal factors (predictor variables = independent variables) have to be used like standards in mass movements' susceptibility modeling [33], [34]. While in some regions, topographical parameters are found as significant; in other regions additional factors such as geological or environmental attributes have been evaluated as imperative. In this paper chi-square (χ^2) (Eq.4) was used to test the association between each predictor variable and the occurrence of mass movements. Then Cramer's V (Eq.5) was derived from χ^2 to tests the strength and type of causal factors association[35], [36].

$$(4):\chi^2=\sum_{i=1}^{r}\sum_{j=1}^{c}\frac{\left(O_{ij}-T_{ij}\right)^2}{T_{ij}}$$

Where O_{ij} is the observed frequency for the cell ij, Tij is the theoretical frequency for cell ij, r is the number of rows in the table, and c is the number of columns in the table.

$$(5):V=\sqrt{\frac{\chi^2}{n(L-1)}}$$

Where n is the number of observations (total frequency), L is the minimum of rows and columns in the contingency table. Cramer's V provides a standardized measure ranged between 0 and 1 [37]. It compares the observed distribution with the one expected under no relationship, and it standardizes this comparison eliminating the effect of n and the size and shape of the contingency table. In this study, the calculated degrees of freedom (Table 1) ($\alpha > 0.05$) prove a highly independence for each two variables association for the eight predictor variables collected for this analysis.

TABLE 1
DEGREES OF FREEDOM OF PREDICTOR VARIABLES
(VALUES < 0.05 INDICATE SOME CONDITIONAL DEPENDENCE)

Predictive variables	SG	L	LU	FD	E	EI	SA
SND	0,92	0,64	0,91	0,19	0,77	0,98	0,77
SG		0,82	0,53	0,92	0,98	0,99	0,86
L			0,62	0,85	0,91	0,85	0,98
LU				0,88	0,73	0,82	0,71
FD					0,98	0,59	0,94
E						0,81	0,99
EI							0,93

This result is confirmed by the significance level of χ^2 (Table 2) because larger than 0.15 for the score of χ^2 for the entering the model and larger than 0.05 for the Wald χ^2 for predictor variables to stay. The obtained values of Cramer's V (Table 2) agree also with the results computed by statistical χ^2 test and the degrees of freedom. The Cramer's V showed that the eight predictor variables are highly independent and could be included in the LR model to explain the dependent variable (MM).

Multicollinearity in logistic regression models is a result of strong correlations between independent variables. The collinearity diagnostic statistics are based on the independent variables only, so the choice of the dependent variable does not matter. Tolerance (*TOL*) and Variance Inflation Factor (*VIF*) for each variable are two powerful indexes for multicollinearity diagnostics. Table 2 shows that all the *TOL* values are larger than 1 and all the VIF values are larger than 2. According to [38], [39], the eight predictor variables constitute a good association whiches are highly independent and does not present no multicollinearity problems. For this reason they were integrated in the LR analysis of this study.

TABLE 2
VALUES OF CHI-SQUARE (χ^2), CRAMER'S V, TOLERANCE (*TOL*), VARIANCE INFLATION FACTOR (*VIF*) AND THE REGRESSION COEFFICIENTS OBTAINED FOR THE EIGHT INDEPENDENT PARAMETERS.

Independent variables	*chi-square (χ^2)*	*Cramer's V*	*TOL*	*VIF*	*LR Coefficient*
SND	103.4	0.09	0.73	1.36	- 0.296996
SG	75.1	0.14	0.88	1.13	- 0.239006
L	86.4	0.27	0.86	1.15	- 0.250024
LU	39.7	0.11	0.89	1.11	0.066340
FD	129.3	0.17	0.69	1.43	0.070000
E	33.8	0.03	0.95	1.04	0.755425
EI	83.6	0.24	0.86	1.15	2.096614
SA	114.5	0.05	0.96	1.03	- 0.222634

5.3 Implementation of Logistic Regression Model

For the implementation of the logistic regression model, ArcSDM application implemented in the ArcGis 10 program was used for the evaluation of the the spatial relationship between MM occurrence and MM influencing parameters. The statistical results (LR coefficients) of the model are summarized in Table 2. They show two types of correlation; one is positive coefficients such as land use and the second is negative coefficients such as slope aspect. Then, to produce a MM susceptibility map of the Zoumi area (Figure 7) the LR equation was applied as shown in Eq. 6.

$$\begin{aligned}(6): y = &-29 + (-0.296996*\mathrm{SND}) + (-0.239006*\mathrm{SG})\\ &+ (-0.250024*\mathrm{L}) + (0.066340*\mathrm{LU})\\ &+ (0.070000*\mathrm{F}) + (0.755425*\mathrm{E})\\ &+ (2.096614*\mathrm{EI}) + (-0.222634*\mathrm{SA})\end{aligned}$$

The obtained susceptibility map (Figure 7) is classified in different categories from low, moderate, high and very high. It reveals that 17,46% of the study area was identied as very high susceptibility. High susceptibility, moderate and low susceptibility zones covered 27,30 %, 37,93 %, and 17,61 % of the area, respectively. Most of the very high and high susceptibility zones are primarily located in the areas presenting a very high

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and high density of stream network and fracturing, have moderately steep terrains with agricultural areas.

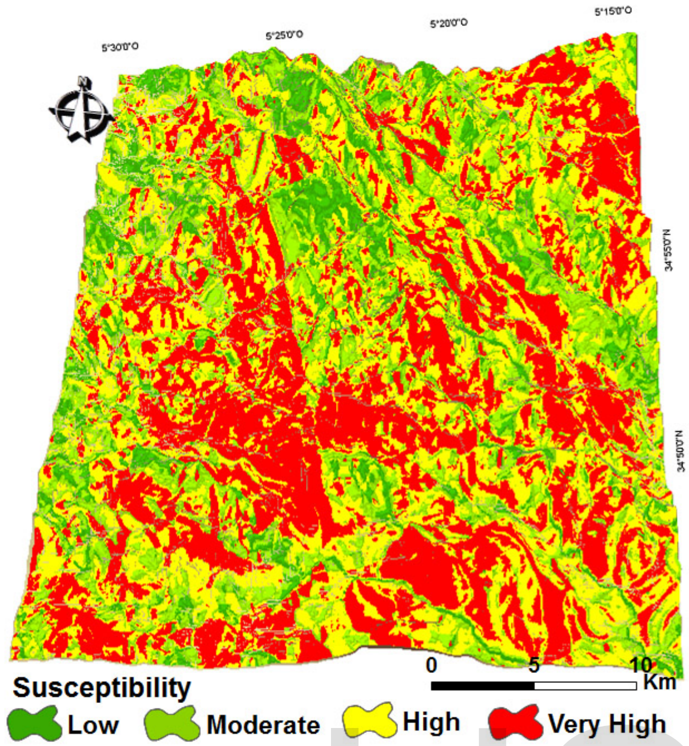

Fig. 7.MM susceptibility map generated using logistic regression coefficients. Susceptibility was ranked into four classes: low, moderate, high and very high.

In literature, there are different validation methods. In this study, in order to validate the susceptibility map, we compared the cumulitave percentages of known MM location with the percentag of each susceptibilty class of the produced mass movements susceptibility map, according to [4]. Figure 8 shows the percentage of the study area ranked from most to least susceptible (x-axis) against the cumulative percentage of landslide area in each susceptibility class (y-axis). The most susceptible (very high class) 17.46% of the study area covers 24.54% of the mass movements area, and the most susceptible (high class) 27.30% of the study area covers 39.35% of the total mapped mass movements. The least susceptible (moderate class), and the least susceptible (low class) presents 37.93 %, and 17.61 % of the area. It covers respectively, 21.28 % and 14.81 of the total mapped mass movements. Figure 8 also provides a quantitative measure of the ability of the susceptibility model to match the known distribution of mass movements in the Zoumi area. These results and the applied LR model appeared to be reliable in as much as the model best corresponded to the actual ground truth in the study area.

6 Conclusion and Discussion

The Zoumi area (610 Km²) situated in the central Rif orogen (North-West of Morocco) is moderately mountainous and located in the South of the Jebha fault zone. This region and its surrounded areas are frequently subjected to mass movements. In the last three decades, natural hazards and especially mass movements have received considerable attention from Moroccan government (charte de l'environnement) and research institutions to be prevented. Although several different quantitative methods and techniques were used and several efforts have been made in the previous years to preventing MM in the Rif, but the number of movements doesn't stop from increasing and giving prejudice in areas supposedly already studied (low or null susceptibility).

This paper applied a qualitative model (LR) within the framework of a GIS using ArcGIS 10 for MM susceptibility mapping in five steps:

- 1° MM (dependent variable) mapping, where a detailed MM inventory map of the study area was constructed from satellite images, aerial orthophotographs, geomorphological maps and extensive field studies. According to the classification done by [18], we classified our mass movements into four categories: rock falls, landslides, debris flow and creeps. Thiers properties were recorded on a standard MM inventory data sheet (shap file). Then, a vector-to-raster conversion was performed to provide a raster layer of the MM areas.
- 2° influencing factors (independent variables) where lithology, fracturing density, slope angle, slope aspect, elevation, stream network density, earthquakes isodepths, and land use were assessed and considered as main parameters controlling the occurrence of MM. Then, the quantitative relationship between dependent and independent variables was achieved by analyzing the spatial distribution of mass movements for each causal factor.
- 3° tests of causal factors association, where the best combination of predictor variables was identified calculating, *Degrees of freedom (a)*, *Chi-Square* (χ^2), *Cramer's V*, *Tolerance (TOL)* and *Variance Inflation Factor (VIF)*. They showed that the eight predictor variables described in this study are highly independent and could be included in the LR model to explain the dependent variable (Mass movements).
- 4° model application, where the regression coefficients of each causal parameter are iteratively calculated.
- 5° susceptibility map validation, where the degree of the applied LR model fit was evaluated by calculating the cumulative percentage of MM area in each susceptibility class, accompanied by expert judgment. The obtained results of this paragraph reveal the applied LR model appeared to be reliable in as much as the model best corresponded to the actual ground truth in the study area.

Mass movements susceptibility assessment is a major step forward in hazard management and can help engineers, contractors; landuse planners, etc. Ranking the slope stability of the study area in categories that range from stable to unstable, it shows where mass movements may occur. For this reason, the produced susceptibility map this research paper can be used for planning protective and mitigation measures by the local and regional authorities. Especially, in the orientation and the choice of implementations in development sites, in urban extensions, as well as in the setting up of new roads and highways in the frame of the National Development Program of provinces in Northern Morocco. Nevertheless, the LR model used in this study may also be applicable to other mass movements prone areas with similar conditions and at various scales, using the same association of predictive variables, to define its reproducibility and the associated uncertainty of predictions.

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References

[1] Varnes D.J., - "Landslide Hazard Zonation, a review of principles and practice" *IAEG Commission on Landslides. UNESCO, Paris*, 63p, 1984.

[2] Thiery Y., "Landslide susceptibility in the Barcelonnette basin (French South Alps): morphodynamic cartography, spatial analysis and probabilistic modelling"PhD Thesis, Caen/basse-Normandie university, Frence, 445p, 2007.

[3] Varnes D.J., "The logic of geological maps, with reference to their interpretation and use for engineering purposes". *U.S. Geological Survey Professional Paper* 837, 48 p, 1974.

[4] Guzzetti F., Carrara A., Cardinali M., Reichenbach P., "Landslidehazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy"*Geomorphology* 31, 181–216p, 1999.

[5] Hansen A., "Landslide hazard analysis. In: Brunsden, D. and Prior, D.B"(eds.) Slope instability, *Wiley & Sons*, New York, 523-602p, 1984.

[6] Rowbotham D., Dudycha D-N., "GIS modelling of slope stability in Phewa Tal watershed, Nepal" *Geomorphology*, 26: 151-170p, 1998.

[7] Dai F.C., Lee C.F., "Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong" *Geomorphology*, 42, 213–228p, 2002..

[8] Agnesi V., Conoscenti C., Di Maggio C., Iudicello C., Rotigliano E., "Landslide hazard analysis in the Giardo River Basin (Middle-Western Sicily) ". Proceedings of the Workshop on Geomorphological sensitivity and system response. Università di Camerino - Università di Modena, Camerino, Italy, 3–11p, 2003.

[9] Van Westen C-J., Castellanos Abella E.A., and Sekhar L.K- "Spatial data for landslide susceptibility, hazards and vulnerability assessment: an overview" Engineering *geology*, 102 (2008)3-4, 112-131p, 2008.

[10] Fares A., "Essai méthodologique de la cartographie des risques naturels liés aux mouvements de terrain. Application à l'aménagement de la ville de Taoimate (Rif, Maroc) ". Thèse Doctorat. Université de Franche Comté. 177 p, 1994.

[11] Margaa Kh., "Essai de cartographie des risqué naturels: application à l'aménagement de la region d'Al Hoceïma (Rif, Nord-Maroc) " Thèse Doctorat. Université de Franche-Compté, 196p, 1994.

[12] El Kharim Y., "Etude des mouvements de versants dans ta région de Tétouan (Rif occidental): lmentaire, analyse et cartographie" Thèse de Doctorat Es-Sciences, Université Abdelmalek Essaadi, Tétouan. Maroc, 250 p, 2002.

[13] Sossey Alaoui F., "Traitement et intégration des données satellitaires optiques et Radar dans un SIG en vue de l'obtention de carte de l'aléa lié aux instabilités de terrain dans la péninsule de Tanger (Rif septentrional, Maroc). Doctorat, Université Mohamed V, Faculté des Sciences, Rabat. 175p, 2005.

[14] Ardizzone F., Cardinali M., Carrara A., Guzzetti F., Reichenbach P., "Uncertainty and errors in landslide mapping and landslide hazard assessment" *Natural Hazards and Earth System Sciences*, 2:1-2, 3-14p, 2002.

[15] Chalouan M., "Les Nappes Ghomarides (Rif septentrional, Maroc), un terrain varisque dans la chaîne alpine" Thèse de doctorat d'état, Université Louis Pasteur, Strasbourg, 317p, 1986

[16] Lespinasse, P., "Géologie des zones externes et des flyschs entre Chaouen et Zumi (Centre des la chaîne rifaine. Maroc) " Thèse Sc. Université de Paris VI. France,248p, 1975.

[17] Millies-Lacroix A., "Les glissements de terrains. Présentation d'une carte prévisionnelle des mouvements de masse dans le Rif (Maroc septentrional) " *Mines et Géologie*, n° 27, 45-55p, 1968.

[18] Selby M.J., "Hillslope Materials and Processes" 2nd Edition, Oxford University Press, 451 p,1993.

[19] Sharpe C.F.S., "Landslides and related phenomena: A study of mass movements of soil and rock" *Columbia University Press*, New York, 137p, 1938.

[20] Varnes D.J., "Landslide types and processes". In Eckel, E. B. (Editor), Landslides and Engineering Practice, Special Report 28: Highway Research Board, National Academy of Sciences, Washington, DC, 20-47p, 1954.

[21] Nemčok A., Paše, J., Rybář J., "Classification of landslides and other mass movements" *Rock Mechanics*, 4: 71-78p, 1972.

[22] Hutchinson J.N., "General report: Morphological and geotechnical parameters of landslides in relation to geology and hydrology" Proceedings 5th International Symposium on Landslides, Lausanne, 1: 3-35p, 1988.

[23] Sassa K., "Geotechnical classification of landslides". *Landslide News, Japan Landslide Society*, No. 3, 21–24p, 1989.

[24] Van Westen, C-J., Van Duren, I., Kruse, H-M-G., Terlien, M.T.J., 1993. GISSIZ: training package for geographic information systems in slope instability zonation. ITC Publication number 15, 2 volumes, ITC, Enschede, The Netherlands.

[25] Hewitt K., "Geomorphic hazards in mountain environments" In Owens, P. and Slaymaker, O. (eds) Mountain Geomorphology, Hodder Scientific, London, chapter 9, 187-218p, 2004.

[26] Mastere M., Van Vliet Lanoe B., Ait Brahim, L., Land use mapping and its relation to mass wasting and gullying in North-Western Rif (Morocco). *Geomorphology: relief, process and environment*. V3, 335-352p, 2013.

[27] Mastere M. Mass movements susceptibility in the Chefchaouen province (central Rif, Morocco): spatial analysis, multi-scale probabilistic modeling and impact on development and planning. PhD thesis, University of Western Brittany,316p, 2011 .

[28] Keefer D-K., "Landslides caused by earthquakes" *Geol. Soc. Am. Bull*, 95, 406–421p, 1984.

[29] Keefer D-K., "Investigating landslides caused by earthquakes, a historical review" *Surveys in Geophysics*, 23 (6), 473–510p, 2002.

ISSN 2229-5518
[30] Papadopoulos G-A., Plessa A., "Magnitude–distance relations for earthquake-induced landslides in Greece". *Engineer Geology* 58, 377–386p, 2000.

[31] Mastere M., Van Vliet Lanoe B., Mansour, M., Ait Brahim, L., The Jbel Akroud debris flow analysis using digital photogrammetry and DEM. *Télédétection* , 10, 147-156p, 2011.

[32] Lee S., Sambath T., "Landslide susceptibility mapping in the Damrei Romel area, Cambodia using frequency ratio and logistic regression models" *Environ. Geol*. 50, 847–855p, 2006.

[33] Song R-H., Hiromu D., Kazutoki A., Usio K., Sumio M., "Modeling the potential distribution of shallow-seated landslides using the weights of evidence method and a logistic regression model: a case study of the Sabae Area, Japan" *International Journal of Sediment Research*, 23, 106-118p, 2008.

[34] Das I., Sahoo S., Van Westen C., Stein A., Hack R., "Landslide susceptibility assessment using logistic regression and its comparison with a rock mass classification system, along a road section in the northern Himalayas (India) " *Geomorphology*, 114, 627-637p, 2010.

[35] Kendall M., Stuart A., "The advanced theory of statistics. Volume 2. Inference and relationship (4e édition). New York: Macmillan, 1979.

[36] Van Den Eeckhaut M., Vanwalleghem T., Poesen J., Govers G., Verstraeten G., Vandekerckhove L., "Prediction of landslide susceptibility using rare events logistic regression: A case-study in the Flemish Ardennes (Belgium) " *Geomorphology*, 76, 392–410p, 2006.

[37] Bai S.B., Wang J., Lü G.N., Zhou P.G., Hou S.S., Xu S.N., "GIS-based logistic regression for landslide susceptibility mapping of the Zhongxian segment in the Three Gorges area, China" *Geomorphology*, 115, 23-31p, 2010.

[38] Menard S.W., "Applied Logistic Regression Analysis" SAGE Publication, Inc., Thousand Oaks, CA, 1995.

[39] Allison P.D., "Logistic Regression Using the SAS System: Theory and Application" *Wiley Interscience*, New York. 288p, 2001.