Landslide Susceptibility Assessment by Weights of Evidence (WOE) in the BENI AHMED Area (RIF, MOROCCO)

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Abstract
The aim of this study is to replace landslides in the specific geodynamic context of the central Rif. We adopted a multisource approach that includs remote sensing data, geology, geotechnical characteristic, landform and climatology. Then, we elaborated a database in a GIS on the permanent and triggering parameters (slope, lithology, fracturing, hydrographical network, land use….
Weights-of-evidence (WOE) is a quantitative 'data driven' method used to combine datasets uses the log–linear form of the Bayesian probability model to estimate the relative importance of evidence by statistical means, This method has been carried out at Beni Ahmed maps at 1:50000 scale. LandSat+ image has been used to map landslides occurred in the study area, to produce Land use map and to improve the faults coverage extracted initially from geological maps. The derived data were integrated to a GIS with others parameters, derived form geological maps (lithological, thickness), topographical maps (slope gradient, aspect, hydrological network), and thematic maps.
An identification and inventory of more than 350 mass movements of large scale covering our study area, the most abundant type, number and area occupied, is represented by landslides (36%) over an area of 46.269 Km2.

The obtained results are confronted with the reality of the land (map of landslides that we have done) to adapt the model to the specificities of the study area.

Introduction
Due to its special geographical position, the Rif's chain is the northernmost part of Morocco; it is characterized by complex geological terrain, morphology in steep terrain, dense precipitation.
The combination of factors pedo-geological, climatic, topographical and anthropogenic made the Rif area undoubtedly the most exposed to natural phenomena such as landslides. The effects of these phenomena are especially important when they affect areas inhabited more or less vulnerable (depending on the number of people, housing, infrastructure and economic activities).
The BeniAhmed region is part of the Rif; it presents several signs of instability. While some areas remain relatively stable, others are subject to factors of instability or a shift asset.

The landslides cover a wide variety of natural phenomena. All shares a destabilized displacement of materials. These complex phenomena can be point, superficial, limited in space and time but also rapid and widespread affecting then slopes intact (Flageollet 1989, Yannick Thiery, 2007). They may be active, latent, inactive, or potential. Some may present a danger to human lives and are responsible for damages large and costly (Maquaire, 2002; Yannick Thiery, 2007).

Indeed, Morocco, the mapping of natural hazards has started for the first time in the sixties by Avenard (1965) who mapped erosion in the basin of Sebu. In 1968, Millies-Lacroix sets for all the Rif card predictive of landslides in 1/1000000ème (Sossey Alaoui, 2005). Insofar as it is often difficult to quantify a level of hazard, frequently, only the susceptibility to instability field is analyzed.

Susceptibility expresses the probability that a spatial type of phenomenon occurs in an area for different local environmental conditions. This assumes that all phenomena are identified and classified, and they recur in the same geological, geomorphological, hydrological and climatic phenomena known.

The evaluation of the susceptibility involves three steps (Varni, 1984; Carrara and al. 1995; Soeters and van Westen, 1996; Leroi, 1996; van Westen, 2001; van Westen and al., 2003; van Westen and al. 2006; Yannick Thiery, 2007) : (a) The inventory phenomena of landslides where each phenomenon is distinguished by its type, (b) The parameter mapping field the most significant (factors predisposition) for the case of spatial phenomena and their analysis, (c) The definition of relative weights to each factor blamed for the localization of landslides.

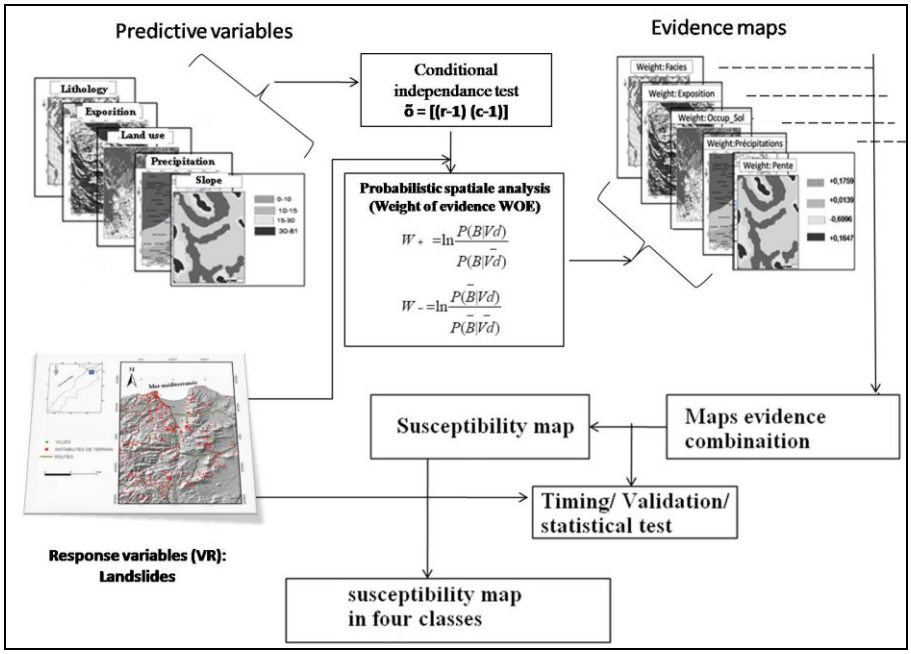

Figure 1: methodological approach advocated (evidence theory)

The definition of these weights reflects the spatial relationship between the landslides and predisposing factors and is defined by various methods.

The techniques of spatial analysis by GIS are increasingly used to assess susceptibility to landslides. One of these methods is weight of evidence theory (Bonham-Carter, 1994, Van Westen and al., 2003, Yannick Thiery, 2006). However, the main drawback of this technique is the problem of information redundancy between predictive factors.

This work aims the following objectives: (a) diagnosis of landslides occurred in the study area through their inventories, their maps and their characterizations, (b) the design of a GIS database in ArcGIS 9.2 has causative factors of the four types of landslides, (c) Evaluation of

conditional independence of these factors (d) the production of the map of susceptibility to landslides through a bivariate probabilistic model based on the Bayes theorem (theory of evidence).

Geomorphological setting

The study area is located in the north of Morocco (figure2), it is highly affected by landslide hazards. The hypsometric prints in the region an important character mountainous, it is marked by the collection of valleys, steep slopes and rock faces fallout in clumps, Characterized by a mountain climate with a Mediterranean influence. The topography is hilly, which makes isolation and difficult access. This mountainous region characterized by wet altitudes relatively low, not exceeding 700 m and rises gradually up to 1700 m north of the region, specifically in Jebel Taria. The morphology shows peaks with approximately the same altitude 700m, separated by basins elongated towards the NE.

Methodology and strategy: Weight of evidence (WOE)

Figure 1 presents the methodology used and data entry. The data preparation, archiving and simulations were performed in ArcGIS 9.2 GIS environment. An indirect approach based on statistical models of spatial analysis was used to quantify the susceptibility. The susceptibility is defined as a space probability of landsliade occurs in an area for different local environmental conditions (Oliver and al Maquaire., 2006). The susceptibility has been simulated by a model based on the theory of evidence.

Weight of evidence is a quantitative 'data-driven' method used to combine datasets. The method uses the log-linear form of the Bayesian probability model to estimate the relative importance of evidence by statistical means. This method was first applied to landslide susceptibility mapping by (Van Westen, 1993; Van Westen and al.,2003; Suzen and Doyurn, 2004, Yannik Theiry and al., 2007). Prior probabilities (PriorP) and posterior probabilities (PostP) are the most important concepts in the Bayesian approach. PriorP is the probability that a TU (terrain unit) contains the RV (response variable) before taking PVs (predictive variables) into account, and its estimation is based on the RV density for the study area. This initial estimate can be modified by the introduction of other evidences. PostP is then estimated according to the RV density for each class of the PV. The model is based on the calculation of positive W+ and negative W− weights, whose magnitude depends on the observed association between the RV and the PV.

$$W^{+} = \ln \frac{P(B|\mathrm{RV})}{P\left(B|\overline{\mathrm{RV}}\right)} \quad (1) \qquad W^{-} = \ln \frac{P\left(\overline{B}|\mathrm{RV}\right)}{P\left(\overline{B}|\overline{\mathrm{RV}}\right)} \quad (2)$$

In Eqs. (1) and (2), B is a class of the PV and the overbar sign '¯' represents the absence of the class and/or RV. The ratio of the probability of RV presence to that of RV absence is called odds (Bonham-Carter, 1994). The WOE for all PVs is combined using the natural logarithm of the odds (logit), in order to estimate the conditional probability of landslide occurrence. When several PVs are combined, areas with high or low weights correspond to high or low probabilities of presence of the RV.

Mapping of susceptibility occurs in several steps, the first corresponds to the statistical analysis of the landslides observed (identification and inventory of landslides), the second step is the characterization and identification of factors affecting (parameters predisposition) lithology, fracturing, slope, precipitation, etc.. The third is the evaluation of the conditional independence of predictive variables. The fourth is the application of the bivariate approach by theory of evidence.

Results

Different weights can be summed calculated using the natural logarithm of odds called logit. In this case the contrast C (C = W + - W-) gives a measure of spatial association between the predictors and landslides (Yannick Thiery and al.2005). This contrast has a value of zero when these two variables are completely independent. The contrast value gives a first overview to accept or reject a predictor in estimating the spatial correlation between this and the landslides. Calculations of values of W + and W-for all selected variables used to calculate the posterior probability, which updates the prior probability. When multiple predictors are combined, areas that have a weight higher or lower respectively correspond to a greater or smaller probability of finding the landslides.

This statistical model is introduced in the ArcGIS 9.2 through the ArcSDM extension (Kemp and al., 2001). The model calculates the prior probabilities, posterior probabilities and hypothesis testing type X2. The procedure to determine the best combination is made add one to one every predictor.

The maps show a good agreement with the landslide inventory map. The surfaces of high, moderate, low and null susceptibility are 12 Km2, 257 Km2, 330 Km2, and 26 Km2, something that is quite understandable given the extent occupied by these sites. This leads us to propose to incorporate other factors namely hydrographical networks, seismicity and the anthropic factor in its various aspects (construction of roads, quarrying, earthworks, etc.).

The analysis of the susceptibility map developed (Fig. 2) shows that the high susceptibility (Strong possibility of triggering landslides) is largely concentrated in northern and west parts of the study area where local environmental conditions are very favourable to the trigging (combination of a slope gradient> 25 °, Relief delivered, strong fracturing, extremely degraded soils or dissected, the absence of forest and vegetation or poorly maintained).

Conclusion

Mush of the landslide susceptibility work is based on the assumption that “the past is key to the future”, and that historical landslides and their causal relationships can be used to predict future ones. As soon as there are changes in the causal factors (e.g. a road with steep cuts is constructed in a slope which was considered as low susceptibility before) (van westen and al., 2008).

This study has demonstrated the necessity of using specific procedures for landslide susceptibility assessment by bivaraite methods, especially at 1 :50 000 scale in the Morocco Rif zone . The thematic maps introduced in the model represent slope gradient, lithology, land use, precipitation, fracturing.

The susceptibility maps describe the conditional probability of future landslide occurrences, which depends on the values of unstable landform densities, it proves to be best suited to guide choices in implementation of development sites, the level of urban extensions, and that at the layout of new roads and highways in the national development program in the Northern provinces.

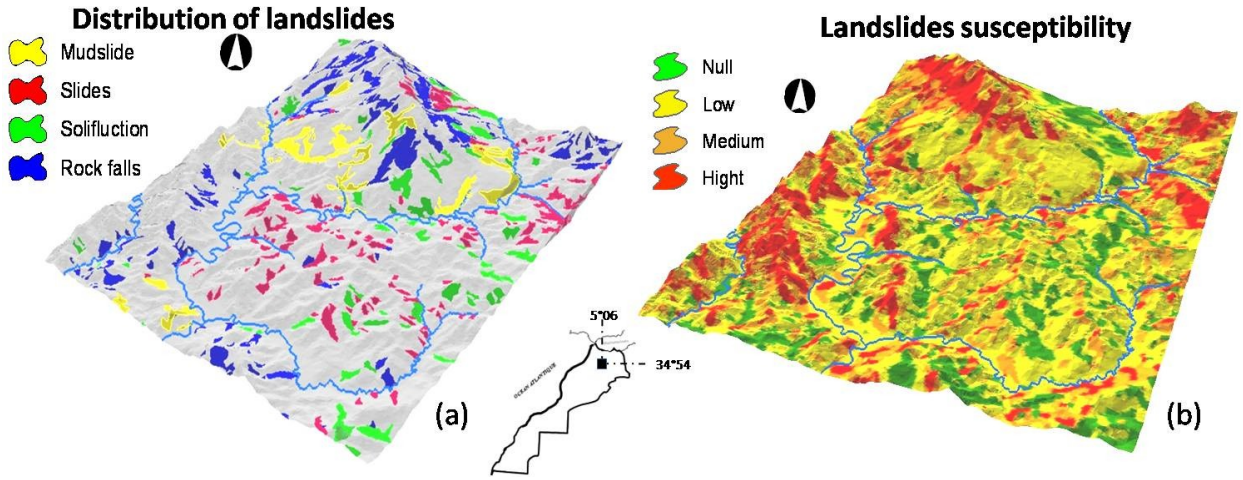

Figure 2: (a) Distribution of landslides inventory; (b) susceptibility map produced with the weight of evidence model

The maps are developed documents to assist decision making for any development plan in Beni Ahmed area (urban sprawl, villages, roads, bridges, factories...).

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