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Landslide hazard zonation assessment using GIS analysis at the coastal area of Safi (Morocco)

F. El Bchari [a, *], B. Theilen-Willige [b], H. Ait Malek [a]

[a] *Department of Earth Science, Polydisciplinary Faculty- University of Cadi Ayyad, Safi, Morocco, elbchari@yahoo.fr*
[b] *Institute of Applied Geosciences, Technical University Berlin, Germany*

* Corresponding author

Abstract: Landslide hazard is one of the major environmental hazards in the coastal area. For helping the planners in selection of suitable locations to implement development projects, a landslide hazard zonation map has been produced for the coastal area of Safi (Morocco) as part of coastal Meseta . For this purpose, after preparation of a landslide inventory of the study area, some major parameters were examined for integrated analysis of landslide hazard in the region. The analyses of parameters were done by geo-referencing and lateral model making, satellite imaging of the study area, and spatial analyses by using geographical information system (GIS). The produced factor maps were weighted with analytic hierarchy process (AHP) method and then classified. The study area was classified into four classes of relative landslide hazards: negligible, low, moderate, and high. The final produced map for landslide hazard zonation in coastal area revealed that: the parameters of slope, geologic formation and fracturation have strong correlation and predict 75% of existing instabilities.

Keywords: landslide hazard zonation map, geographical information system (GIS), analytic hierarchy process (AHP), Coastal area, Safi, Morocco

1. Introduction

Landslide are belonging to the most damaging natural hazards. Preventing damage requires a reliable predictive inventory of the dynamic processes and the implementation of risk maps, necessary as base for any development. It is essential to define the factors and mechanisms that cause the movements in order to contribute to a better approach for the detection of the phenomena of instability and to risk assessment.

The assessments of landslide hazard and susceptibility are the relative spatial probability of a new landslide occurring in the future (Remondo et al., 2003), and their assessment in a given area should normally be based on the analysis of instability factors. Using geographical information system (GIS) analysis provides a powerful tool to model the landslide hazards for their spatial analysis and prediction (Dai et al., 2002; Cevik and Topal, 2003; Ayalew and Yamagishi, 2005; and Fall et al., 2006). Thus, it is necessary to look at the conditions under which landslide have occurred in the past, and to use the critical combinations of preparatory factors for delineating the possible occurrence of further landslides. The most common natural triggering factors are intense rainstorms, prolonged periods of wet weather, or seismic activities. Stronger earthquakes could be a triggering factor as well as long-term, neotectonic movements.

Several algorithms and models have been proposed for generating the Landslide Susceptibility that mainly include Analytical Hierarchy Process (AHP) (Saaty, 1980; Saaty and Vargas, 2001),logistic regression(Carrara et al.,1983),fuzzy-logic(Gee et al., 1991),artificial neural network analysis (Ermini et al. 2005; Regmi et al. 2010; Ruff and Rohn 2008, Canani et al ,2008). modeling approaches(Perriello Zampelli et al ,2012) , Fuzzy Analytical Hierarchy Process (FAHP) (Shadman Roodposhti et al., 2010), Geographically weighted principal component analysis (Faraji Sabokbar et al., 2014), GIS matrix method (GMM) (Irigaray1995; Irigaray et al. 1999, 2007; Clerici et al. 2002; Jiménez-Perálvarez et al. 2009; Jiménez-Perálvarez 2012 etc, that most of which are related to the weight of landslide factors. Above studies demonstrate that many techniques have been used for landslide susceptibility mapping and have achieved excellent results. One of these methods is the AHP that was used.

AHP gives a proven, effective means to deal with complex decision making and can assist with identifying and weighting selection criteria, analyzing the data collected for the criteria and expediting the decision-making process. AHP has been shown to be the best method of eliciting and using multi criteria preference relationships in a range of applications. The AHP is based on a matrix of pair wise comparisons between criteria, and it can be used to evaluate the relative performance of decision alternatives (for example products and services) with respect to the relevant criteria. The AHP was seen to be a suitable tool for the purpose here, as it is a method that is particularly suited to decisions made with limited information (Saatyet al. 2001).

AHP allow some small inconsistency in judgment because human is not always consistent.

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In this paper, AHP (Saaty, 1980; Saaty and Vargas, 2001) was adopted to establish landslide susceptibility maps.

The AHP method is used to determine the weights of various themes for identifying the landslide area based on weights assignment and normalization with respect to the relative contribution of the different themes to landslide occurrence for classified into four categories low, medium, high and very high potential zone identify through integration of various thematic maps with GIS techniques (Jhariya et al , 2016). The weights of each factor were computed statistically using multi-influencing factor technique followed by heuristic approaches driven method for assigning ranks to each sub-classes of factor maps at resulted for AHP model. In this context, multi-criteria decision making (MCDM) is rather a simple, effective and reliable technique for AHP process for the identification of landslide hazards areas.

A multi parametric data set comprising remote sensing data and conventional maps at the caterious wise all five different thematic layers were integrated with weighted overlay in GIS. For analysis result to different of thematic layers, namely, geomorphology, geology, soil type, slope, and land use/land cover, are prepared using satellite imageries, topographic maps, and secondary data set, and integrated with weighted overlay in GIS to generated landslide zonation map.

2. Materials and Methods

2.1 Study area

The study area is located in the coastal area of Moroccan atlantic ocean (Figure1). It covers an area of about 4110 Km2 between longitudes 09°20′W and 08°51′E, and latitudes 32°24′N and 32°68′N. The geomorphology of the studied area is characterized by the abundance of consolidated sand- stone of a Plio-Quaternary age, forming the dune reliefs parallel to the ocean, with a SSW-NNE orientation

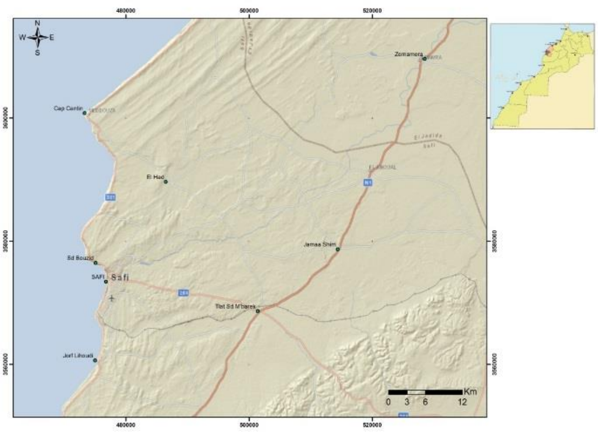

Figure 1: Location of study area

The atlantic moroccan coast of safi is characterized by longest (60 Km) and high live cliffs. They are developped in the mesozoic layers, made up of alternate beds of clay, marls and limestones wich give different sections vertical in parts only. The processes of evolution of the cliffs as a consequence of landslides are now active and dangerous.

The altitude varies from 500 to 50 m, and it decreases from the southeast to the northwest. The study area has a semi-arid climate with mean annual precipitation of 325 mm and mean annual temperature of 22°C. The rainiest month is November and the driest month is August.

This area belongs to the mesetian domain characterized by Meso-Cenozoic tabular formations deposited on the Paleozoic basement (Roch 1950; Gigout 1951; Michard 1976; Saaidi 1988; Witam 1988; Ouadia 1998).

The encountered geological formations are the Evaporitic Complex and Yellow Dolomite (Upper Jurassic), Lower Limstone (Late Berriasian), Brown Clay (basal Valanginian), Dridrat Limestone (Hauterivian), The "red sandy clay beds" of the Upper Hauterivian and clastic and Shelly limestone (Plio-Quaternary); (Figure 2). These geological formations are the most sensitive to landslide. However, the formation most susceptible to sliding is Brown Clay localized in the north coastal cliffs.

The tectonic structure is essentially tertiary in age, characterized by two main directions of folds: NS and SW-NE to EW, inherited respectively from Hercynian and Alpine orogeny (Ferré and Ruhard 1975). These tectonic directions guide and control the development of landslide structures

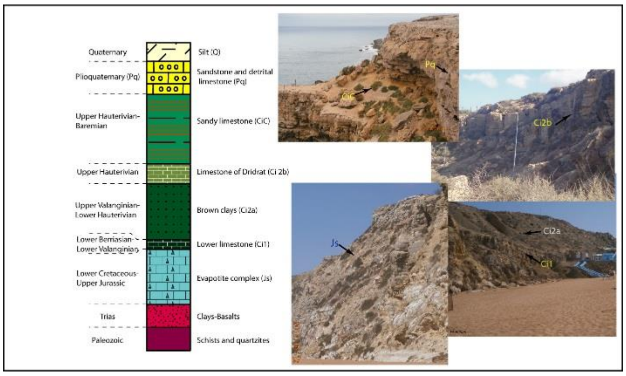

Figure 2: Geological setting of Safi region

2.2 Data

The occurrence of landslides is a function of direct and indirect natural and human factors.

In this study, a spatial database considering landslide-related factors (Figure 3) based on extensive field work and previous inventory maps, such as topography, geology, and land cover, was used. Land cover was detected from satellite images such as TM images. The landslide map is in the form of point coverage, the topographic map in the form of line and point coverage at a scale of 1:50,000, the geological map in the form of polygon coverage at a scale of 1:50,000. Eight factors, extracted from the constructed spatial database, were considered when calculating the probability.

The slope, aspect, were obtained from the Digital Elevation Model (DEM). The distance from stream and road was calculated using the topographic map. A lithology and fault map of the study area is digitized from the existing geology map at the scale of 1:200,000. A fracturation map was extracted from Landsat TM image using filter processing. Finally, land cover data was classified from a LANDSAT TM image using the supervised (maximum likelihood) classification method

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The precipitation is also one of major parameters because Most of the landslides occur after heavy rainfall; so that water infiltrates rapidly upon heavy rainfall and increases the degree of saturation and potential of landslide occurrence [Pourghasemi et al., 2009].

The main factors affect the susceptibility mappings are: landslide inventory, precipitation, lithology-geology, aspect, slope, land cover, distance to stream, and distance to road (Figure 3).

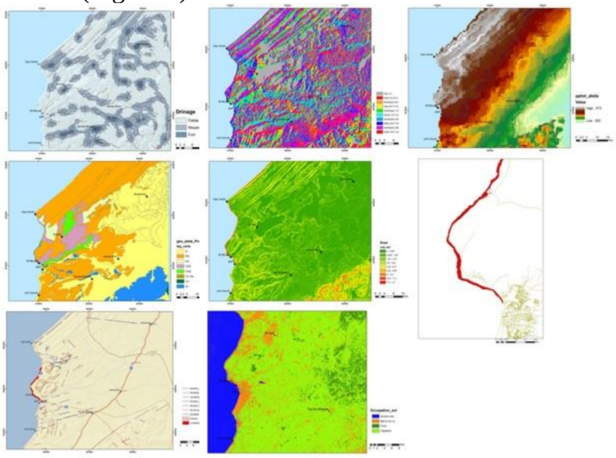

Figure 3 : Example of imput Data

2.2.1. *Landslide inventory*

It is very important to determine the location and area of the landslide correctly when preparing the landslide susceptibility maps. Landslide inventory is an essential part and basic information for any landslide zoning such as susceptibility, risk and hazard zonings. It involves the location, classification, volume, travel distance, state of activity and date of occurrence of land sliding in an area (Fell et al. 2008a) There are different methods to identify landslides. They include aerial photos, satellite images, literature survey for historical landslide records and field observations (Figure 4).

Figure 4; Example of Landslide of the study area

The landslide inventory was determined from field records and visual interpretation of aerial photographs and satellite images. In this study, the field record has been used to determine 170 landslides.

The majority of landslides identified in this region have been occurred in cliffs banks and roads. The landslides in cliffs are often due to loss of land cover, steep slope topographic, and erosions. Road construction has been caused of many landslides in this region as well.

2.2.2. *Lithology-geology*

The main source of data related to the geomorphology of an area of land is determined by the lithology properties of that land (Dai et al. 2001). The landslide phenomenon, a part of the geologic studies and research, is related to the lithology and weathering properties of the material of the land (Yalcin, 2008). In the most of recent studies, such as references (Ayalew et Yamagishi, 2005) and (Yalcin, 2008), this parameter has been considered as the most important factor in landslide susceptibility mapping.

The most important formations in this region having high potential for occurring landslide are Brown Clays (Ci2a). These formations are commonly composed of marl and clay rocks.

Marl has high cohesion and is very sensitive in neighborhood of water. In these formations, landslide occurs when water infiltrates in internal layers and external layers are exposed to weathering. In this region, the rocks are exposed to physical and chemical factors. in order to consider the effect of lithology and geology, this region has been divided into 7 parts.

2.2.3. *Slope*

The slope is one of the main parameters in the slope stability analysis. The slope angle directly affects landslide; thus it is used in preparing landslide susceptibility maps (Pant, M., 1992, Lee et al., 2004a, Lee, 2005, Saha et al., 2002).

In some of the recent studies, such as by Yao et al. 2008 and Nandi et Shakoor 2009, this parameter has been considered as the most important factors in landslide susceptibility mapping. For preparing landslide susceptibility map, the slope map was divided into nine slope categories (See Table. 2). According to the landslide inventory map, most landslides had occurred in 17-31 degree of slope ranges.

2.2.4. *Aspect*

Despite the fact that some authors mentioned that aspect has no significant influence on land sliding, several researchers have reported a relationship between slope orientation and landslide occurrence (DeGraff et al., 1980, Marston et al. 1998). Aspect-related parameters such as exposure to sunlight, drying winds, rainfall (wetness or degree of saturation) and discontinuities may control the occurrence of landslides. In this study slope aspect is divided every 45°. Thus there are 8 intervals

2.2.5. *Land cover*

Land use/land cover are also key factors responsible for landslide occurrences.

Generally, land cover has effect on strength of slope materials against sliding and control of water content of slope. In addition, plant roots reinforce the slope and normally are considered as reinforcements. Land cover absorbs the water of soil and decreases the potential of landslide. This is an important issue in marl soils. In studies performed by Komac 2006 and Leventhal et Pant, 1992, this parameter has been considered as one of the most important factors in preparing landslide susceptibility maps. Land cover is determined from satellite images and field investigations. In this study, land cover map is divided into four land cover categories.

2.2.6. *Precipitatin*

Rainfalls produce sudden floods which cause shallow landslides. Most of the landslides occur after the heavy; so that water infiltrates rapidly upon heavy rainfall and increases the degree of saturation and potential of landslide occurrence (Pourghasemi et al., 2009).

2.2.7. *Fracturation*

Fracturation are the structural features, which describe a zone of weakness with relative movement, along which landslide susceptibility is higher (Pourghasemi et al ,2009). It has generally been observed that the probability of landslide occurrence increases near of the fracturation, which not only affect the surface material structures but also make contribution to terrain permeability causing slope instability (Iovine et al, 2008)

2.2.8.*Distance from road*

The distance to road parameter reflects human activities. In other words, landslides may occur on the slopes intersected by roads (Nielsen et al, 1979). A road or power line constructed beside slopes causes a decrease in the load on both the topography and the heel of slope.

According to recent studies, cutting slopes for road construction and frequency vibrations caused by cars would induce landslides (Mittal et al., 2008). During field studies, some landslides were observed, which certify the effect of instability caused by road constructions (Figure. 5).

Figure 5: Road near Safi prone to landslide

2.2.9. *Distance from streams*

Generally, potential of landslides increases by decrease in distance to streams, because streams may adversely affect stability by eroding the slopes or by saturating the lower part of material, resulting in water level increases (Ercanoglu et al., 2004).

2.3 Analysis

AHP has gained wide application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis (Ayalew et al 2005). Using this method, each layer is broken into smaller factors, and then these factors are compared based on their importance. For comparison of importance of factors relative to each other, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 (Table 1).

Description Dominant	Value
Equal importance	1
Moderate prevalence of one over another	3
Strong or essential prevalence	5
Very strong or demonstrated prevalence	7
Extremely high prevalence	9
Intermediate values	2,4,6,8

Table 1. Fundamental scale for pair-wise comparisons (after Saaty and Vargas (2001)

In order to establish a pair-wise comparison matrix (A), factors of each level and their weights are shown as: A_1, A_2, … , An and w_1, w_2, … , w_n. The relative importance of ai and aj is shown as a_{ij}. The pair-wise comparison matrix of factors $A_1, A_2, \dots, A_n$ as $A=[a_{ij}]$ is expressed as:

$$A = \{a_{ij}\}_{n\times n} = \begin{bmatrix} 1 & a_{12} \dots & a_{1n} \\ a_{21} & 1 \quad \dots & a_{2n} \\ \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \frac{w_1}{w_2} \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & 1 \quad \dots & \frac{w_2}{w_n} \\ \vdots & \vdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & 1 \end{bmatrix} \quad (1)$$

In this matrix, the element, aij = $1/a_{ji}$ and thus, when i=j, a_{ij}=1. A matrix is normalized using:

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad i,j = 1,2,\dots\dots,n \qquad (2)$$

And finally, weights of factors are computed using

$$w_i = \left(\frac{1}{n}\right)\sum_{j=1}^{n} a'_{ij} \qquad i = 1,2,\dots\dots,n \qquad (3)$$

In matrix-based pair-wise comparison, if the factor on the horizontal axis is more important than the factor on the vertical axis, this value varies between 1 and 9. Conversely, the value varies between the reciprocals 1/2 and 1/9 (Table 1). In AHP, for checking consistency of matrix, consistency ratio is used, which depends on the number of parameters. The consistency ratio (CR) is obtained by comparing the consistency index (CI) with

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average random consistency index (RI). The consistency ratio is defined as: CR = CI/RI

The consistency index of a matrix of comparisons is given by:

$$\text{Consistency Index (CI)} = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

And the average random consistency index (R.I.) is derived from a sample of randomly generated reciprocal matrices using the scales 1/9, 1/8,…., 8 and 9 (see Table 2).

Nnumber of factors	RI	Nnumber of factors	RI
1	0.00	**6**	1.25
2	0.00	**7**	1.35
3	0.52	**8**	1.40
4	0.89	**9**	1.45
5	1.11	**10**	1.49

Table 2: Average random consistency index (RI)

The AHP methodology consists of pairwise comparison of all possible pairs of factors and try to synthesize the judgments to determine the weights (Saaty, 2001).in this study the relative rating for the dominance between each pair of factors was guided by expert knowledge. A comparison matrix of scores was created (Table 3). In this study, the value of CR is obtained by the ratio between the values of the indexes CI (matrix's consistency index, whose expression is shown in Eq. (4)] and a random index RI, which is the average consistency index

The consistency ratio (CR) calculated is 0.053, therefore less than 0.1.

Weight-decision matrix	Precipitation	Slope	Lithology	Aspect	Land cover	Distance from road	Fracturation	Streams	Criteria Weigth
Precipitation	1	2	2	3	4	3	3	4	**0,2551**
Slope	0,5	1	3	3	3	4	3	4	**0,2251**
Lithology	0,5	0,33	1	3	2	6	4	4	**0,1854**
Aspect	0,33	0,33	0,33	1	2	2	1	2	**0,0873**
Land cover	0,25	0,33	0,5	0,5	1	2	2	2	**0,0806**
Distance from	0,33	0,25	0,16	0,5	0,5	1	2	1	**0,0584**
Fracturation	0,33	0,33	0,25	1	0,5	0,5	1	2	**0,0625**
Streams	0,25	0,25	0,25	0,5	0,5	1	0,5	1	**0,0457**

Table 3. Pairwise comparison matrix of scores for calculating weight

After obtaining weight of each parameters, they is multiplied in the map calculated by criteria weights by applying the following Eq (5):

$$S = \sum_i w_i x_i * \prod_j c_j \quad (5)$$

with S is the linear combination of factor values (xi) weighted by weights (wi) and multiplied by the product of constraints (cj)

3. Results and discussion

The analysis of the susceptibility map obtained (Figure 6) shows that areas with high susceptibility to sliding are largely concentrated in the western part of the studied area at the cliffs area, due to local environmental conditions.

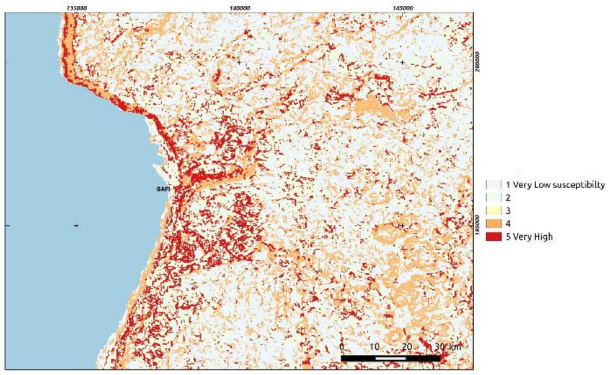

Figure 6: Landslide susceptibility maps

Landslide research and susceptibility mapping is an essential component of hazard management. Comprehending the processes of occurring landslide provides fundamental knowledge about the evolution of landscapes and decreasing the risk due to landslides. There are various methods for landslide susceptibility mapping.

In this study, AHP method was used to prepare landslide susceptibility maps in The coastal area of Safi (Morocco).

This region is a landslide prone zone because of its own characteristics including the cliffs topography, climate conditions, geology and geomorphology structures. In this study area, using field records, 170 landslides have been determined. Majority of these landslides occurred because of losses of land cover, slope topographic, fracturation, abscence of végétation, erosion, and unsystematic road construction in marl and clay sediment .

After preparing landslide inventory map, eight layers have been considered. To confirm the practicality of the results, the susceptibility map was compared with existing landslide. The results demonstrated that the active landslide zones had a high correlation to the high and very high susceptibility class of map. The AHP map shows 80% of the active landslide reas located at high and very high susceptibility are generally related to gray marl rocks that are very sensitive in the neighborhood of water. Based on this study, it can be stated that the high and very high susceptibility landslide zones identified by the AHP method, can predict potential landslide areas in the reality. The result of this study shows, that when field conditions are properly determined by good proficiency, the AHP method can give more truly results (Moradi et al., 2012).

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