J-READING
JOURNAL OF RESEARCH AND DIDACTICS IN GEOGRAPHY
2, 8, December, 2019, pp. 31-42 DOI: 10.4458/2801-02

J - READING
JOURNAL OF RESEARCH AND DIDACTICS IN GEOGRAPHY
homepage: www.j-reading.org

Validation of landslide susceptibility using a GIS-based statistical model and Remote Sensing Data in the Amzaz watershed in northern Morocco

Abdelhak El-fengour[a], Carlos Bateira[b], Hanifa El motaki[a], Mohammed Laatiris[a]
[a] Department of Geography, University Ibn Tofail, Kenitra, Morocco
[b] Riskam, CEG, ULisboa/Fac Letras, University of Porto, Portugal
Email: elfengourabdo@gmail.com

Received: July 2019 – Accepted: December 2019

Abstract

The main objective of this research is to examine and validate the landslide susceptibility assessment (LSA) results of the spatial probability of landslide occurrence in the Amzaz watershed area in Northern Morocco, setting out to create a helpful agent for the decision-makers of land-use policies. In order to reach the main goal of this study, two sub-objectives were defined: the presenting of the physiography and the cartography of the geographical components of the study area, and the analysis of the LSA using a statistical-based method, Information Value Method (IVM), as a criteria required by the Model. Lastly, the validation of the results through the prediction and success rates was carried out. Landslide susceptibility is the probability that landslides will be generated in the predicted zone depending on local terrain characteristics.

Several methods are proposed for landslide susceptibility assessment worldwide. IVM has been applied to prepare the landslide susceptibility map. This paper envisages the definition of the settings of the study area as well as the geophysical characteristics by means of the acquisition and preparation of predisposing factors, such as the geology, land use and climate and the application of the IVM on LSA using a statistically based method for each subset of the landslide inventory.

This study is aimed at a prediction vision for sustainability as an alternative and this is not limited to degradation processes. It also concerns the efforts made to adapt to the impacts and even those of mitigating change. The promotion of sustainable development in risk areas requires an effort to analyze and evaluate local practices and approaches. This is what we are trying to do through this work, which starts from a methodological basis to validate a model for predicting landslides affecting the Moroccan Central Rif area.

Keywords: Landslide Susceptibility, Information Value Method, Validation, Amzaz Watershed, Morocco

1. Introduction

Landslides are natural hazards that affect the marl slopes in the Amzaz watershed and are mostly triggered by heavy rainfall (Gartet, 2010). They have generated important economic, social and ecological effects, by their destruction of parts of useful agricultural areas and the damaging of houses, roads, tunnels and other basic infrastructures (Chakon, 1995). The reduction of socio-economic losses due to landslide activity needs an effective methodology for analysis, quantification and prevention of these hazards (Carrara et al., 1999). The Rif mountain areas in northern Morocco are well known for the frequencies of its kind of risks (Figure 1). The landslide causes are mainly related to geomorphologic instability and they occur at various spatial and temporal scales (Crozier and Glade, 2006; Weerasinghe, 2008).

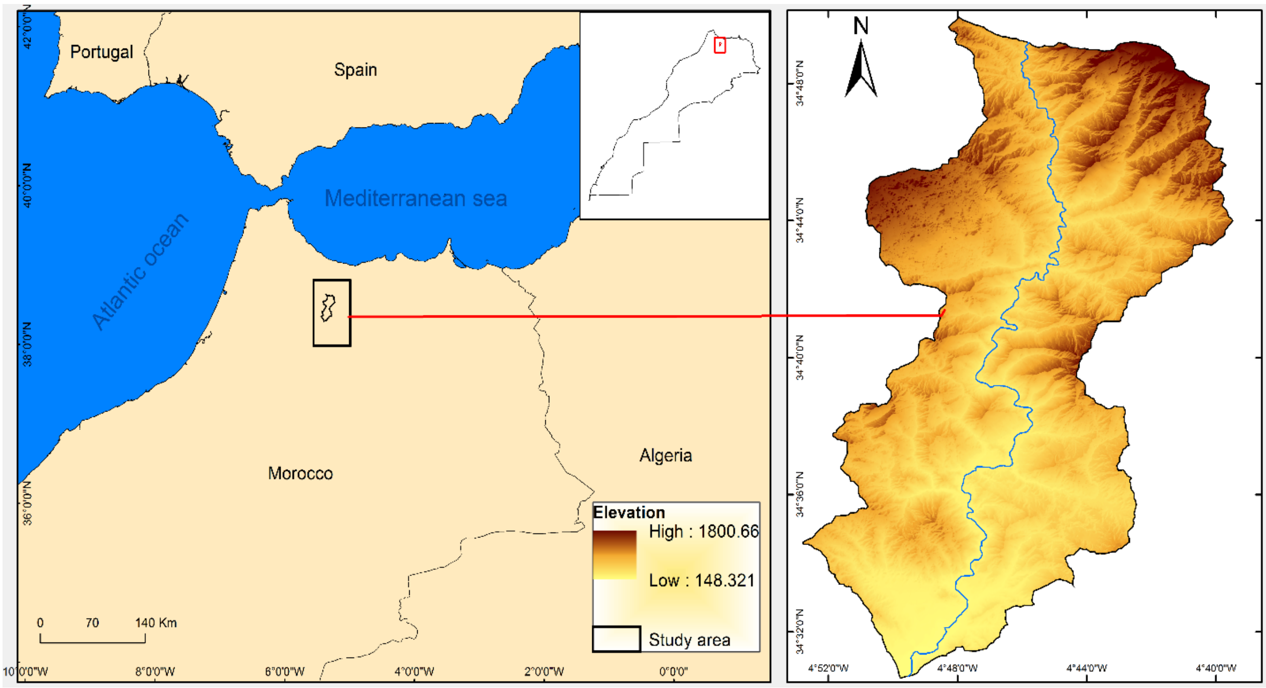

Figure 1. Geographical placement of the Amzaz watershed in the Rif mountain areas in northern Morocco. Source: Authors' elaboration.

2. Data and settings

Two main sets of factors influence the slope instability: conditioning factors including geology, geomorphological characteristics, slope angle and aspect, faults, thickness and elevation of the soil and the trigger factors such as rainfall and seismic activity (Chigira et al., 2003). These factors make the slope actively unstable acting to increase the shear stress (Terzaghit, 1950). Human actions can act as an external factor and associated with the rainfall can increase the slope instability (Sharma and Nakagawa, 2005). This analysis gives the major features that characterize the study area in terms of mass movement predication in the Amzaz watershed in northern Morocco.

2.1 Geology

The Amzaz watershed belongs to the Rif belt which is a portion of the Euro-Mediterranean Alpine belts. It is divided into three zones, according to structure and stratigraphy criteria, from north to the south, Intrarif, Mesorif, and Prerif (Figure 2).

2.1.1 Intrarif

The Intrarif zone includes two units. The Ketama unit consists mainly of the Lower Cretaceous series where siliciclastic turbidites predominate, and involves at least two sub-units (Puglisi, 2009). The southern unit begins with Sinemurian massive limestones, then the syn-rift series involves ammonite-rich marly limestones (Middle Liassic), silty marls (Toarcian), hemipelagic (Aalenian) and Posidonomya marls (Dogger).

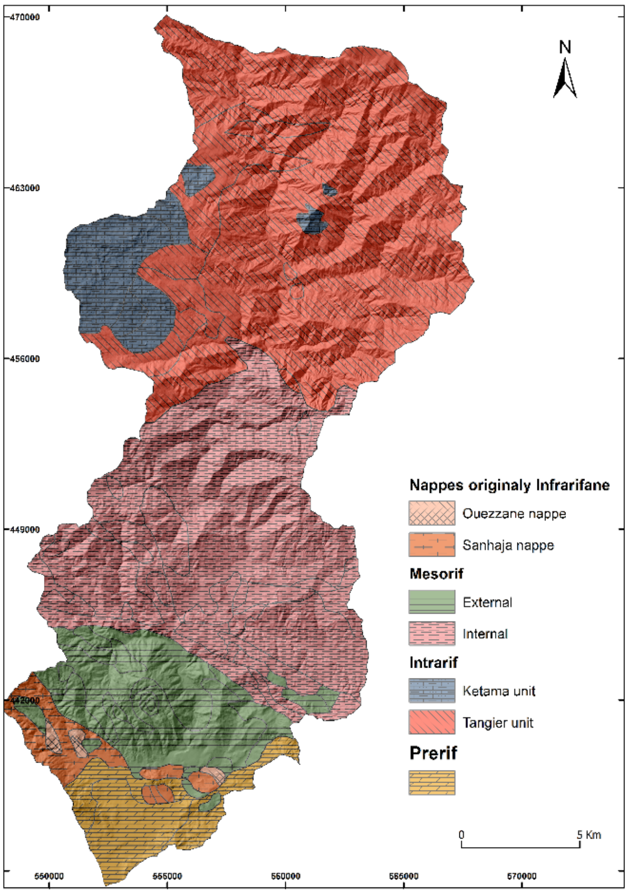

Figure 2. Geological structural context of the Amzaz watershed area. Source: Sauter and Mattauer, 1964.

The Tangier unit, partly detached from the underlying Ketama, and the Aknoul nappe, totally detached and thrust over the Mesorif and Prerif (and even over the MiddleAtlas foreland in the easternmost Rif), expose the Upper Cretaceous Eocene marly-pelitic formations of the Intrarif zone (Suter, 1980). The Tangier series spans the Cenomanian-Maastrichtian interval in the Central Rif, whereas it is diverticula in the Western Rif into an Internal Tangier unit (Cenomanian-Senonian) and External Tangier unit (Campanian-Paleocene).

2.1.2 Mesorif

The Mesorif zone displays different characteristics in the Western-Central Rif and Eastern Rif, east of the Nekor fault, respectively: the Western and Central Rif which are characterized by antiforms with Lower-Middle Miocene rocks in the core and mainly Mesozoic thrust units above them. The allochthone units have two possible origins, either infra- or supra-Ketama, and the Eastern Rif which is complete and easily recognizable from the Liassic to Upper Cretaceous levels, up to the unconformable Lower-Middle Miocene turbidites. In contrast, the stratigraphic formations are less continuous and less easily dated in the North Temsamane sub-zone, which consists of more or fewer diverticula units, duplicated and folded together during the pre-Miocene synmetamorphic event (Chalouan et al., 2008). Their metasediments are deformed into overturned folds stretched along their WSW-trending axes, which is consistent with a sinistral throw during the Alboran Terrane-Africa oblique collision.

2.1.3 Prerif

It is dominated by Jurassic and Cretaceous formations, the same as the Mesorif domain, and are represented by three different series (Wildi, 1981):

- A thick formation of flysch.
- A limestone series, forming the Sofs line.
- An alternating series with dominant marl formations.

These lithological materials are very friable and have a very high sensitivity to climatic variations.

2.2 Lithological facies

The Ketama unit involves at least two sub-units. The southern unit begins with massive Sinemurian limestones suggesting a continental substrate. Then the syn-rift series involves ammonite-rich marly limestones (Middle Liassic), silty marls (Toarcian) and Posidonomya marls. The overlying post-rift series consists firstly of Upper Jurassic "ferrysch" (a rythmic marly-clastic formation), followed upward by Tithonian Berriasian pelagic limestones. Then a politic sandy sedimentation corresponding to the Valanginian, Barremian and Aptian-Albian times, is characterized by thick quartzose turbidite Vraconian belemnite marls and spongolites are preserved to the north.

Marly-pelitic formations of the Intrarif zone expose in the upper Cretaceous Eocene also some facies in contrast with the dominant pelites, such as the Cenomanian-Turonian phtanites. The formation from the Loukkos unit is typified by thicker Cenomanian deposits, a higher proportion of carbonates and frequent diapiric intrusions of the Triassic clay-gypsum complex, Moreover the Intrarif Eocene sediments consist of white siliceous marls and marly limestone rocks along the Habt thrust sheet and the Intrarif In Ksar El Kebir – Arbaoua (Zakir, 2004; Zakir et al., 2004). This study noted the presence of ramps and accommodation folds. The area is also marked by the frequency of earthquakes of moderate magnitude and is an area of tectonic deformation and under the potential threat of natural hazards induced by seismicity (Buforn et al., 1995).

2.3 Climate

The Amzaz watershed is characterized by a subhumid climate (Sadiki et al., 2009) displaying a strong seasonality in temperature and precipitation (Figures 3 and 4).

The data of rainfall available at (*Le Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification*), (HCEFLCD) (Lelandais and Fabre, 1996), shows that the quantity of rainfall rises on the altitude from the south to the north of the study area toward the Mediterranean sea.

The mean temperature of the area falls within a range of 11 to 29, the difference between the summer and winter temperature is in the order of 11, with the lowest temperatures occuring in January. In winter, the temperature has the highest variance and the largest oscillation. In summer the temperature is not only higher but also more stable as the conditions of the Amzaz indicate.

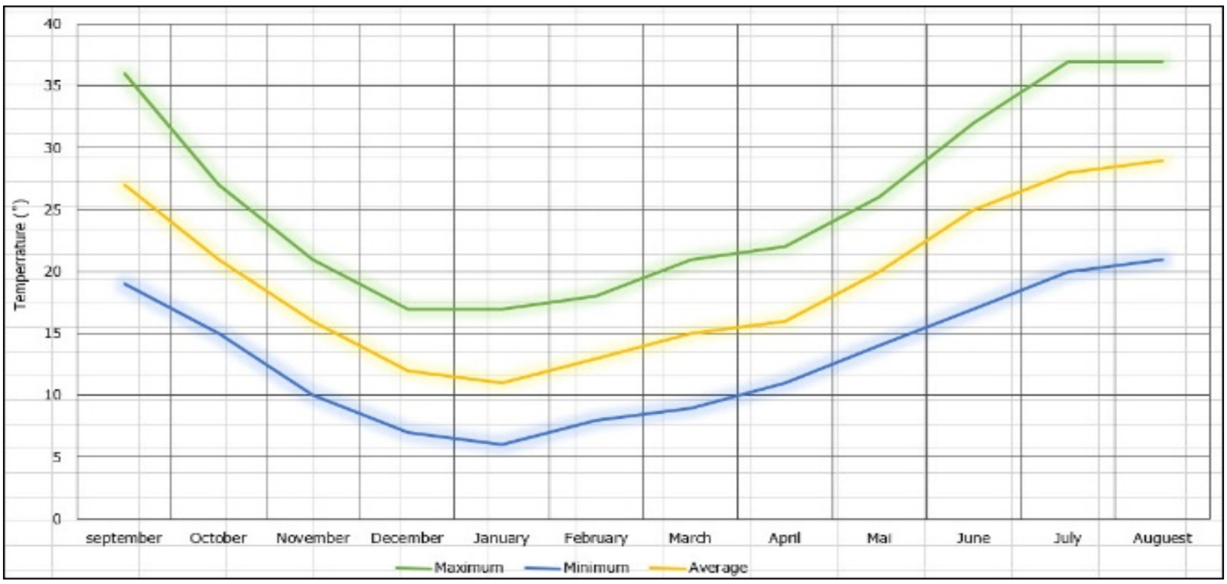

Figure 3. The average monthly temperature at Ourtzagh meteorological weather station. Source: Authors' elaboration.

Rainfalls are often short but very intense Their distribution is irregular both in time and in space and most of the water Wadis are ephemeral, apart from the Amzaz Wadi that drains the watershed (Abdelhamid et al., 2007). With the annual rainfall in the range of between 412 and 2471 mm, the area can be defined as semi-arid to humid (Chaaouan et al., 2013) and the relative abundance of rainfall must be attributed to the formation of local depressions over the western Mediterranean. This weather system is generated by the penetration of the cold air from the jet stream over the European landmass that becomes separated from the Atlantic by the Iberian peninsula. Conditions for its formation are highly favorable in the autumn when the influence of the Azores anticyclone is still significant and the higher temperatures over the Mediterranean warm the air and charge it with precipitation.

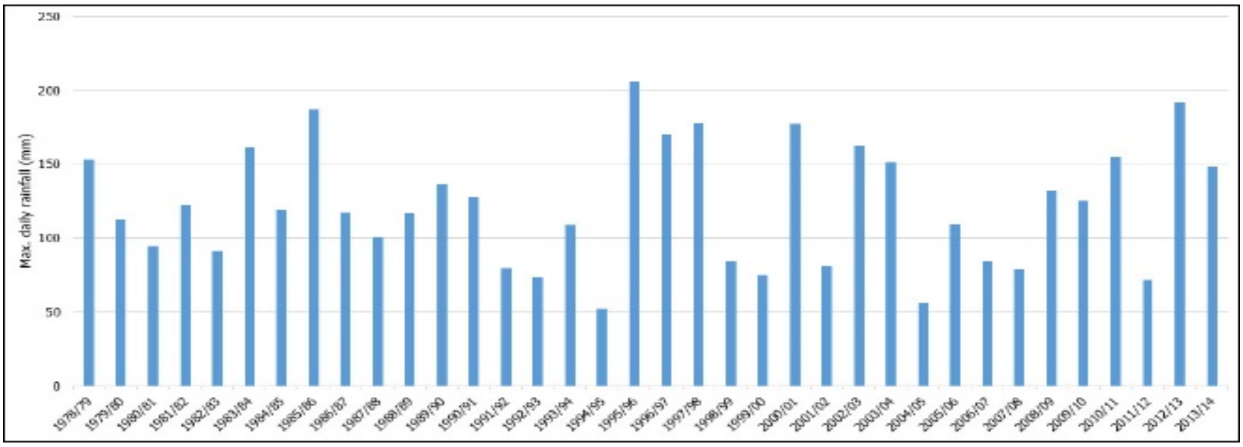

Figure 4. Interannual variation of annual rainfall at the Oudka meteorological weather station. Source: Authors' elaboration.

3. Relief and morphology

Based on a hypsometric map (Figure 5), the average altitude of 1010 m with a peak of 1820m and river mouth with 220 m, we can divide the Amzaz watershed into an upstream with a large number of peaks with a high altitude, especially Jbel Lmesfeld with 1820 m and Jbel Isfoula with 1020 m also Jbel Outka with an altitude 1600 m (Figure 6, topographic section A). The rough morphology of this part of the watershed testifies a powerful dynamic. The high altitudes (1630 m) decrease to low altitudes (230 m) within a distance of around 14 kilometers.

The second part of the watershed starts with an altitude of 455 m (Figure 6, topographic section B), where we can observe a balance between the altitude of the front of Jbel Beni Ounnai to the West (970 m) and the peak of Ballouta to the East (1030 m). This part is transitional between the upstream and downstream which starts with weak altitudes (Figure 6, topographic section C) characterized by the low altitudes especially at Sidi el Mokhfi (230 m) and Galaz (375 m) comparing with the other areas of the watershed with its smooth morphology characterized by sedimentation process.

The relief of the Amzaz watershed shows that from the North-East to the South-West along 35 kilometers, it is characterized by a contrasting morphology. It is marked by peak crest lines and hill knolls and ridges that juxtapose a V-shaped and U-shaped watershed with

cols and saddles that dissect the landscape. Derivative and winning structures form bowl-like structures and cones at different heights all through its profile.

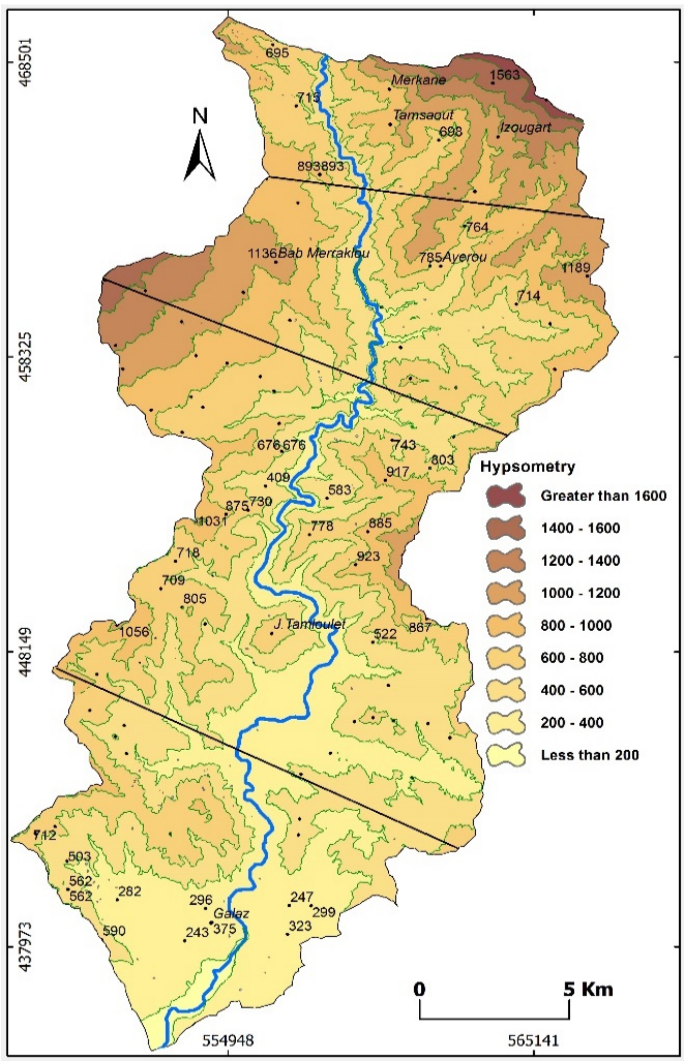

Figure 5. Hypsometric map with a cross profile (straight black line) of the Amzaz watershed. Source: Authors' elaboration.

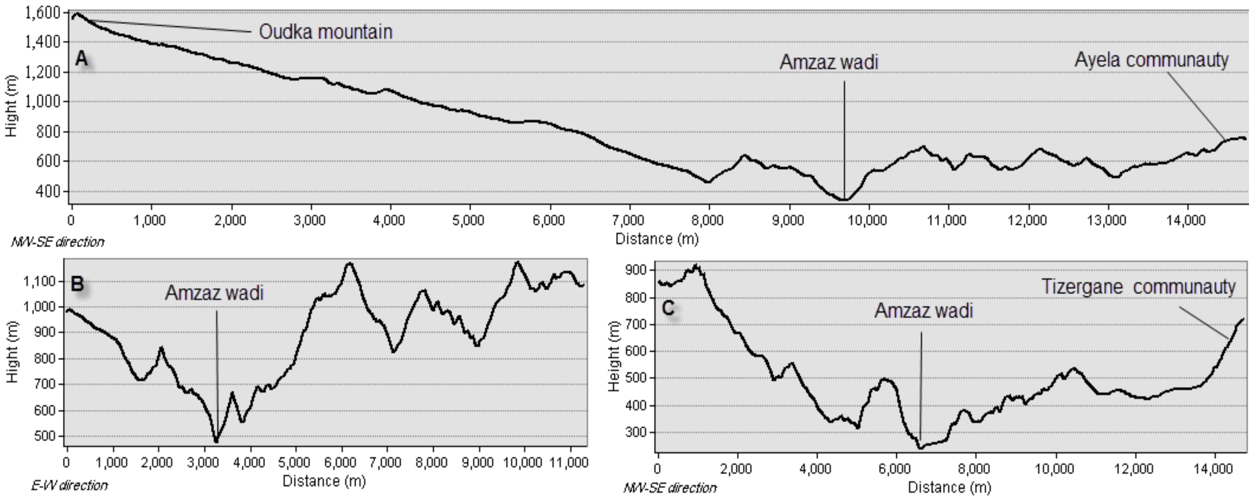

Figure 6. General cross-section of the study area. Source: Authors' elaboration.

4. Informative value method application

There are two basic methods for landslide susceptibility zonation: the direct and indirect mapping methods (Guzzetti et al., 1999; Henriques, 2014; Schuster and Krizek, 1978), direct mapping based on the geomorphologist's experience and knowledge of local conditions, directly determining the degree of susceptibility. Indirect mapping which utilizes either statistical or deterministic models to predict landslide-prone areas. The statistical models are based on information gathered from the interconnection between landslide conditioning factors and the distribution of landslides **(**van Westen et al., 2003**).**

The IVM estimates the influence of each conditioning factor to mass wasting and its ability to differentiate which class has more impact within a relevant layer. The method was originally proposed by (Yin and Yan, 1988) expressed as (Equation 1).

$$Ii = \log \frac{Si/Ni}{S/N} \qquad \text{Equation 1}$$

Where,

- Si is the area with landslides belonging to the modeling group present on the variable Xi.
- Ni is the area with variable Xi.
- The S is the total area with landslides belonging to the modeling group.
- N is the total area.
- The S/N means an a priori probability, the likelihood of each pixel having a landslide without any consideration of the predisposing factor.
- Si/Ni is the conditional probability of having a landslide given the presence of variable Xi.

The final susceptibility is then determined for each cell by the sum of the information value obtained for each theme used as a conditioning factor (Equation 2)

$$IV_j = \sum_{i=1}^{m} X_{ij}\ IV_i \qquad \text{Equation 2}$$

Where,
IVj is a total informative value of terrain j,
m is a number of variables,
Xij is either 0 if the variable is not present in the pixel j, or 1 if the variable is present.

5. Informative Value Method output

The analysis of the data shows the result of the combination of the spatial distribution of past mass movement with spatial patterns of the relevant conditioning features of slope instability. The IVM shows the relative susceptibility of the field unit to the occurrence of a certain specific type of landslide. The informative value for each type of mass movement was calculated separately (Table 1).

Predisposing factors	ID	Class	Rotational	Translational
Lithology	1	Alluvium	-0.6719	-0.7011
	2	Black flysch with benches of siliceous sandstone	**0.4487**	**0.0143**
	3	Deposits of steep slopes	**0.4998**	-0.7011
	4	Dolomite, limestone missives	**0.2137**	-0.4234
	5	Flysch with benches of sandstone and shale	-0.5569	**0.3250**
	6	Marl and sandstone	**0.8413**	-0.7011
	7	Marly flysch	-0.6164	0.4047
	8	Saliferous clay	-2.5736	-0.7011
	9	Sandstone thick siliceous coarse	-2.6008	-0.7011
Superficial formations	1	Acrisol	-1.6157	-1.0598
	2	Carbonate rocks	-2.3224	-2.8762
	3	Colluvium	-2.2391	-2.8762
	4	Greysol	-0.7633	-2.8762
	5	Mollisol	-2.3224	-2.8762
	6	Outcrops of marl or flysch	**0.7111**	-0.2203
	7	Rankers	-2.3224	-2.8762
	8	Raw mineral soil	-0.1156	**0.6603**
	9	Regosol	-0.2466	**0.3602**
	10	Rocky outcrops	-2.3224	-2.8762
	11	Vertisol	-1.3452	**0.2902**
Slope aspect	1	North	**0.5187**	-0.4371
	2	Flat	-0.3963	**0.1415**
	3	Northeast	-0.2611	**0.0855**
	4	East	**0.5969**	**0.3967**
	5	Southeast	-0.1509	-0.4599
	6	South	-1.0076	0.1962
	7	Southwest	-0.2929	**0.1342**
	8	West	-0.8031	-0.4237
	9	Northwest	**0.1265**	-0.2278
Slope angle	1	> 40	**0.5187**	-0.4371
	2	35 - 40	-0.3963	**0.1415**
	3	30 - 35	-0.2611	**0.0855**
	4	25 - 30	**0.5969**	**0.3967**
	5	20 - 25	-0.1509	-0.4599
	6	15 - 20	-1.0076	**0.1962**
	7	10 - 15	-0.2929	**0.1342**
	8	5 - 10	-0.8031	-0.4237
	9	< 5	0.1265	-0.2278
Topographic wetness index	1	0	**0.1343**	**0.4171**
	2	0 - 0.00001	-0.1661	-0.0069
	3	0.00001 - 0.0001	**0.0613**	-0.1158
	4	0.0001 - 0.001	**0.1458**	-0.3774
	5	0.001 - 0.01	-0.1838	-0.5131
	6	0.01 - 0.1	**0.0820**	**0.4939**
	7	> 0.1	-0.8500	-0.5709
Curvature	1	Concave slope	**0.1152**	**0.1995**
	2	Rectilinear slope	-0.0266	-0.7166
	3	Convex slope	-1.1955	-0.1576
Land use	1	Rainfed tree crops	-2.6817	-2.4788
	2	Bare soil heavily eroded	-2.6817	-2.4788
	3	Cropland and shrubland	**0.7314**	-0.7672
	4	Cropland on zone heavily eroded	**0.4389**	-2.4788
	5	Cropland and tree crops	**0.2811**	**0.3746**
	6	Cultivated areas	**0.8647**	-2.4788
	7	Dese natural forest	-0.5162	-1.0288
	8	Dense reforestation	-2.5023	-2.4788
	9	Ermes	-2.6817	-2.4788
	10	Intensive crops around settlements	-1.2392	-1.6140
	11	Mosaic forest / cropland	**1.1807**	**0.9891**
	12	Mosaic forest/open shrub land	-2.6817	**0.2740**
	13	Natural forest over open shrubland	**0.3543**	-0.6537
	14	Open shrub land	-0.2860	**0.3371**
	15	Open Trees	-2.6817	-0.5541
	16	Open Trees on closed scrubland	-2.6817	-1.3179
	17	Rainfed cropland	-0.7344	**0.0054**
	18	Reforestation n Sparse shrub land	-0.5261	**0.5361**

Table 1. Information values obtained for each class conditioning factor and for each landslide type, with significant values above zero highlighted in bold. Source: El-Fengour, 2016.

6. Validation Model

This study aims to validate the result of IVM applied to slope instability modeling. The modeling of landslide susceptibility without any validation is worthless and may have no importance. (Chung and Fabbri, 2003). Validation is important in order to make sure that the model can be applied for practical purposes also, to check its accuracy and reliability. Many methods were developed to validate the quality of the susceptibility map and are available in literature and were widely used (Chung and Fabbri, 2003; Fabbri et al., 2002; Frattini et al., 2010; Guzzetti et al., 2006; Liu and Shih, 2013)

In this study, the validation is based on success and PRC (van Westen et al., 2003) that demonstrate the way the model and controlling factors predict landslides. To measure the success rate, the susceptibility map should be compared with the landslide inventory used to build the susceptibility model (El-Fengour, 2016).

For the predictive rate, the validation process requires that the susceptibility map should be crossed with a group of landslides independent of those that were used to generate the susceptibility model. In this study, all landslide inventories were divided randomly into two groups for both rotational or translational slides (Figures 7 and 8).

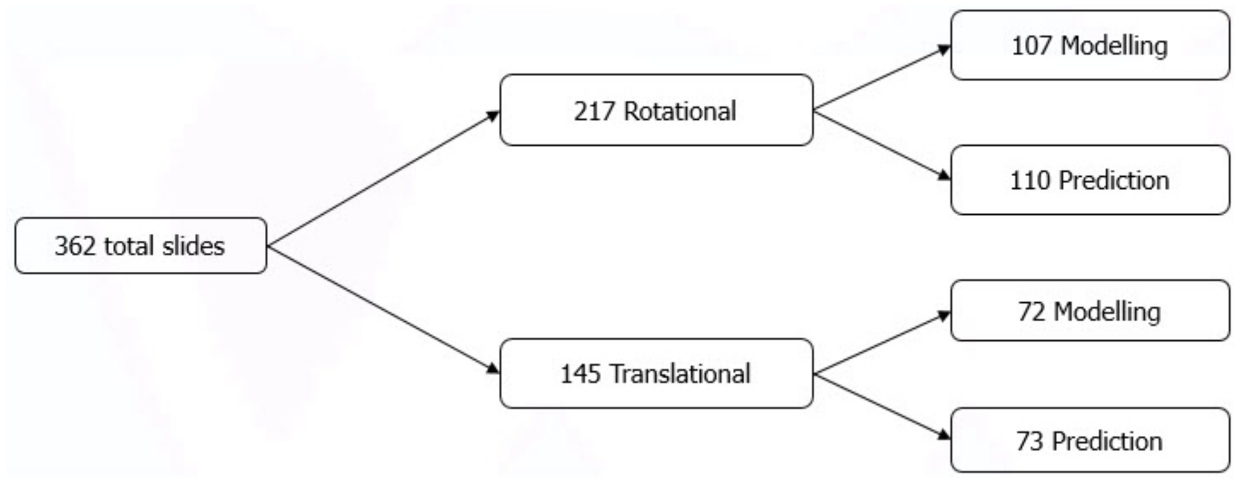

Figure 7. Landslide groups division. Source: Authors' elaboration.

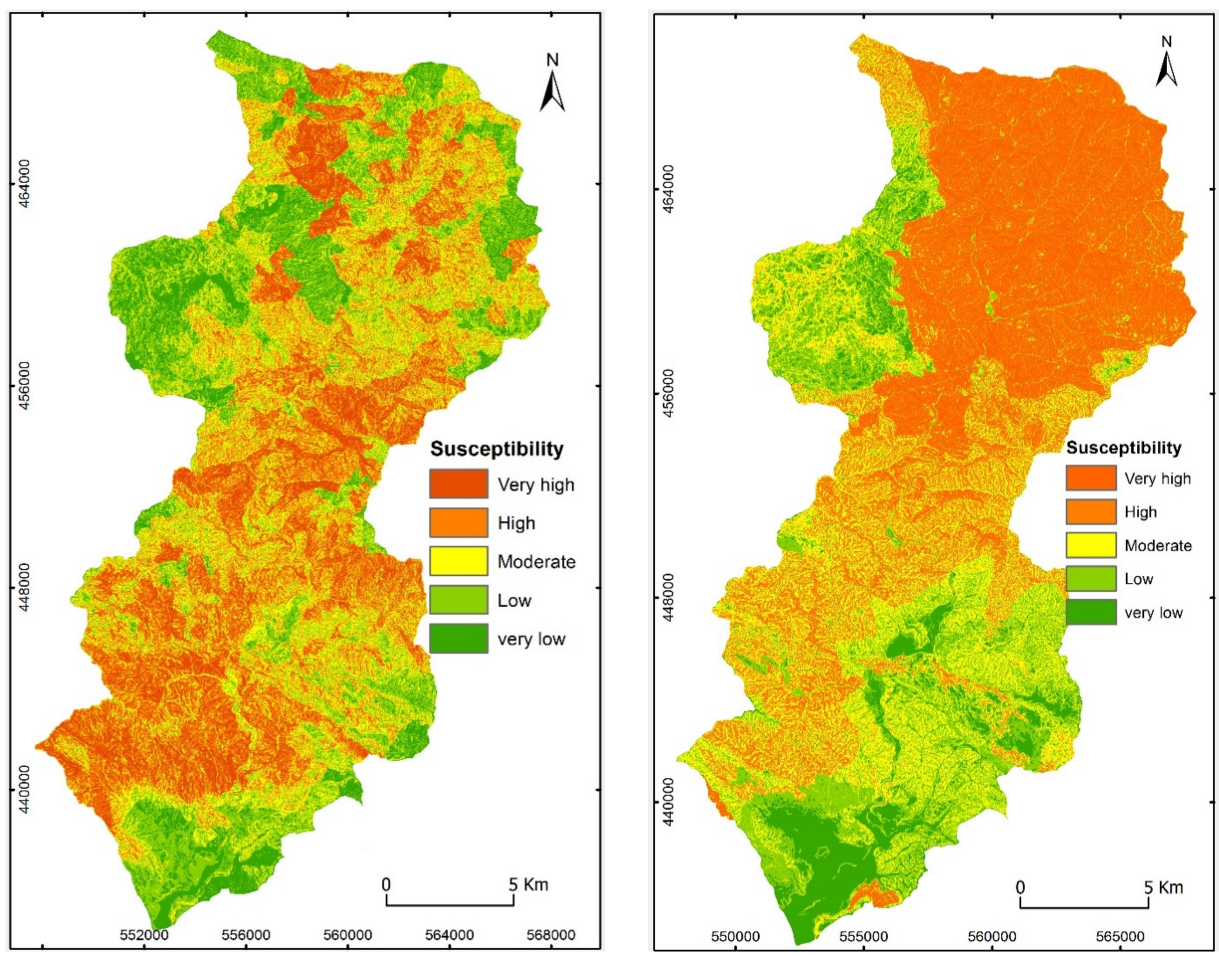

Figure 8. Landslide zonation assessment based on IVM in the Amzaz watershed (Shallow landslides in the left map and rotational landslides in the right map). Source: Authors' elaboration.

To obtain the rate curves, the calculated landslide susceptibility index values for all grids in the Amzaz watershed were categorized in descending order. The cumulative percentage of observed landslides is mapped on the landslide susceptibility as a function of the total area covered. The validation in terms of success and prediction rate curves (PRC) is shown graphically in percentage terms with the scale ranging from 0 to 1. The success rate is graphically represented starting from the origin of the graph and shows a model with a degree of success. The higher its value, the better the model is (Bennett et al., 2003).

Guzzetti (2005) considered that the Area Under Curve (AUC) values between 0.75 and 0.80 correspond to an acceptable model (Equation 3), whereas AUC values between 0.8 and 0.9 indicate a good susceptibility model, finally, AUC values greater than 0.9 exemplify the model.

$$\mathrm{AUC} = \sum_{i=1}^{n} \left[(Lsi - Li) * \frac{ai + bi}{2} \right] \quad \text{Equation 3}$$

Where,
- (Lsi-Li) is the amplitude of the class
- Ai is the ordinate value corresponding to Li
- Bi is the ordinate value corresponding to Lsi

The model was validated through success and PRC for both types of landslides separately. The cumulative frequency diagram for translational slides (Figure 9) illustrates the susceptibility in the Amzaz watershed ranked in decreasing order (x-axis) and the ordinate axis is the cumulative distribution function of the landslide area. The area under the curve of 0.76 for the modeling group and 0.69 for the prediction group concerning translational slides (Figure 10), was obtained from some of the predisposing factors (TWI, land use, lithology, superficial formations, slope aspect, slope angle, and curvature) because the other factors do not have any influence on susceptibility. It provides an indication of the landslides that occurred at the highest susceptibility levels (van Westen et al., 2006).

The validation was the same for rotational slides, the AUC value for the generated landslide susceptibility map is 0.75 for the prediction rate curve, whereas for success rate curve was 0.73 obtained from four predisposing factors (Twi, slope angle, curvature, and superficial formations), this can be considered as excellent according to Hosmer and Lameshow (2000) and indicate that the overall success rate is about 0.74.

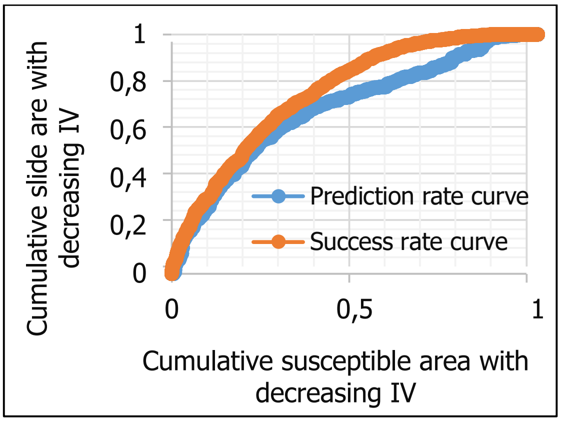

Figure 9. Success and prediction rate curve for translational slides. Source: Authors' elaboration.

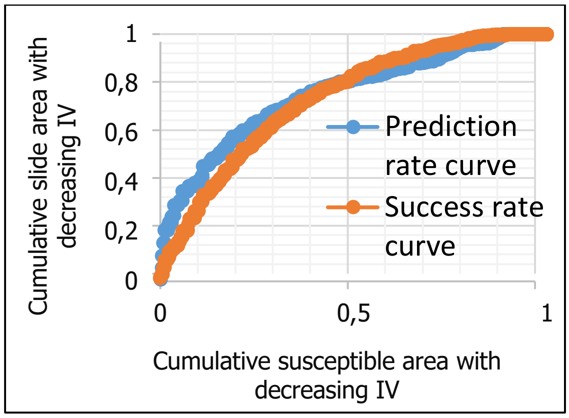

Figure 10. Success and prediction rate curves for rotational slides. Source: Authors' elaboration.

7. Results

The quality of the landslide susceptibility map depends largely on the input characteristics used in the analysis. The most important component is the landslide inventories data. In this study landslide inventories were prepared through satellite image interpretation and historical records obtained from public geotechnic laboratories (DPLT et LPEE laboratory). Details on landslides in the Amzaz watershed are very limited except for the landslides that became obvious in infrastructure damage.

Furthermore, there are several constraints that prevent the recognition of landslide evidence in the Amzaz watershed due to:

- Rapid disappearance because of vegetation growth;
- As a result of the agricultural nature of the study area, landslide evidence is constantly removed.

Based on land use maps, landslides mostly occurred within cultivated areas (Rainfed tree crops, cropland in heavily eroded zones, cropland and tree crops, cultivated areas), this is due to fact that overexploitation of land, road construction, deforestation for private residential areas, moreover, lack of knowledge of farmers about mass wasting has led to the use of traditional tools for cropping, thereby disturbing those areas and exposing it to weathering agents. Some areas are relatively flat and thus not very prone to landslides.

Regarding the information value of slope angle classes, negative values are associated with a slope gradient of more than 35 degrees and less than 5 degrees. The slope angle classes from 10-15 to 25-30 degrees show positive values which means the influence on landslide occurrence. The highest positive value is at slope class 20-25 degrees, indicating a high potential landslide occurrence within that slope class.

8. Conclusion

The natural hazards such as landslides are the biggest challenge for the development activities in mountain areas. Steep slopes, complex geology, random construction and heavy exploitation of agricultural land have contributed to the landslide susceptibility of the Rif mountains. Hence, landslide susceptibility modeling is quite important for planning and development work implementation. The main objective of this study is to prepare a Landslide Susceptibility map for the Amzaz watershed area in the Central Rif. IVM bivariate statistical methiod was used. Each predisposing factor was weighted on the basis of former landslides, just like all bivariate statistical methods are. The Information Value is simpler than complex mathematical analysis and yields scientifically reliable results.

IVM has the advantage of assessing landslide susceptibility in an objective way. Each predisposing factor is crossed with the landslide distribution. The method allows quantitative prediction of landslide susceptibility by means of a score, even in zones that have not yet been exposed to mass movements.

The LSA considering landslide typology needs to be given to the decision-makers and civil protection agencies that should implement landslide loss-mitigation plans for reducing the potential for damage to occur and reduce their social and economic impacts. Although quite an important vulnerable element including population, roads, properties and economic activities exist in the areas threatened by a landslide, local authorities do not give the required attention to such kind of problems.

There were difficulties in applying bivariate statistical IVM in the study area, as the result obtained for the landslide susceptibility map depends on the quality of data used in the model. This indicates that poor data will obviously lead to less robust results. That is very import for the condition factor maps of the Amzaz watershed with a small scale. That means the absence of information and the generalisation of the data. The same conclusion can be stated with regard to the shortcoming of the inventories with a negative impact on the susceptibility assessment.

Acknowledgment

This paper is part of the thesis submitted by Mr. El-fengour Abdelhak under the supervision of Prof. Carlos Bateira, completed by the other authors within the ongoing project Reclimplan in the framework of Ibn Khaldoun program for scientific research, coordinated by the University Mohamed V in Rabat, Morocco.

References

1. Bennett K.P., Bij J.B. and Edu R., “Regression error characteristic curves”, *Paper presented at the Twentieth international conference on machine learning (ICML-2003)*, Washington, DC, 2003.
2. Buforn E., De Galdeano C.S. and Udías A., “Seismotectonics of the Ibero-Maghrebian region”, *Tectonophysics*, 248, 3, 1995, pp. 247-261.
3. Carrara A., Guzzetti F., Cardinali M. and Reichenbach P., “Use of GIS Technology in the Prediction and Monitoring of Landslide Hazard”, *Natural Hazards*, 20, 2-3, 1999, pp. 117-135.
4. Chaaouan J., Faleh A., Sadiki A. and Mesrar H., “Télédétection, sig et modélisation de l’érosion hydrique dans le bassin versant de l’oued amzaz, rif central”, *Revue française de photogrammétrie et de télédétection*, 203, 2013, pp. 19-25.
5. Chakon J., “Mouvements de versants et risques associés dans les cordillères de la Méditerranée occidentale”, *Paper presented at the Program. Med. Campus ETAGE*, Marrakech, 1995.
6. Chalouan A., Michard A., El Kadiri K., Negro F., de Lamotte D.F., Soto J. and Saddiqi O., “The Rif Belt”, in Michard A. (Eds.), *Continental evolution: The geology of Morocco: Structure, stratigraphy, and tectonics of the Africa-Atlantic-Mediterranean triple junction*, Springer, 2008, pp. 203-302.
7. Chigira M., Wang W.N., Furuya T. and Kamai T., “Geological causes and geomorphological precursors of the Tsaoling landslide triggered by the 1999 Chi-Chi earthquake, Taiwan”, *Engineering Geology*, 68, 3-4, 2003, pp. 259-273.
8. Chung C.-J.F. and Fabbri A.G., “Validation of Spatial Prediction Models for Landslide Hazard Mapping”, *Natural Hazards*, 30, 3, 2003, pp. 451-472.
9. Crozier M.J. and Glade T., “Landslide hazard and risk: issues, concepts and approach”, in Glade T. et al. (Eds.), *Landslide hazard and risk*, West Sussex, Wiley, 2006, pp. 1-40.
10. El-Fengour A., *Landslide susceptibility assessment in the Amzaz Valley*, Central Rif, 2016.
11. Fabbri A., Chung C., Napolitano P., Remondo J. and Zêzere J., “Prediction rate functions of landslide susceptibility applied in the Iberian Peninsula”, *Management information systems*, 5, 2002, pp. 703-718.
12. Frattini P., Crosta G. and Carrara A., “Techniques for evaluating the performance of landslide susceptibility models”, *Engineering Geology*, 111, 1-4, 2010, pp. 62-72.
13. Gartet A., *Mouvements de terrain et risques environnementaux dans l’agglomération de Fès et son arrière-pays: aménagement, gestion et prévention*, Secrétariat d’État auprès du Ministre de l’Énergie, des Mines, de l’Eau et de l’Environnement, chargé de l’Eau et de l’Environnement, 2010.
14. Guzzetti F., “Landslide hazard and risk assessment: concepts, methods, and tools for the detection and mapping of landslides, for landslide susceptibility zonation and hazard assessment, and for landslide risk evaluation”, Ph.D. Thesis, St. Bonaventure University, New York, 2005.
15. Guzzetti F., Carrara A., Cardinali M. and Reichenbach P., “Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy”, *Geomorphology*, 31, 1-4, 1999, pp. 181-216.
16. Guzzetti F., Reichenbach P., Ardizzone F., Cardinali M. and Galli M., “Estimating the quality of landslide susceptibility models”, *Geomorphology*, 81, 1-2, 2006, pp. 166-184.
17. Henriques C.D.S., *Landslide susceptibility evaluation and validation at a regional scale*, Universidade de Lisboa, SFRH/BD/46816/2008, 2014.
18. Hosmer D.W. and Lameshow S., *Applied Logistic Regression*, London, John Wiley and Sons, 2000.
19. Lelandais F. and Fabre G., “Plan d’aménagement anti-érosif du bassin-versant de l’oued Ouergha (Maroc), Risques d’érosion et systèmes d’information géographique”, *Bulletin du Réseau Erosion*, 16, 1996, pp. 439-443.
20. Liu J.-K. and Shih P.T., “Topographic correction of wind-driven rainfall for landslide analysis in Central Taiwan with

validation from aerial and satellite optical images", *Remote Sensing*, 5, 6, 2013, pp. 2571-2589.
21. Puglisi D., "Early Cretaceous flysch from Betic-Maghrebian and Europe Alpine Chains (Gibraltar Strait to the Balkans); comparison and palaeotectonic implications", *Balcanica*, 38, 1-3, 2009, pp. 15-22.
22. Sadiki A., Faleh A., Navas A. and Bouhlassa S., "Assessing soil erosion and control factors by the radiometric technique in the Boussouab watershed, Eastern Rif, Morocco", *Catena*, 71, 1, 2007, pp. 13-20.
23. Sadiki A., Faleh A., Zezera J. and Mastas H., "Quantification de l'Erosion en Nappes dans le Bassin Versant de l'Oued Sahla-Rif Central Maroc.", *Cahiers Géographiques*, 6, 2009.
24. Schuster R.L. and Krizek R., *Landslides: analysis and control*, 1978, Retrieved from.
25. Sharma R.H. and Nakagawa H., "Shallow landslide modeling for heavy rainfall events", *Annuals of Disaster Prevention*, 2005.
26. Suter G., "Carte structurale de la chaîne rifaine au 1: 500,000", *Notes et Mémoires du Service géologique du Maroc*., 1980.
27. Terzaghit K., "Application of Geology to Engineering Practice", in Paige S. (Ed.), *Engineering Geology*, Berkey, Geological Society of America, 1950, pp. 83-123.
28. van Westen C.J., Rengers N. and Soeters R., "Use of Geomorphological Information in Indirect Landslide Susceptibility Assessment", *Natural Hazards*, 30, 3, 2003, pp. 399-419.
29. van Westen C. J., van Asch T.W.J. and Soeters R., "Landslide hazard and risk zonation—why is it still so difficult?", *Bulletin of Engineering Geology and the Environment*, 65, 2, 2006, pp. 167-184.
30. Weerasinghe M., Malalasekara A., Dahanayake K. and Perera S.J., *Learning to live with Landslides Natural Hazards and Disasters*, Sri Lanka, Department of Institutional Development, National Institute of Education, 2008.
31. Wildi W., "Le Ferrysch: cône de sédimentation détritique en eau profonde à la bordure nord-ouest de l'Afrique au Jurassique moyen à supérieur (Rif externe, Maroc)", *Eclogae Geologicae Helvetiae*, 74, 2, 1981, pp. 481-527.
32. Yin K.L. and Yan T.Z., "Statistical prediction model for slope instability of metamorphosed rocks", *Paper presented at the Proceedings of the 5th international symposium on landslides*, Lausanne, 1988.
33. Zakir A., "Les bassins tertiaires d'avant-fosse du Rif externe nord-occidental: approche sedimentologique et structurale des siries turbiditiques de la reion d'El Ksar El Kebir", Ph.D. Thesis, Universite Mohammed V, Rabat, 2004.
34. Zakir A., Chalouan A. and Feinberg H., "Tectono-sedimentary evolution of a fore-chain domain: example of the Habt and Sidi Mrayt basins, northwestern external Moroccan Rif; stratigraphic precisions and tectonic modelling", *Bulletin de la Société géologique de France*, 175, 4, 2004, pp. 383-397.

