International Journal of Geosciences, 2017, 8, 821-836
http://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Cartography of Landslide Susceptibility around the Dias Horst and Thies Cliff-Senegal

Issa Ndoye[1], Mapathé Ndiaye[1], Déthié Sarr[1], Papa Sanou Faye[1], Ibrahima Khalil Cissé[2]

[1]Laboratoire de Mécanique et Modélisation, UFR Sciences de l'Ingénieur, Université de Thiès, Thiès, Sénégal
[2]Laboratoire de Mécanique des Sols et des Matériaux, Ecole Polytechnique de Thiès, Thiès, Sénégal
Email: issa.ndoye@univ-thies.sn

How to cite this paper: Ndoye, I., Ndiaye, M., Sarr, D., Faye, P.S. and Cissé, I.K. (2017) Cartography of Landslide Susceptibility around the Dias Horst and Thies Cliff-Senegal. *International Journal of Geosciences*, **8**, 821-836.
https://doi.org/10.4236/ijg.2017.86047

Received: April 6, 2017
Accepted: June 25, 2017
Published: June 28, 2017

Abstract

The aim of this work is to map the susceptibility of sites to landslides. To assess the susceptibility of the zone, GIS techniques were used. Susceptibility factors are selected and split into two groups: active and passive factors. Passive factors regroup all the intrinsic conditions existing on the field at all times. The active factors or triggering factors are present sporadically and are added to the passive factors to trigger a landslide. With the weighted overlay method using *ArcGIS*©, four scenarios have been developed. A first scenario where only passive factors are combined and three scenarios for which we have for each scenario the passive factors combined with an active factor. With these different scenarios, five levels of susceptibility are obtained in the zone. These levels range from very low to very high susceptibility. For the different scenarios, the results show that the zone consists mainly of very low to low susceptibility with at least 61% of the area, followed by moderate susceptibility (23.54% to 38.24%) and last land with high susceptibility to very high with less than 1% of the surface. Fields with high to very high susceptibility are located on the slopes of the hills. Among the active factors, only the rainfall significantly modifies the percentage of land susceptible to landslide but remains in the field of moderate susceptibility. The predicted susceptibilities are closer to the observed landslides around the Thies Cliff than to the Dias Horst.

Keywords

Cartography, Susceptibility, Landslides, Dias Horst, Thies Cliff

1. Introduction

The Thies region is rich in mineral and hydrogeological resources that contribute to the economic development of the country and require good management

[1]. It is an important sector because it contains the nature reserves of Popenguine and Bandia, the Pout forest, and large holdings of calcareous aggregates, laterites, phosphates and attapulgites. This has resulted in a scarcity of spaces that can be used as dwellings, thus encouraging people to erect dwellings on the feet and sometimes on the slopes of the hills. Yet witnesses of land movements are observed on almost all the slopes of the hills of the area. This area of Senegal hosts the Dias Horst and the Thies Cliff, two areas of relief culminating respectively at 65 and 142 m. In addition, slopes exceeding 60˚ are encountered at some outcrops. This geomorphological configuration favors landslides.

Landslides studies carried out in Senegal focus mainly on the Dakar coasts [2] [3] [4] [5]. The sectors of the Dias Horst and the Thies Cliff have had very little analysis. The few stability studies carried out in the Dias Horst area have used rock mechanics techniques [6] [7]. In this work, the approach that we are going to use is that of natural risk studies, which makes it possible to develop a Geographic Information System (GIS) for mapping the landslide susceptibility.

2. Geological Setting

The area, located in western Senegal, covers the geological domains of Dias Horst and Thies Cliff (Figure 1). It straddles the administrative regions of Dakar and Thies. The climate is Sahelian with annual precipitation between 500 and 660 mm.

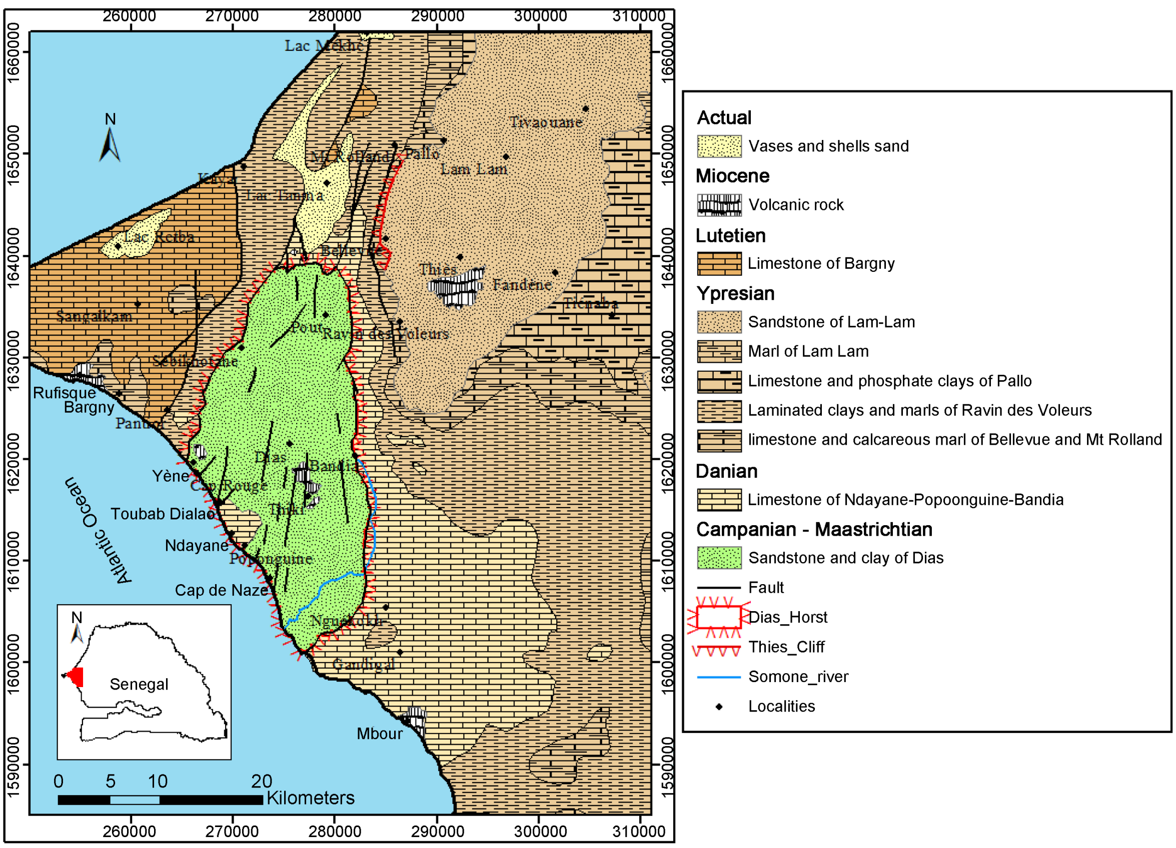

Figure 1. Geological map of the study area [10], modified.

In terms of geology, the area is part of the Senegal-Mauritanian-Guinean Sedimentary Basin [8]. This passive margin basin covers 3/4 of the Senegalese territory. The deposits are dated from the Triassic to the Actual and rest on the Meso-Proterozoic basement [9]. At the outcrop, one finds mainly limestones, marls, clays and sandstones distributed in the different formations dated from the Upper Cretaceous to the Actual.

We have the sandstones and clays of the Dome of Dias distributed in Paki Formation of Campanian age and in Formation of the Cap de Naze dated Maastrichtian. The limestones of Ndayane-Poponguine-Bandia are dated to the Danian. The Ypresian corresponding to the Thies Formation is represented by the laminated clays, the marls of Ravin des Voleurs, the marls of Lam Lam, the limestones and phosphate clays of Pallo, the limestone and calcareous marl of Bellevue and Mt Rolland and the sandstone of Lam-Lam. The limestones of the Plateau of Bargny, attached to the formation of Bargny are dated Lutetien [8]. The present deposits are represented by vases and sands shells. In addition to these sedimentary formations, volcanic events dating from the Miocene period [10] are also noted (**Figure 1**).

3. Material and Methods

The mapping of susceptibility is a key component of preventing landslides. Several methods have been proposed by different authors. At present, there is no unified method for assessing susceptibility and producing risk maps [11].

On the basis of previous work [12] [13] [14] [15], Aleotti and Chowdhury [16] proposed a classification of methods for assessing risks of landslides in two groups: qualitative methods and quantitative methods.

Qualitative methods are based exclusively on the judgment of the person responsible for assessing susceptibility. These methods, also known as expert assessment approaches [14], are split into two types [16]: field geomorphological analysis and the combination or overlaying of index maps with or without weighting. The geomorphological analysis make it possible to obtain a rapid assessment of the stability of a given site. They can be used on several scales and do not necessarily require the use of Geographic Information Systems (GIS).

For the synthesis based on overlay or combination of index maps, the expert selects and maps the factors that affect slope stability and, based on personal experience, assigns to each weighted value that is proportionate to its expected relative contribution in generating failure.

Assigning weight on a subjective basis to the many factors that govern slope stability is the main limitation of qualitative methods.

Quantitative methods use different approaches: statistical analysis, geotechnical engineering approaches and the neural network analysis.

- Statistical analysis compare the spatial distribution of landslides with the parameters considered. In the bivariate statistical analysis, each factor is compared to the landslide map. The weights assigned to each class of each parameter are determined on the basis of landslide density for in each individual class. The bivariate statistical approach is widely used by geologists and many parameters can be considered: lithology, slope angle, height of slope, land use [17] in [16].

- Geotechnical methods may be deterministic or probabilistic. Deterministic approaches involve analyzing specific engineering sites or embankments. The main physical properties are quantified and applied to specific mathematical models and the safety coefficient is calculated. These models are commonly used in soil mechanics for slope stability studies. In probabilistic approaches, basic geotechnical models are maintained but the variability of material properties is taken into account.
- Neural network analysis consists of selecting input parameters for the different neurons and assigning weights at the connections. These weights are in turn summed and the output obtained is compared with the expected output, which makes it possible to determine the error. The procedure proceeds iteratively until convergence.

The current trend of assessments of landslides favors the use of quantitative methods specifically based on GIS [18]. The ability of GIS to combine information from a variety of sources makes it a useful and powerful tool in identifying the probable location of landslides [19].

In this study, GIS techniques are used to map the risk of landslides, combining several factors of instability. Two-variable statistical analysis, which is a quantitative method, has also been used. The landslides encountered in the area are listed and their geographical coordinates recorded. Although these coordinates do not reflect the nature or magnitude of the phenomenon, they still allow the map of landslides to be generated in points [19] [20]. A total of 70 points were listed, randomly subdivided into two groups of 35 each. The first group is used to weight the different instability factors and the second group for the validation of the susceptibility maps (**Figure 2**).

Landslides can be triggered by a variety of external stimuli, such as heavy rainfall, earthquakes, fluctuations in the level of groundwater, storm waves etc. These stimuli are at the origin of a rapid increase in the stress or the decrease in the shear strength of the materials forming the slope.

The choice of instability factors plays an important role in the accuracy of stability modeling results [19]. Some authors indicate that the most common instability factors are slope angle, lineaments density, lithological nature, rainfall or hydrology [16] [21].

In this study, we added to these factors the proximity of the road and the land use.

The slopes and the hydrographic network are extracted from the ASTER imagery (ASTER DEM October 2011). Lineaments were extracted from the band 7 of the Landsat 8 (OLI) images to which we applied a 3 × 3 enhancement Laplacian filter and Sobel 7 × 7 directional filters [22] [23].

The pre-treatment is carried out under Erdas©. From the pre-processed images, the digitization of the lineaments was done under ArcMap©.

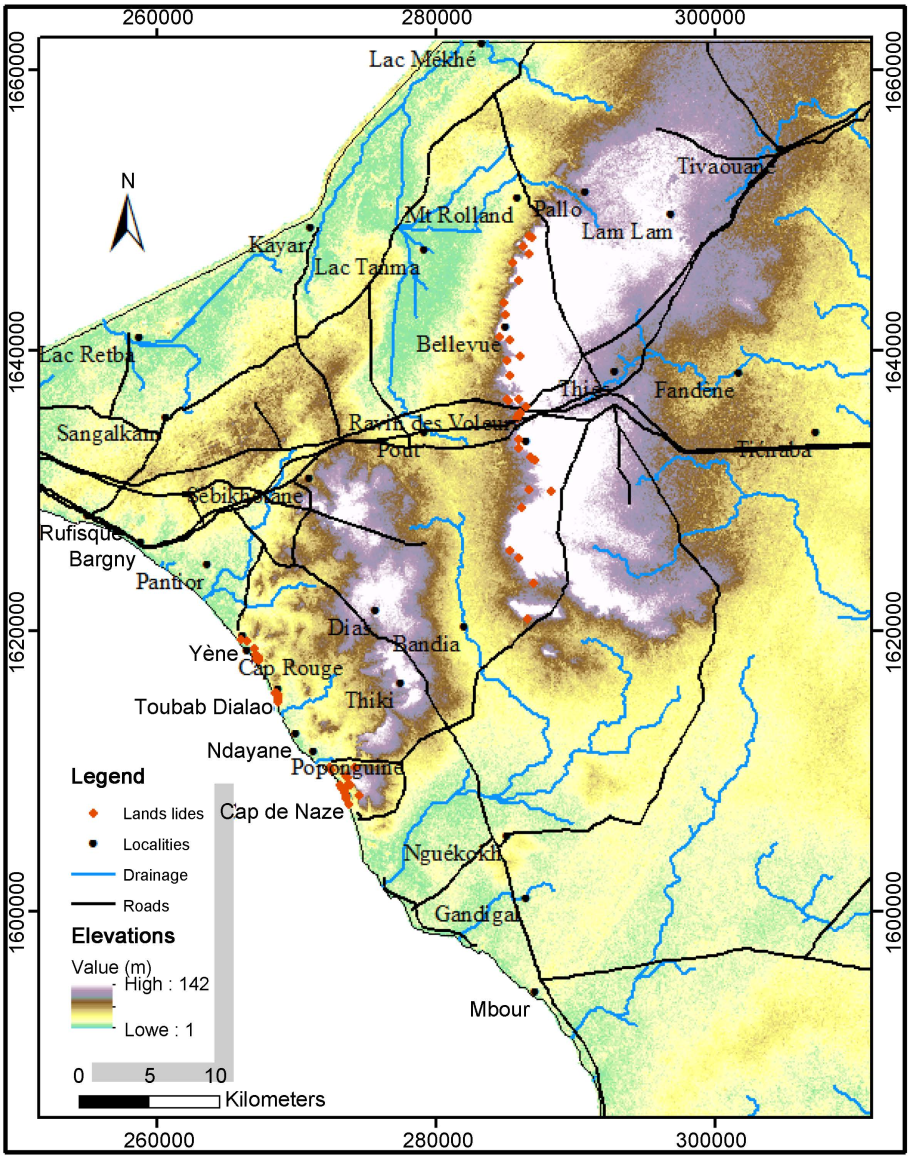

Figure 2. Map of landslides observed in study area.

The density of lineaments and the density of hydrographic network were generated from the ArcGIS© *Line Density module*. Land us is mapped from Landsat 8 (OLI) colored compositions.

Factors are split into two groups: passive and active (Table 1). The passive factors group together all the intrinsic conditions existing permanently on the environment. This is the case of the slope, the lithological nature, the density of lineaments or the land use. The active factors or triggering factors are present sporadically and are added to the passive factors. They can change the state of equilibrium and possibly cause a landslide. This is the case for rainfall, the seasonal hydrographic network or traffic related to the road network. Failing to obtain the intensity of the rainfall or the duration of the rainfall we used the annual rainfall.

Each factor is classified into five levels of susceptibility ranging from very low

Table 1. Ranking and weighting of instability factors.

Factor	Rank	Susceptibility levels	Weight
Passive factors			
Slopes (˚)	11 - 31	Very high	5
	6 - 11	High	4
	3 - 6	Moderate	3
	1 - 3	Low	2
	0 - 1	Very low	1
Lineaments (km of lineaments per km²)	2.03 - 3.46	Very high	5
	1.47 - 2.03	High	4
	0.94 - 1.47	Moderate	3
	0.35 - 0.94	Low	2
	0 - 0.35	Very low	1
Lithology	Shell Sands and Vases	Very high	5
	Clays and sands	High	4
	Marl	Moderate	3
	Limestone	Low	2
	Volcanic rocks	Very low	1
Land use	Quarries	Very high	5
	Buildings	High	4
	Waters bodies	Moderate	3
	Bare floors	Low	2
	Vegetation	Very low	1
Active Factors			
Rainfall (mm)	620 - 660	Very high	5
	590 - 620	High	4
	560 - 590	Moderate	3
	530 - 560	Low	2
	500 - 530	Very low	1
Hydrographic network (km/km²)	0.825 - 1.031	Very high	5
	0.618 - 0.825	High	4
	0.412 - 0.618	Moderate	3
	0.206 - 0.412	Low	2
	0 - 0.206	Very low	1
Road network (Proximity in meters)	0 - 100	Very high	5
	100 - 200	High	4
	200 - 300	Moderate	3
	300 - 400	Low	2
	400 - 500	Very low	1

to very high [19] [23] and a weight is assigned to each level (Table 1).

In order to weigh the factors, a spatial correlation between observed land movements and factors (passives and actives) was performed. The correlation coefficient is used to determine the influence factor according to the following relationship Equation (1):

$$I_i = \frac{100}{N} \times R^2 \quad (1)$$

I_i is the influence of the I^{th} factor, N is the total number of factors and R^2 is the correlation coefficient. The weighting of each factor will be defined by the following relation Equation (2):

$$P_i = \frac{I_i}{\sum_{k=1}^{N} I_k} \times 100 \quad (2)$$

The integration of factors for field susceptibility mapping was done in two stages. In the first step, the passive factors are combined to produce a basic map that describes the initial conditions (scenario 1). In the second step, the base map is combined with each active factor to define scenarios 2, 3 and 4. We note, however, that the list of scenarios is not exhaustive and other scenarios could be considered.

The correlations between landslides and passive factors are presented in Table 2. They were used to calculate the influence and weight of each passive factor in the generation of the susceptibility map (Table 2).

The hydrographic network is the active factor with the best correlation. Watercourses are essentially temporary and the density of the river system depends on the rainy season which lasts at most 4 months. We also considered the high density of the hydrographic network, which results in significant infiltration, thus leading to an increase in pore water pressures.

The active factors are combined one by one with the passive factors defining the different scenarios. The influence of the active factor is determined according to the scenario. Table 3 presents the weights of the factors included in a given scenario.

The different steps of the methodology used are summarized in the following diagram (Figure 3).

The integration of the factors involved in each scenario is achieved using the ArcGIS© *Weighted Overlay module* from the corresponding maps sorted and converted to the 10-meter resolution raster format.

It should be noted that Weighted Overlay supports only integer weights. Thus, the Pi represented in Table 3 have been rounded.

4. Results and Discussions

The results of the mapping are represented in Figures 4-7 and correspond to the

Table 2. Correlation of passive factors with the landslide map.

Passives Factors	R^2	Significant R	I_i	P_i
Slopes	0.9989	0.8900	22.25	30.17
Lithology	0.9976	0.7600	19	25.76
Land use	0.9972	0.7200	18	24.41
Lineaments	0.9958	0.5800	14.5	19.66
				100.00

Table 3. Factor weight for scenarios.

Scenario 2				
Factors	R^2	**Significant** R	I_i	P_i
Slopes	0.9989	0.8900	17.8	24.05
Lithology	0.9976	0.7600	15.2	20.54
Land use	0.9972	0.7200	14.4	19.46
Lineaments	0.9958	0.5800	11.6	15.68
Hydrographic Network	0.9975	0.7500	15	20.27
Scenario 3				
Factors	R^2	**Significant** R	I_i	P_i
Slopes	0.9989	0.8900	17.8	28.53
Lithology	0.9976	0.7600	15.2	24.36
Land use	0.9972	0.7200	14.4	23.08
Lineaments	0.9958	0.5800	11.6	18.59
Rainfall	0.9917	0.1700	3.4	5.45
Scenario 4				
Factors	R^2	**Significant** R	I_i	P_i
Slopes	0.9989	0.8900	17.8	25.50
Lithology	0.9976	0.7600	15.2	21.78
Land use	0.9972	0.7200	14.4	20.63
Lineaments	0.9958	0.5800	11.6	16.62
Proximity to roads	0.9954	0.5400	10.8	15.47

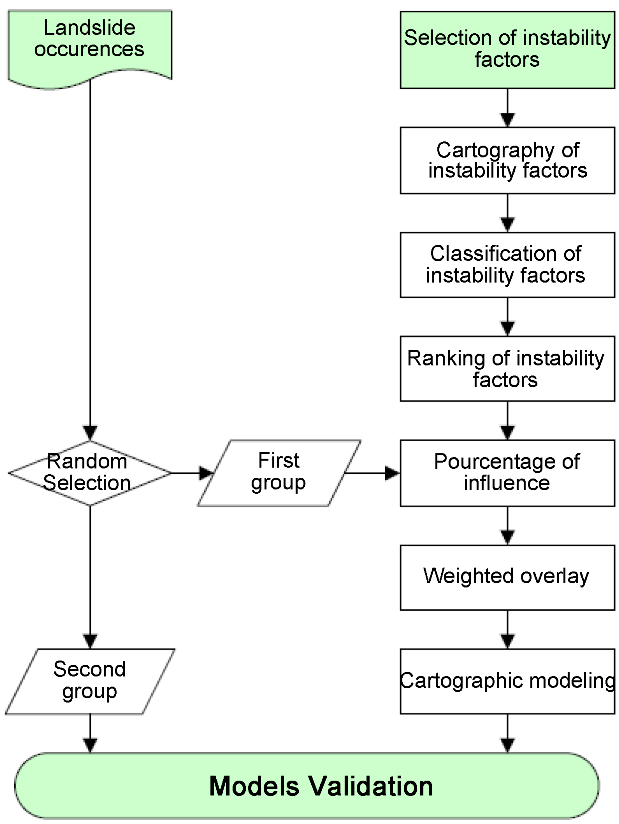

Figure 3. Methodology of the study.

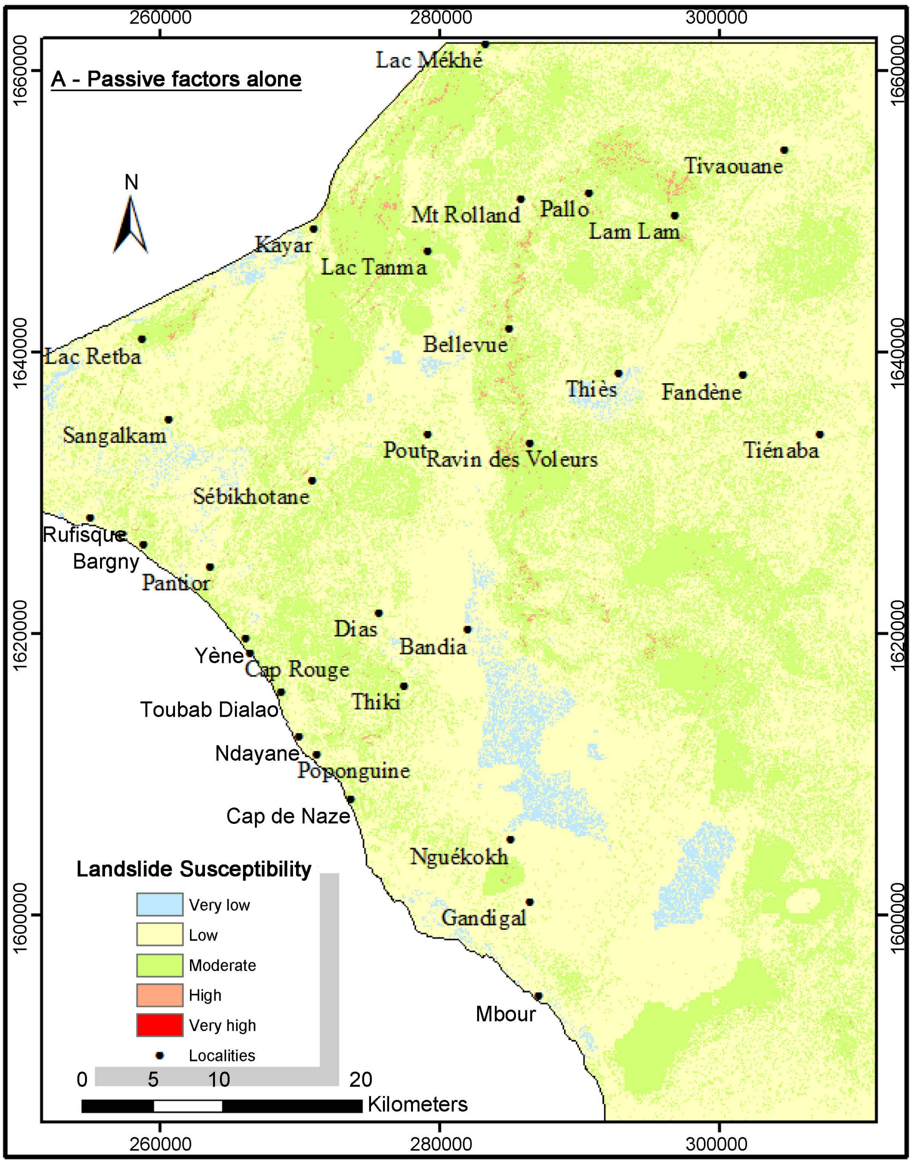

Figure 4. Landslides susceptibilities considering passive factors alone.

integration of the passive factors (**Figure 4**), the combination of the passive factors with the different active factors: the hydrographic network (**Figure 5**), rainfall (**Figure 6**) and proximity to the road network (**Figure 7**).

The combination of the passive factors, without involving the active factors, makes it possible to distinguish in the zone five (05) levels of susceptibility going from "very low" to "very high". Lands with high to very high susceptibility account for about 1% of the area. These lands are located mainly at the slopes of the Thies Cliff and the Dias Horst (**Figure 4**). The rest of the area is subdivided into moderate susceptibility (32.75%), low susceptibility (64.25%) and very low (2.01%).

By combining passive factors with the hydrographic network (scenario 2 and **Figure 5**), five levels of susceptibility are noted. For this scenario, the percentage of land with moderate susceptibility decreases from 32.75% to 26.72%.

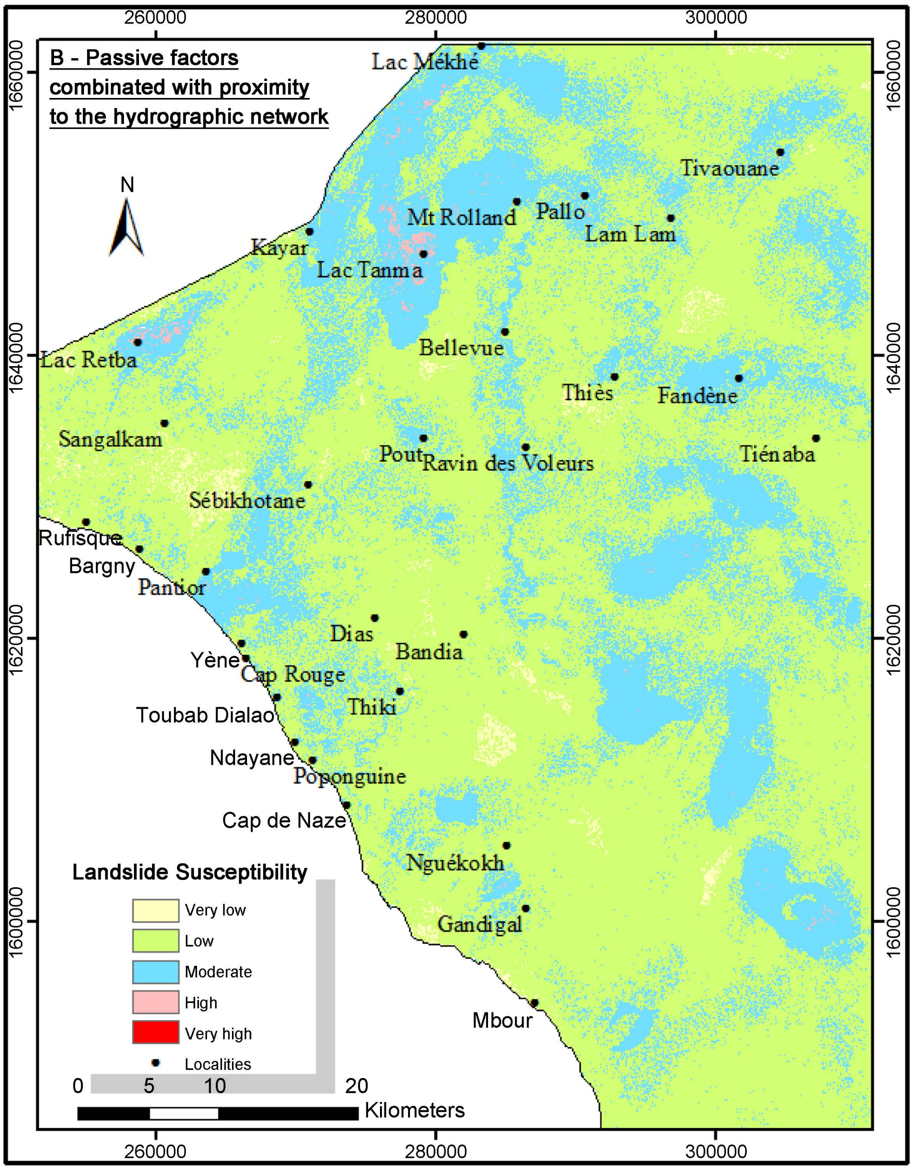

Figure 5. Landslides susceptibilities considering passive factors combinated with the proximity to the hydrographic network.

The combination of the passive factors with the rainfall makes it possible to distinguish in the zone five levels of susceptibility (scenario 3 and Figure 6). For this scenario, the percentage of land with moderate susceptibility increases from 32.75% to 38.24%.

For Scenarios 2, 3 and 4, we noted that more than 90% of the study area consists of low to moderate susceptibility. Lands with high to very high susceptibility represent less than 1% (Table 4).

By combining passive factors and proximity to the road network (scenario 4 and Figure 7), we distinguished four susceptibility levels in the zone from "very low" to "high". The very high susceptibility is not encountered and the percentage of land with moderate susceptibility decreases compared to the control scenario (scenario 1) from 32.75% to 23.54%.

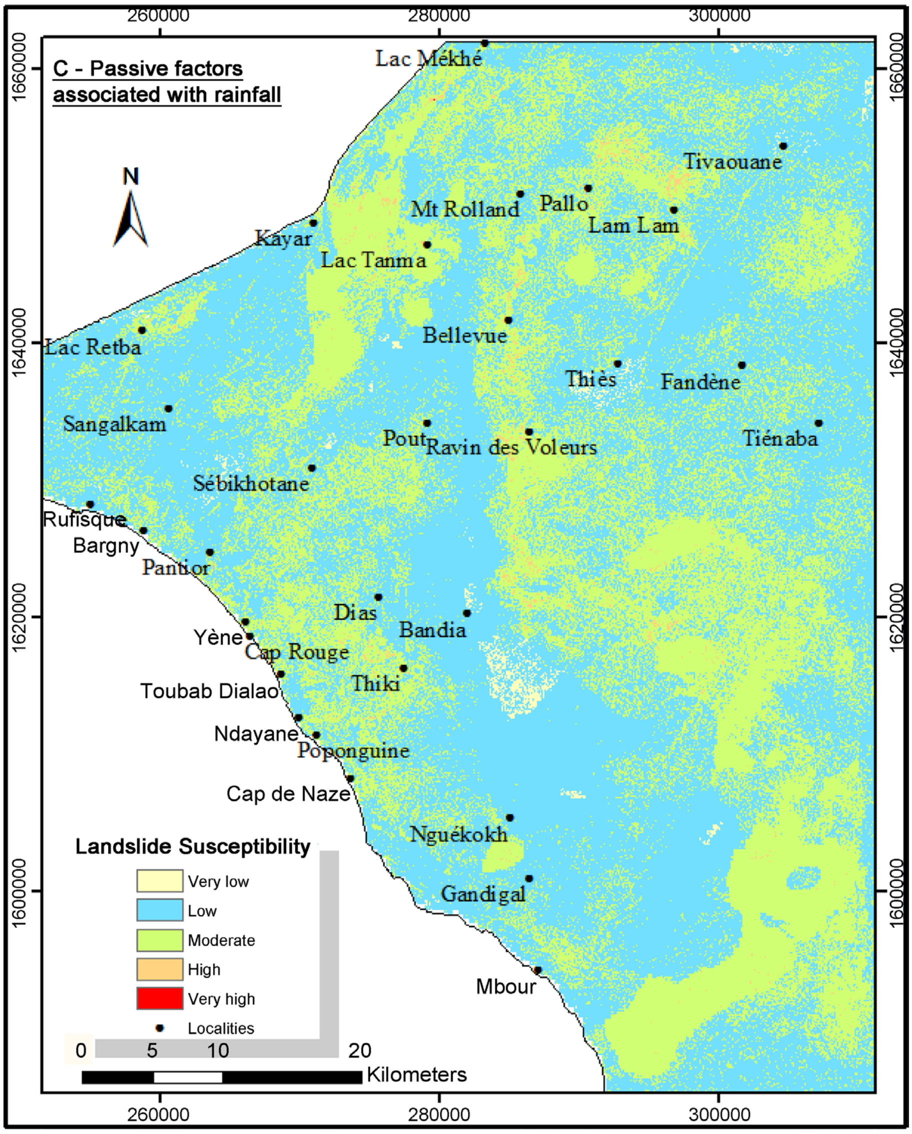

Figure 6. Landslides susceptibilities considering passive factors combinated with the rainfall.

For the various scenarios, the details of the percentages of land as a function of the susceptibility class are given in Table 4.

The combination of the passive factors with the different active factors shows significant variations in the proportion of low and moderate susceptibility sites. The results show lower proportions for soils with very low or high susceptibility.

Analysis of scenarios involving active factors shows that rainfall is the most influential factor that significantly increases the proportion of moderate susceptibility sites.

The area as a whole consists of stable to very stable soils, but the occurrence of significant precipitation can alter this state of equilibrium and cause local instabilities in certain slopes.

5. Validation of Cartographic Models

For validation, the models corresponding to the different scenarios are correlated

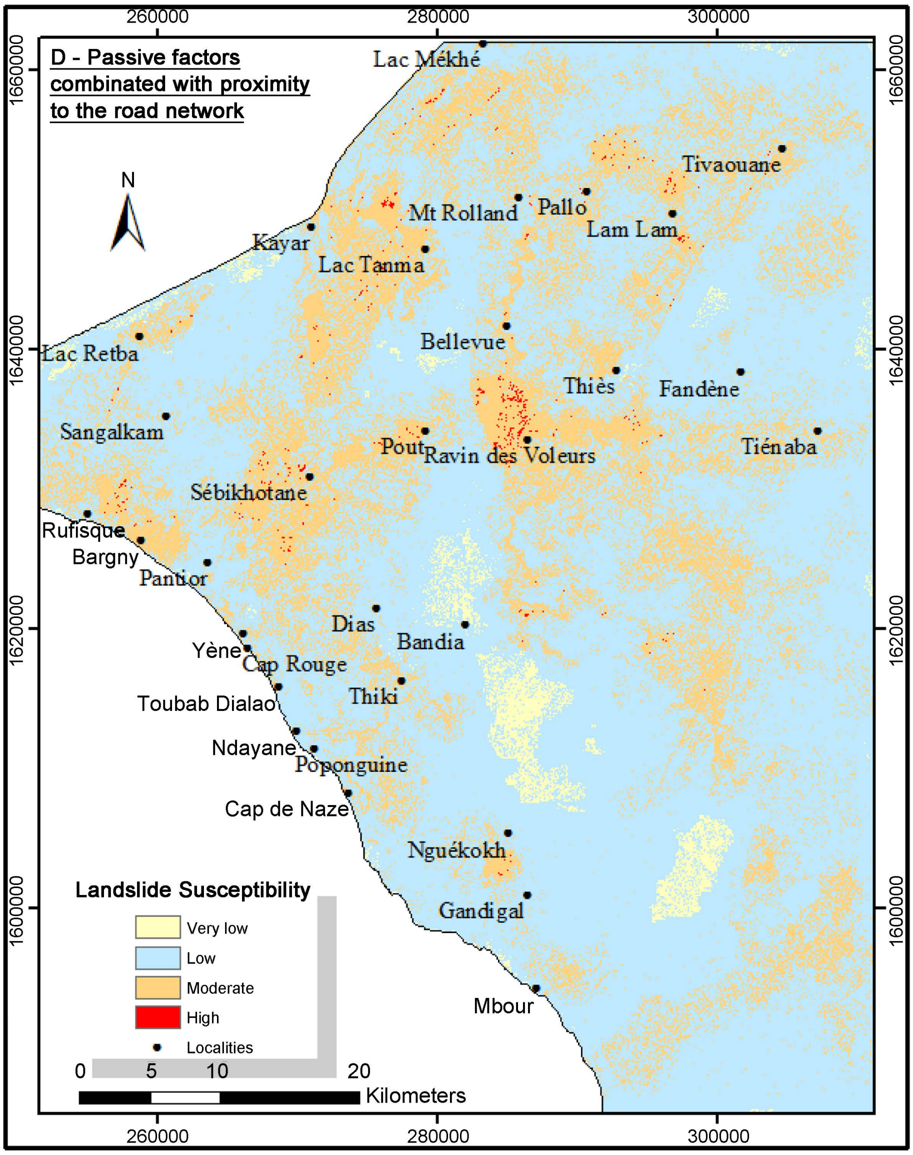

Figure 7. Landslides susceptibilities considering passive factors combinated with the proximity to the road network.

Table 4. Percentage of land in different susceptibility classes.

Susceptibility classes	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Very low	2.01	1.36	0.71	2.31
Low	64.25	71.56	60.56	73.97
Moderate	32.75	26.72	38.24	23.54
High	0.56	0.34	0.48	0.18
Very high	0.43	0.02	0.01	

with the landslides map. The *ArcGIS proximity tool*, was used to compare the distances between the positions of the predicted susceptibilities and the observed landslides. The results are presented in the histograms below (Figure 8).

Passive factors alone (Figure 8(a)) show two populations:

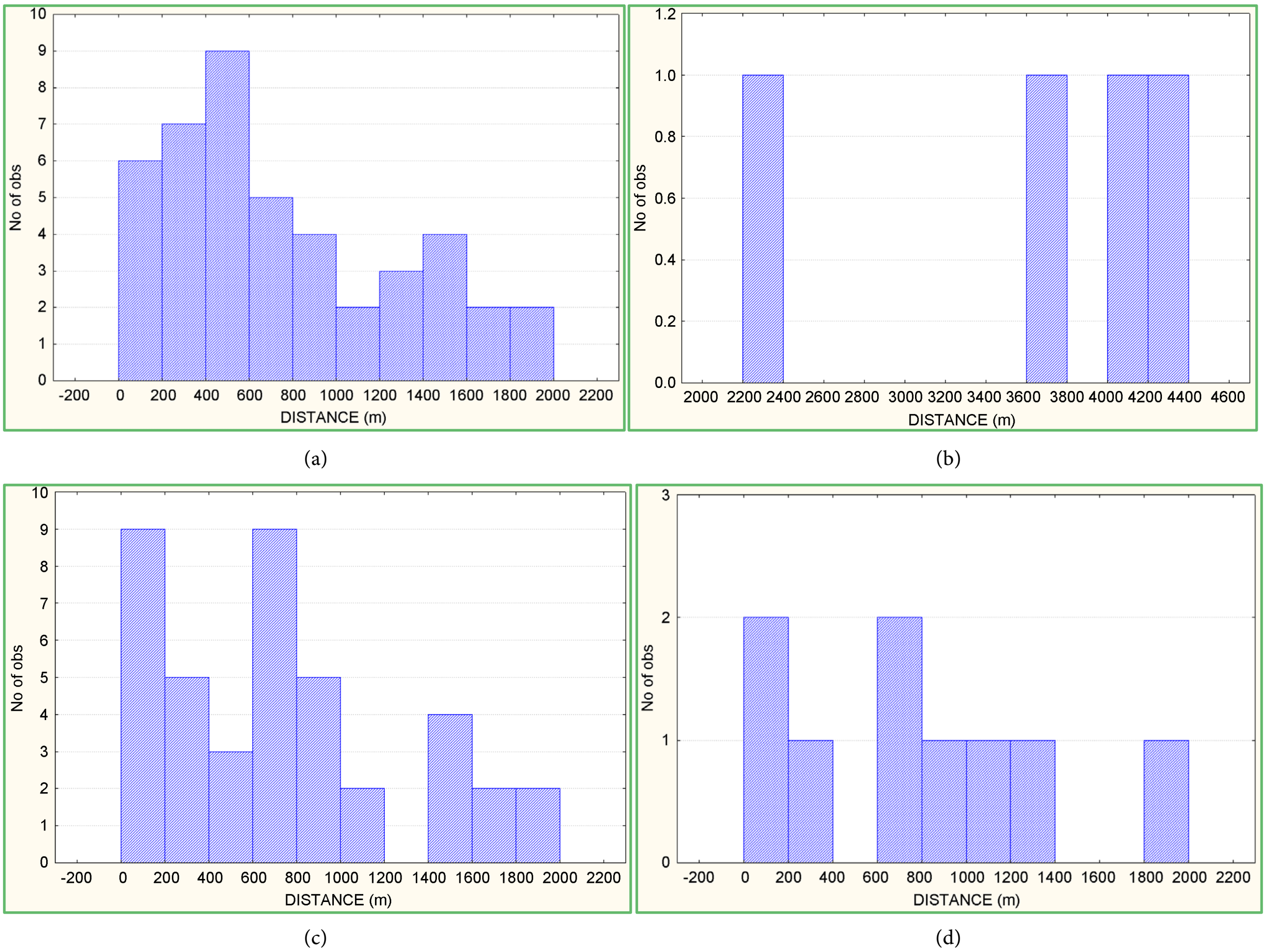

Figure 8. Distances between predicted susceptibilities and observed landslides by considering passive factors alone (a) passive factors associated with proximity to the hydrographic network (b), passive factors associated with rainfall (c), and passive factors combined with proximity to the road network (d).

- a first population containing 70% of the sample at distances of less than 1000 m and
- a second population comprising 30% of individuals with distances greater than 1000 m.

Passive factors combined with rainfall (Figure 8(c)) show similar bimodal distributions, but with different percentages. Indeed, 80% of cases of predicted susceptibilities are located at less than 1200 m of the observed field movements and the remaining 20% between 1400 and 2000 m.

By combining passive factors with proximity to the road network, 33% of predicted susceptibilities are localized within 400 m of the observed landslides, 55% between 600 and 1400 m and 12% between 1800 and 2000 m (Figure 8(d)).

In all cases, the predicted susceptibilities are closer to the observed landslides around the Thies Cliff than to the Dias Horst.

The predicted susceptibilities by combining the passive factors and the hydrographic network are always located at distances greater than 2200 m from the observed movements. This situation is due to the weak influence of the hydrographic network on susceptibility (Figure 8(b)).

6. Conclusion

This work shows that the zones of the Dias Horst and the Thies Cliff while remaining globally stable present locally areas susceptible to instabilities. The susceptibility factors classified as passive factors and active factors allowed us to generate four models of susceptibility. Apart from Scenario 4 (passive factors combined with proximity to the road network), all other models subdivide the area into five levels of susceptibility. For the model obtained with Scenario 4, no very high level of susceptibility was noted. For all scenarios, we noted the predominance of low to very low susceptibility sites. This could be explained by the low relief. Rainfall is the active factor that most influences susceptibility. High to very high susceptibility sites occupy less than 1% of the area and are encountered at the Thies Cliff and some slopes of the Dias Horst hills. The hydrographic network, although considered as an active factor, does not seem to influence the susceptibility to the landslides in our study area. For all our models, the prediction is better around the Thies Cliff. In a later study, it would be interesting to spatialize the active factors or to weigh them according to their geographical positions. Moreover, the development of a software allowing to take into account the decimal part of the scores should improve the results obtained.

Acknowledgements

The authors would like to thank Drs. Ibrahima MALL (Department of Geology-Cheikh Anta DIOP University of Dakar) and Makhaly BA (UFR Engineering Sciences-Thies University) for their valuable contributions and advice in this research project.

References

[1] Thiam, M.M., Ndiaye, M., Fall, M., Sarr, R. and Medou, J.O. (2014) Contribution to the Numerical Geological Mapping of the Paleocene in the Western Part of Thiès (Senegal). *Open Journal of Geology*, **4**, 495-504. https://doi.org/10.4236/ojg.2014.410036

[2] Gladima, S.A. (1988) Etude de la stabilité de la Corniche Est de Dakar. Mem. Ing. IST., No. 14, UCAD.

[3] Fall, M. (1993) Etude de la stabilité du versant naturel des Madeleines. Mem. Ing. IST., No. 41, UCAD.

[4] Ndoye, I. (2009) Etude de la stabilité de la tête de la presqu'île de Dakar-Corniche Est. Mem. de DEA. UCAD.

[5] Fall, M., Samb, S.S., Ndiaye, M., Sall, O.A. and Samb, F. (2011) Cam-Clay Models Using Castem 2000© and Plaxis© for the Study of the Slope Stability of the "Corniche Ouest" of the Dakar Peninsula (Senegal, West Africa). *Geomaterials*, **1**, 51-58. https://doi.org/10.4236/gm.2011.12009

[6] Gomis, B. and Diedhiou, S. (2012) Etude du comportement géomécanique de la falaise du Cap de Naze et environs par les méthodes RMR, GSI et GEOSLOPE. Projet de Fin d'Etudes d'Ingénieurs de Conception. UFR-SI Université de Thiès.

[7] Coly, A.D. and Diamanka, S. (2013) Utilisation des outils géomécaniques pour la

caractérisation de la stabilité de la falaise du Cap de Naze et de la falaise de Popenguine. Projet de Fin d'Etudes d'Ingénieurs de Conception. UFR-SI Université de Thiès.

[8] Roger, J., Banton, O., Barusseau, J.P., Castaigne, P., Comte, J.-C., Duvail, C., Nehlig, P., Noël, B.J., Serrano, O. and Travi, Y. (2009) Notice explicative de la cartographie multi-couches à 1/50 000 et 1/20 000 de la zone d'activité du Cap-Vert. Ministère des Mines, de l'Industrie et des PME, Direction des Mines et de la Géologie, Dakar, 245 p.

[9] Bellion, Y.J.C. (1987) Histoire géodynamique post paléozoïque de l'Afrique de l'ouest d'après l'étude de quelques bassins sédimentaires (Sénégal, Taoudenni, Iullemmeden, Tchad). Thèse Université d'Avignon et des pays de Vaucluse, 266 p.

[10] Flicoteaux, R. (1975) Sur l'attribution à l'Eocène moyen des couches calcaires et argiles—Phosphatées de Pallo (Plateau de Thiès, Sénégal occidental). *Bull. Soc. Géol. France*, *7*, 430-434.

[11] Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V. and Reichenbach, P. (1989) Landslide Hazard Mapping by Statistical Methods: A "Black-Box" Model Approach. In: Siccardi, F. and Brass, R., Eds., *International Workshop on Natural Disasters in European-Mediterranean Countries*, Perugia, 27 June-1 July 1989, CNR-US NFS, 427-445.

[12] Carrara, A. (1982) Cartografia tematica. stoccaggio ed elaborazione dati. In: *atti del Convegno Conclusivo* P.F. Conser. Suolo, Sottopr. Fenomeni Franosi, Relazione Generale, 9-10 giugno 1982, Roma, 265-281.

[13] Hansen, A. (1984) Landslide Hazard Analysis. In: Brundsen, D. and Prior, D.B., Eds., *Slope Instability*, Wiley, New York, 523-602.

[14] Leroi, E. (1996) Landslide Hazard—Risk Maps at Different Scales: Objectives, Tools and Developments. *Proceedings of the VII International Symptom on Landslides*, Trondheim, June 1996, 35-52.

[15] Soeters, R. and Van Westen, C.J. (1996) Slope Stability: Recognition, Analysis and Zonation. In: Turner, A.K. and Shuster, R.L., Eds., *Landslides*: *Investigation and Mitigation*, Transportation Research Board, National Research Council, Special Report 247, 129-177.

[16] Aleotti, P. and Chowdhury, R. (1999) Landslide Hazard Assessment: Summary Review and New Perspectives. *Bulletin of Engineering Geology and the Environment*, **58**, 21-44. https://doi.org/10.1007/s100640050066

[17] Bortolami, G.C., De Luca, D.A. and Masciocco, L. (1994) Studio sullarealizzazione di carte dellafranosità a scala regionale. *Proceedings of the IV Geoengineering International Congress* "*Soil and Groundwater Protection*", Torino.

[18] Ercanoglu, M., Kasmer, O. and Temiz, N. (2008) Adaptation and Comparison of Expert Opinion to Analytical Hierarchy Process for Landslide Susceptibility Mapping. *Bulletin of Engineering Geology and the Environment*, **67**, 565-578. https://doi.org/10.1007/s10064-008-0170-1

[19] Roopnarine, R., Eudoxie, G. and Opadeyi, J. (2013) Soil Friction Angle as an Instability Factor in Landslide Susceptibility Modeling. *Journal of Earth Sciences and Geotechnical Engineering*, **3**, 55-71.

[20] Nandi, A. and Shakoor, A. (2006) Preparation of a Landslide Susceptibility Map of Summit County, Ohio, Using Numerical Models. *Proceedings of the* 10*th IAEG Congress*, The Geological Society of London, Nottingham, England, Paper No. 660.

[21] Guzzetti, F., Carrara, A., Cardinali, M. and Reichenbach, P. (1999) Landslide Hazard Evaluation: A Review of Current Techniques and Their Application in a Multi-Scale Study, Central Italy. *Geomorphology*, **31**,181-216.

[22] Kouamé, K.F. (1999) Hydrogéologie des régions de montagne: Apports des données de télédétection et des méthodes statistique et fractale à l'élaboration d'un système d'information hydrogéologique à référence spatiale des aquifères discontinus du secteur Man-Danané. (Ouest de la Côte d'Ivoire). Thèse de Doctorat 3è cycle, Université de Cocody.

[23] Mall, I., Diaw, M., Madioune, H.D., Ngom, P.M. and Faye, S. (2014) Use of Remote Sensing and GIS for Groundwater Potential Mapping in Crystalline Basement Rock (Sabodala Mining Region, Senegal). Nova Science Publisher, Hauppauge, 317-336.