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LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN THE AMZAZ VALLEY, CENTRAL RIF, MOROCCO

APPROVED BY

SUPERVISING COMMITTEE:

Carlos Valdir de Meneses Bateira (supervisor)
Faculty of arts, University of Porto

Laura Maria Pinheiro de Machado Soares (Chairman)
Faculty of arts, University of Porto

José Augusto Alves Teixeira (Main arguer)
Faculty of arts, University of Porto

Classification:.....Values

Faculty of arts of University of Porto

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LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN THE AMZAZ VALLEY, CENTRAL RIF, MOROCCO

BY

ABDELHAK EL-FENGOUR

THESIS

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Abstract

The aim of this dissertation is to assess mass wasting susceptibility and the causes that influence its spatial occurrence. The study area named Amzaz valley (385 km^2) located in northern region of Morocco, administratively belongs to the Fez-Meknes district. This river catchment was chosen for its geological and geomorphological features in addition to that area is heavily prone to slope instability that damaging houses, infrastructures and agricultural areas. These effects can be minimized or avoided if mass movement prone areas are identified in advance by landslide susceptibility assessment.

Landslide susceptibility is the likelihood of landslide occurrence in area predicted on the basis of local terrain conditions. Several methods proposed worldwide for landslide susceptibility assessment. Information Value Method has been applied to prepare landslide susceptibility map.

Seven geo-environmental factors that believed to have influence on slope instability were used, factors included are: slope orientation, slope angle, topographic wetness index, curvature, land use, lithology and superficial formations, all parameters are space variables. Landslide inventory data base was built from the archive of local authorities and satellite image interpretation.

It was possible to obtain susceptibility map for each two types of landslides. The values of AUC obtained were 0.73 for rotational landslides and 0.75 for translational landslides.

Key words: Landslides, Information Value, Susceptibility, Rif, Slope instability

Resumo

O objetivo deste trabalho é avaliar a susceptibilidade de deslizamentos e as causas que influenciam sua ocorrência espacial. A área de estudo é denominada como bacia de Amzaz (com 385 km^2), localizada na região norte de Marrocos e administrativamente pertence ao distrito Fez-Meknes. Esta bacia foi escolhida pelas suas características geológicas e geomorfológicas, numa area que é muito propensa a instabilidade que, por vezes, provocam danos em habitações, infra-estruturas e áreas agrícolas. Estes efeitos podem ser minimizados ou evitados se as áreas propensas a movimento de massas foram identificadas previamente pela avaliação de susceptibilidade de deslizamentos.

A susceptibilidade de deslizamentos é a probabilidade de ocorrência de deslizamentos de terra na área prevista com base na análise estatística de variáveis físicas. Os métodos para o cálculo da susceptibilidade podem variar mediante o autor, no presente estudo optou-se pelo valor informativo.

Foram utilizados sete fatores geo-ambientais que têm influência sobre a instabilidade de vertentes, nomeadamente: orientação de vertentes, declives, índice topográfico de humidade, curvatura, uso do solo, litologia e formações superficiais. A base de dados com o inventário relativo a deslizamentos (translacionais e rotacionais) foi construída a partir da interpretação de imagens de satélite e inventários cedidos pelas autoridades locais.

Conseguiu-se obter um mapa de susceptibilidade para cada um dos dois tipos de deslizamentos. O mapa de movimentos rotacionais obteve uma taxa de sucesso de 0.73, e translacionais obteve-se o valor de0.75.

Palavras-chave: Deslizamentos; Valor Informativo; Suscetibilidede; Rif instabilidade de vertentes.

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Acronyms and abbreviations

ABHS *(L'Agence de Bassin Hydraulique de Sebou)* hydrological agency of Sebou river basin

ANCFCC (*Agence Nationale de la Conservation Foncière, du Cadastre et de la Cartographie*) National Agency of Land Conservation, Land Registry and Mapping

API Aerial Photographic Interpretation

AUC Area Under Curve

DEM Digital Elevation Model

DPLT *(La direction provinciale de l'équipement et de transport de Taounate)* provincial direction of equipment and transportation in Taounate

EPOCH European Programme on Climate and Natural Hazards

FAO Food and Agriculture Organization

FS Factor of Safety

GIS Geographic Information System

HCEFLCD (Le Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification) High Commissariat of Water, Forest and Combating Desertification

HCP (*Haut commissariat au plan*) High Commission for Planning

LI Landslides inventories

LPEE (*laboratoire public d'essais et d'etudes à Taounate) public laboratory for experiments and studies*

MAPM Ministry of Agriculture and Sea Fishing

TWI Topographic Wetness index

UNESCO: United Nations Educational, Scientific and Cultural Organization

WP/WLI The International Geotechnical Societies' UNESCO Working Party on World landslide inventory.

Introduction

Context

Landslides, slips, slumps, mudflows, rockfalls are just some of the terms which are used to describe movements of soils and rocks under the influence of gravity. These movements can at best be merely inconvenient, but from time to time they become seriously damaging or even disastrous in their proportions and effects (Bertran, P., 1993) .

Slope instability is widely recognized as an ever-present danger. Landslides and other gravity-stimulated mass movements are important and costly problem, and they are a continual source of concern for geotechnical engineers and geologists throughout the world, particularly in geologically 'active' regions (Maurer, G., 1968).

Problem definition

Landslides are natural hazard that affect marly slopes in the Amzaz valley mostly triggered by heavy rainfall (Gartet, A., 2010). Landslides have generated important economic, social and ecological effects, by destruction parts of useful agricultural areas, and by damaging houses, roads, tunnels, careers and other basic infrastructures (Chakon, J., 1995). The reduction of socio-economic losses due to landslide activity needs effective methodology for analysis, quantification and prevention of this hazard (Carrara, A. *et al.*, 1999).

The landslides causes are mainly related to geomorphologic instability, they occur at various spatial and temporal scale (Crozier, M. J. and Glade, T., 2006; W, K. M. *et al.*, 2006).

There are two major sets of factors that trigger slope movement; conditioning and triggering factors. Conditioning factors include: geology, geomorphic settings, slope angle, slope aspect, faults, soil thickness and elevation. The trigger factors make the slope actively unstable, they are generally external forces acting to increase the shear stress (Terzaghit, K., 1950) trigger factors include earthquakes (Chigira, M. *et al.*, 2003), human actions and rainfall.(Sharma, R. H. and Nakagawa, H., 2005).

There are two basic methods for landslide susceptibility/hazard zonation: the direct and indirect mapping methods (Guzzetti, F. *et al.*, 1999; Henriques, C. d. S., 2014; Schuster, R. L. and Krizek, R., 1978), direct mapping, the geomorphologist based on his experience and knowledge of the terrain conditions determines the degree of susceptibility directly. Indirect mapping uses either statistical models or deterministic models to predict landslide prone areas, based on information obtained from the interrelation between landslide conditioning factors and the landslide distribution.(Van Westen, C. J. *et al.*, 2003).

Regarding indirect mapping technique, a set of methods have been developed for this purposes can be classified into qualitative factor overly, statistical models, and geotechnical processes (physically-based) models (Henriques, C. d. S., 2014).

Qualitative approach (Heuristilc analysis) rely heavily on the a priori knowledge of landslides and their processes in a region; they can be carried out with either the direct geomorphologic mapping method or the indirect qualitative map combination method.

Statistical approaches attempt to use quantitative relationships between past landslides and the environmental conditions that led to them to indirectly predict future landslides in areas with similar environmental (Varnes, D. J., 1984) conditions under the assumption that the "*past and present are the keys to the future*" (Soeters, R. and van Westen, C. J., 1996).

Aims and objectives of the study

The main objective of this research is to access the spatial probability of landslide occurrence in the Amzaz catchment area trying to create a helpful agent for decision about land use policies.

In order to reach the main goal of this study, two sub objectives were defined, such as:

- Presenting the physiography and making cartography of geographical components of study area;
- Landslide susceptibility assessment using a statistically-based method (Information Value Method). Validation through the quantification of the

model prediction and success rate

To answer these objectives, this dissertation was constructed in 4 chapters:

Chapter 1: entitled "physiography of the study area", will define boundaries of study area as well as geophysical background, its geology, land use and climate.

Chapter 2: entitled "slope instability" will establish the criteria of landslide classification as well as landslide inventories for the study area.

Chapter 3: entitled "landslide susceptibility assessment using Information value method" was assigned to Perform landslide susceptibility assessment using statistically-based method (Information Value Method) for each landslide inventory by acquisition and preparation of predisposing factors.

Chapter 4: entitled "analysis and validation of results" aims to Validate landslide susceptibility assessment model, discussion and conclusion.

CHAPTER 1: PHYSIOGRAPHY OF THE STUDY AREA

1. Physiography of the study area

This chapter will demonstrate a brief different characterizations of the study area contextualized geographically in the northern Morocco.

1.1. Geographical placement

Amzaz valley sub-catchment is located in the central Rif, is a part of river catchment named Ourgha (Figure 1.1), limited from North east by sub-catchment Sahla of Sra valley, South east by Sahla valley sub-catchment, from the west by Aulay valley sub catchment, on the south part is the confluence with Ourgha river, the north limit is the divide of main drainage basin located in Oudka mountain. Its boundaries were defined by a ridge lines in total area of 384 $Km^{2.}$ this area was chosen for its geological and geomorphological characterization. It is quite important to mention that this study include just the downstream of Amzaz valley.

The study area belongs administratively to the region Fes Meknes, province of Taounate, commune of Ghafsai, characterized by a high density of population(82.36 inhabitant per km^2) (HCP, 2004).

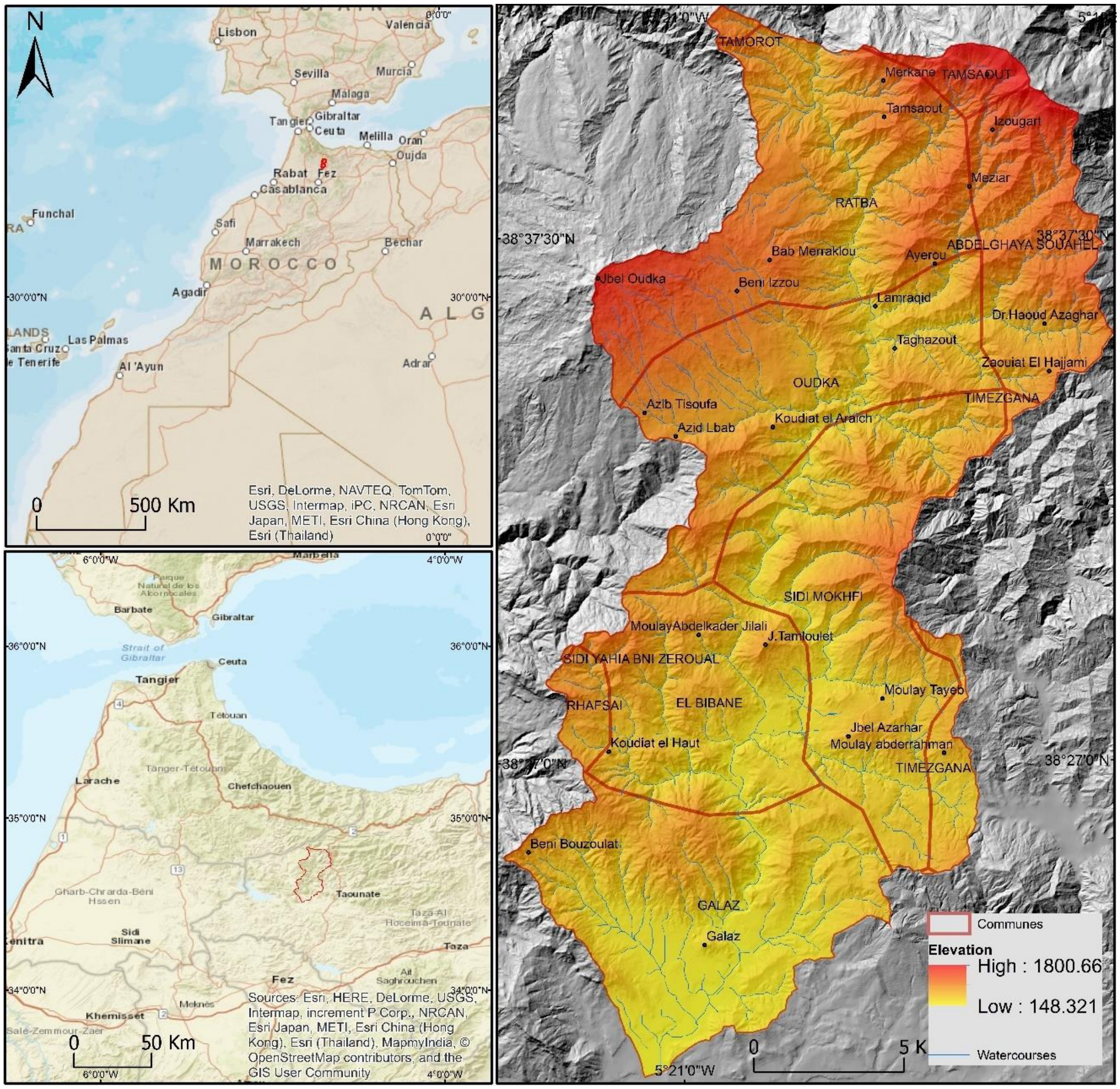

Figure 1.1— Gegraphical placement and limites of Amzaz valley. Source: Esri data & maps 2013

Administratively the sub-catchment has inter-rural communes covering distributed among the communes of Souahel (25.2 %), Elbibane (2.7 %), Galaz (15.3 %), Oudka (10.9 %), Ratba (19.4%), Ghafsai (1.3 %), Sidi Mokhfi (8.9%), and Timzgana (13.2%)

1.2. Geology and geomorphology

The study area belongs to the Rif belt which is a segment of the Mediterranean Alpine belts.

1.2.1. Geology of Amzaz valley

Amzaz valley is divided into three zones, according to structure and stratigraphy criteria, from north to the south, Intrarif, Mesorif and Prerif (Figure 1.2).

1.2.1.1. Intrarif

The Intrarif zone includes the most distal units derived from the African paleomargin. These units crop out immediately beneath the Maghrebian Flyschs and Dorsale units.

The Ketama unit consists mainly of Lower Cretaceous series where siliciclastic turbidites predominate, involves, at least, two sub-units.(Puglisi, D., 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).

The Tanger 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, G., 1980). The Tanger series spans the Cenomanian-Maastrichtian interval in Central Rif, whereas it is diverticulated in Western Rif into an Internal Tanger unit (Cenomanian-Senonian) and and External Tanger unit (Campanian-Paleocene).

1.2.1.2. Mesorif

The Mesorif zone displays different characteristics in Western-Central Rif and Easern Rif, east of the Nekor Fault, respectively: Western and Central Rif which characterized by antiforms with Lower-Middle Miocene rocks in the core and mainly Mesozoic thrust units above them. The allochthones units have two possible origins, either infra- or supra-Ketama, and Eastern Rif which is complete and easily recognized 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 less diverticulated units, duplicated and folded together during the pre-Miocene synmetamorphic event (Chalouan, A. *et al.*, 2008). Their meta sediments are deformed into over turned folds stretched along their WSW-trending axes, which is consistent with a sinistral throw during the Alboran Terrane-Africa oblique collision.

1.2.1.3. Oligocene-Miocene "Post-Nappe" Cover

The youngest levels of the late orogenic, deeply unconformable Ghomaride-Malaguide cover, include two groups of formations, defined at the Betic-Rif scale, from bottom to top, the late Oligocene-Aquitanian Ciudad Granada Group, and the

Burdigalian Vinuela Group (Serrano, I. *et al.*, 2003) The Fnideq Formation and its Betic counterpart the Alozaina Fm both belong to the Ciudad Granada Group. They begin with quartzose conglomerates passing upward to alternating sandstones and marls with benthic and pelagic fossils of Late Oligocene and Aquitanian age.

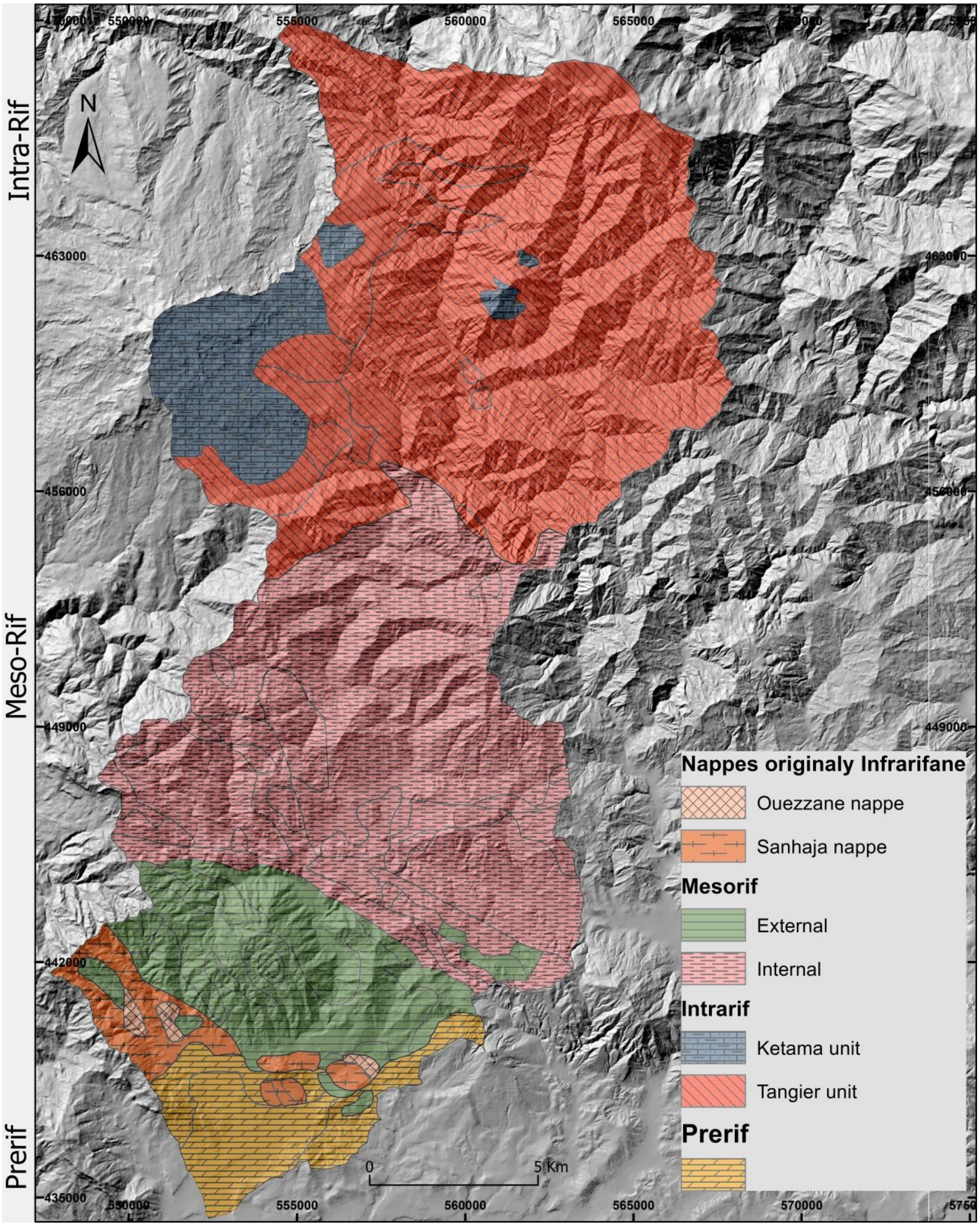

Figure 1.2 — Structural context of Amzaz catchment area (Extracted from structural scheme of geological map of Taounate- Ain Aicha Sauter, G. and Mattauer, R., 1964)

1.3. Lithological facies

As it was discussed in section 1.2.1.1 Ketama unit involves, at least, two sub-units. The southern unit begins with Sinemurian massive 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 corresponds to the Valanginian, Barremian and Aptian-Albian times, being characterized by thick quartzose turbidites Vraconian belemnite marls and spongolites are preserved to the north.

Marly-pelitic formations of the Intrarif zone expose the upper Cretaceous Eocene also some facies contrast with the dominant pelites, such as the Cenomanian-Turonian phtanites. The formation come from 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 limestones.

1.4. Geodynamic settings of study area

The structure and the tectonic style of the External Rif are dominated by major southward-directed thrusts that bound the various domains (Chalouan, A. *et al.*, 2001) The main tectonic phase in the External Rif is Middle to Late Miocene in age, (Chalouan, A. and Michard, A., 2004; Negro, F. *et al.*, 2007) they have also been active since the Early Miocene (Late Burdigalian) and the Late Miocene (Tortonian),(Asebriy, L. *et al.*, 1993; Leblanc, D., 1990), the deformation that had affected external Rif, developed east-west oriented structure including folds, thrust and foliation.

However, these structures locally show a north-south preferred orientation along the western Mesorif, Benyaich, A. (1991) described west-vergent folds and thrust that deform the Mesoorif and Intrarif units of Loukkous and external Tanger; in the Ouzzane thrust sheets, located north, west and south of Ouzzane, where Tejera De Leon, J. (1993); (Tejera De Leon, J., 1997) described thrusts and folds that deforme Eocene to middle Miocene rocks; along the Habt thrust sheet and the Intrarif In the region of Ksara El Kebir – Arbaoua; This region was studied by (Zakir, A., 2004; Zakir, A. *et al.*, 2004) who noted the presence of ramps and accommodation folds. The area also characterized by the occurrence of earthquakes of moderate magnitude and it is an area of complex tectonic deformation and is under the potential threat of natural hazards induced by seismicity(Buforn, E. *et al.*, 1995).

1.5. Climate

Amzaz valley characterized by a subhumide climate (Sadiki, A. *et al.*, 2009) displaying a strong seasonality in temperature and precipitation

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

The mean temperature of the area falls within a range from 11 to 29, the difference between the summer and winter temperature is in the order of 11, the lowest temperatures occur on January. In winter, temperature has the highest variance and the largest oscillation. In summer the temperature not only higher but also more stable as the conditions of Amzaz indicate (Figure 1.3).

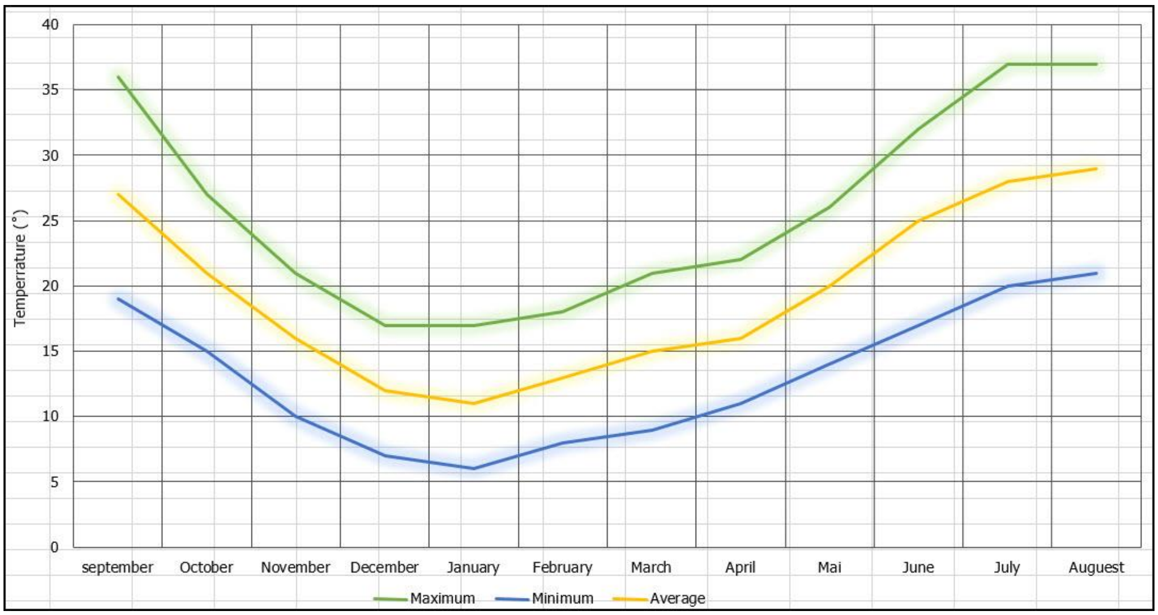

Figure 1.3 — Mean monthly temperature of the station Ourtzagh

Rainfalls are often short but very intense. Their distribution is irregular both in time and in space and most of the water courses are ephemeral, apart from the Aamzaz River that drains the catchment (Sadiki, A. *et al.*, 2007).

With the annual rainfall in the range between 412 and 2471 mm (Figure 1.4) the area can be characterised as semi-arid to humid (Chaaouan, J. *et al.*, 2013) 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 favourable in the autumn for then the influence of the Azores anticyclone is still significant and the higher temperatures over the Mediterranean warm the air and charge it with precipitation.

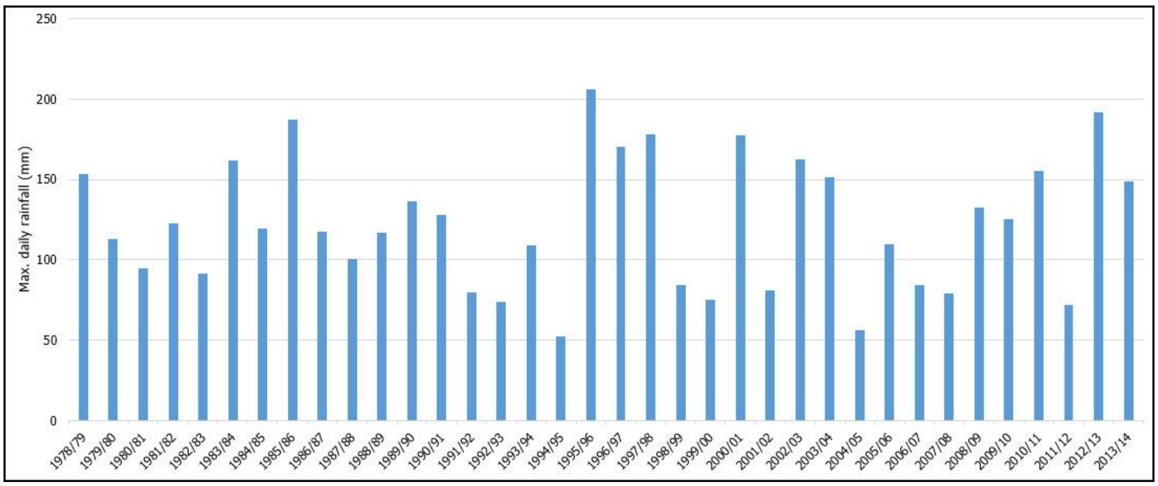

Figure 1.4 — Interannual variation of annual maximum monthly rainfall for Jbel Oudka meteorological station source: HCEFLCD

For the study area of the Amzaz valley, information on daily precipitation is available from the nearby meteorological station at Oudka mountain. This station, with absolute daily rainfall value of 205.90 mm (Figure 1.4) was recorded during the hydrological year 1995/96.

1.6. Relief and morphology

Based on hypsometric map (Figure 1.5) the average altitude of 1010 m with a peak of 1820m and river mouth with 220 m, we can divide Amzaz catchment 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 the altitude 1600 m, this part of the catchment is rough testifies a powerful dynamic. The rapid passage from high altitudes (1630 m) to low altitudes (230 m) has a distance around 14 kilometres. The second part of the catchment starts with altitude of 455 m, we observe a balance between the altitude of the front of Jbel Beni Ounnai on the West (970 m) and the peak of Ballouta on the East (1030 m). This part can be considered as a canal which will play the role of intermediary between the upstream and downstream which starts with weak altitudes (449 m) characterized by the low altitudes especially at Sidi el Mokhfi (230 m) and Galaz (375 m) comparing to the other areas of the catchment with its smooth morphology characterized.by sedimentation process.

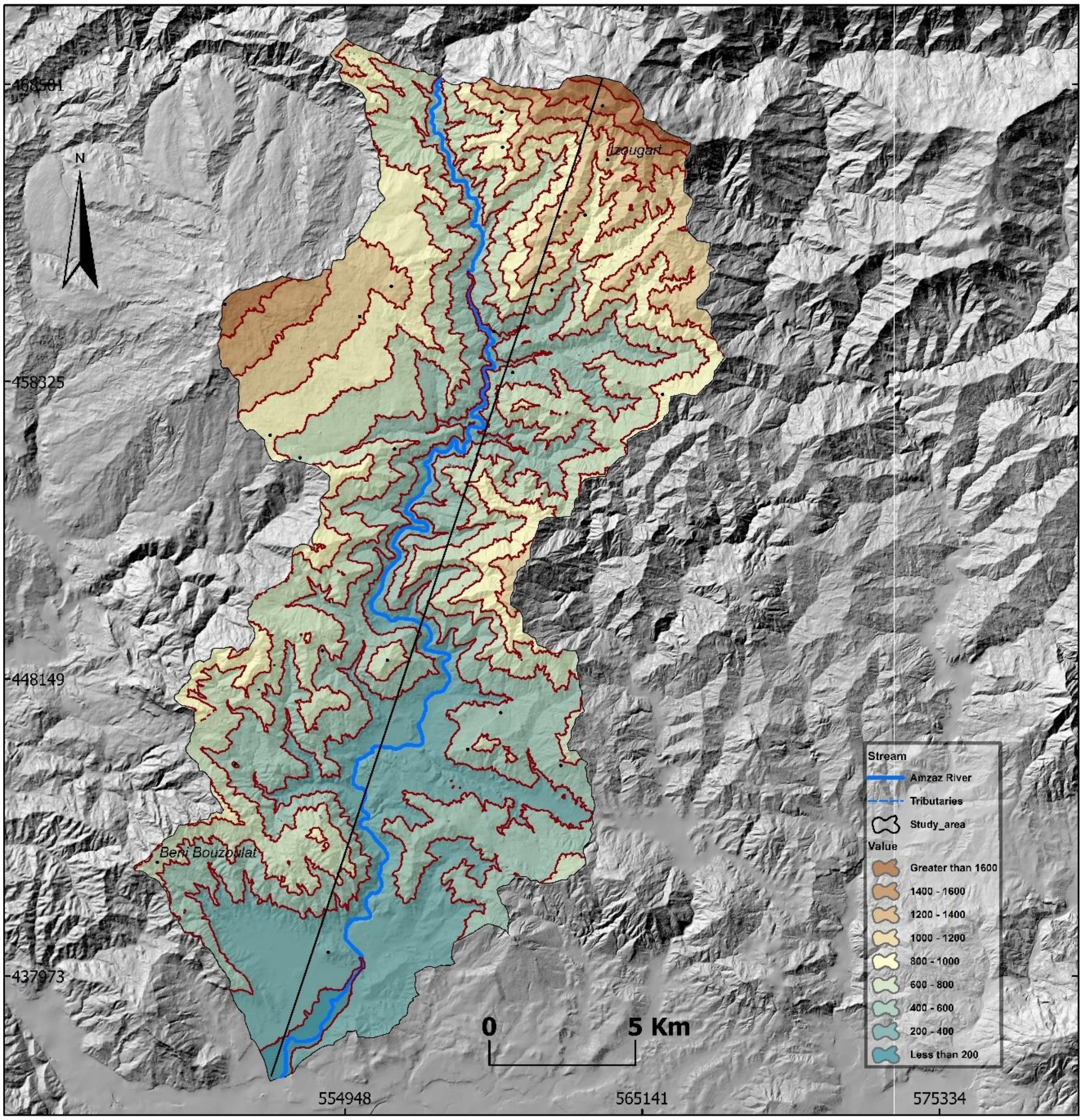

Figure 1.5 — Hypsometric map with a cross profile (straight black line) of the study area

The general cross section profile (Figure 1.6) shows that from the North-East to the south-west along of 35 kilometres is characterized by a contrasting morphology. It is marked by peak crest lines and hills knolls and ridges that juxtapose V-shape and U-shaped valleys with cols and saddles that dissects the landscape. Derivative and winning structures, all through its profile, form bowl-like structures and cones at different heights.

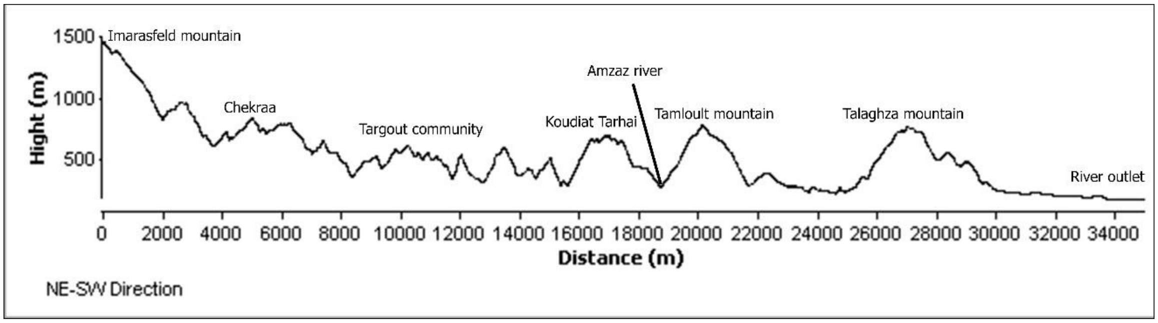

Figure 1.6 — General cross section of the study area

1.7. Drainage system

Hydrographic network of the study area varies depending on the local morphology although dominated by a parallel drainage patterns network which are often found in areas with steep relief (Oudka and Sidi Ali Mohamed mountains) and is over non-cohesive materials. Detail stream shows a parallel drainage network at steep slopes and dendritic network patterns are typical of adjusted systems on erodible sediments and uniformly dipping bedrock in the low lowlands (Pidwirny, M., 2006).Most first order streams at the high altitudes are with parallel drainage patterns with stream flowing close to each other over a short distance because of the steep nature of slopes. Flow is fast and straight flowing in the same direction.

1.8. Summary

Amzaz catchment is a part of central Rif characterized by antifoams with Lower-Middle Miocene rocks in the core and mainly Mesozoic thrust unit above them, the Tifelouest-Tafraout-Afress-Ghafsai group of Infra-Ketama units corresponds to folded duplexes at the very front of the Ketama Massif, the post-rift sequence begins with the Callovian-Oxfordian “ferrysch”, followed by Kimmeridgian and Tithonian-Berriasian micrites, and Neocomian pelites.

The study area mainly characterised by steep slopes, on these slopes, relatively deep soils may be present or form rapidly through weathering of the weakly compacted and cemented marls. These soil-mantled slopes have a strong disposition to landsliding when the equilibrium between shearing resistance and shear stress is disturbed. The neotectonic activity in the area can lead to seismic triggering of landslides but most if not all recent landslides are rainfall-induced and caused by elevated pore pressures on the lithic contact between the soil and the marl bedrock.

CHAPTER 2: SLOPE INSTABILITY

2. Slope instability

The purpose of this chapter is to establish the norms for the definition and classification of the landslides that will be used in this work, in addition, the explanation of methodology that was used to fulfil landslides inventories of the study area.

2.1. Susceptibility and hazard

According to Glade, T. and Crozier, M. J. (2005) the susceptibility is a relative spatial likelihood for the occurrence of a certain phenomenon of a particular type and volume in a given area. In other terms defined susceptibility as (Crozier, M. and Glade, T., 2004) "the propensity of an area to undergo landsliding. However, the hazard is the probability of occurrence of a particular phenomenon within a specified period of time and in a given area (Ardizzone, F. *et al.*, 2002).

Landslide Evaluation methods can be subdivided into direct and indirect mapping methods (Henriques, C. d. S., 2014), In the direct mapping (e. g. geomorphic mapping and mapping based on aerial photograph interpretation), the geomorphologist based on his experience and knowledge of the field conditions determines the degree of susceptibility directly. Whereas, indirect mapping (e. g. statistical mapping, landslide isopleths and heuristic assessment). uses either statistical model or deterministic model to predict landslide prone areas based on information obtained from the interrelation between landslides conditioning factors and landslides distribution(Van Westen, C. J. *et al.*, 2003).

On any slope there are two forces acting antagonistically. There is the sheer stress, which promote movement, and the shear strength that tries to resist to movement. Generally, when a slope is stable, the shear strength tends to exceed the shear stress, In slopes that are at the point of movement, the shear stress and shear strength are approximately equal; in this case there is no margin of stability (Crozier, M. J., 1986) whenever the shear stress exceeds the shear strength, slope movement may occur, this increase in shear stress may be due to internal forces and/or external transient forces; for example, rainfall and/or earthquakes.

Slope movement is not always due directly to factors increasing the shear stress. If there is a decrease in shear strength, automatically the shear stress increase, and whenever it exceeds the shear strength movement occurs, some of the factors that may contribute to decreased shear strength are: weathering, change in water regime and organic decay.

Varnes, D. J. (1978) states that mass movement results from both internal and external influences. The following are some of the exogenic factors which lead to slope instability:

1. The steepening or heightening of slopes,
2. The removal of lateral or underlying support (especially as a result of stream or road cuts),

3. Loading ("surcharge") of the upper edge of the slope following construction, landfill dumping, land sliding or other factors,
4. Changes in either relative relief (local differences in altitude) or slope gradient as a result of faulting, tectonic uplift, or the creation of artificial slopes by grading with construction machinery,

These factors are complemented by internal causes of landslide which include the following:

1. Weathering processes which promote the physical and chemical breakdown of slope materials,
2. Removal of vegetation either by wildfire or through human activities,
3. Increase in pore water pressure,

2.2. Slope movement typology

Cruden, D. M. (1991 p.28) defined slope movement as "the movement of a mass of rock, debris or earth down a slope". This supersede the simply and widely used definition of a landslide given by Varnes, D. J. 1958 in Schuster, R. L. (1978 p.2) indicated that slope movement would be the most appropriate terms since it didn't infer process. "A downward and outward movement of slope forming materials under the influence of gravity".

Varnes, D. J. (1978) classified landslides on five kinetically distinct types of landslides: falls, slides, flows, topples and spreads (Cruden, D. M. and Varnes, D. J., 1996).(Figure 2.1), the scale of the diagrams could vary from a few meters to hundreds of meters as shown by the example the bellow.

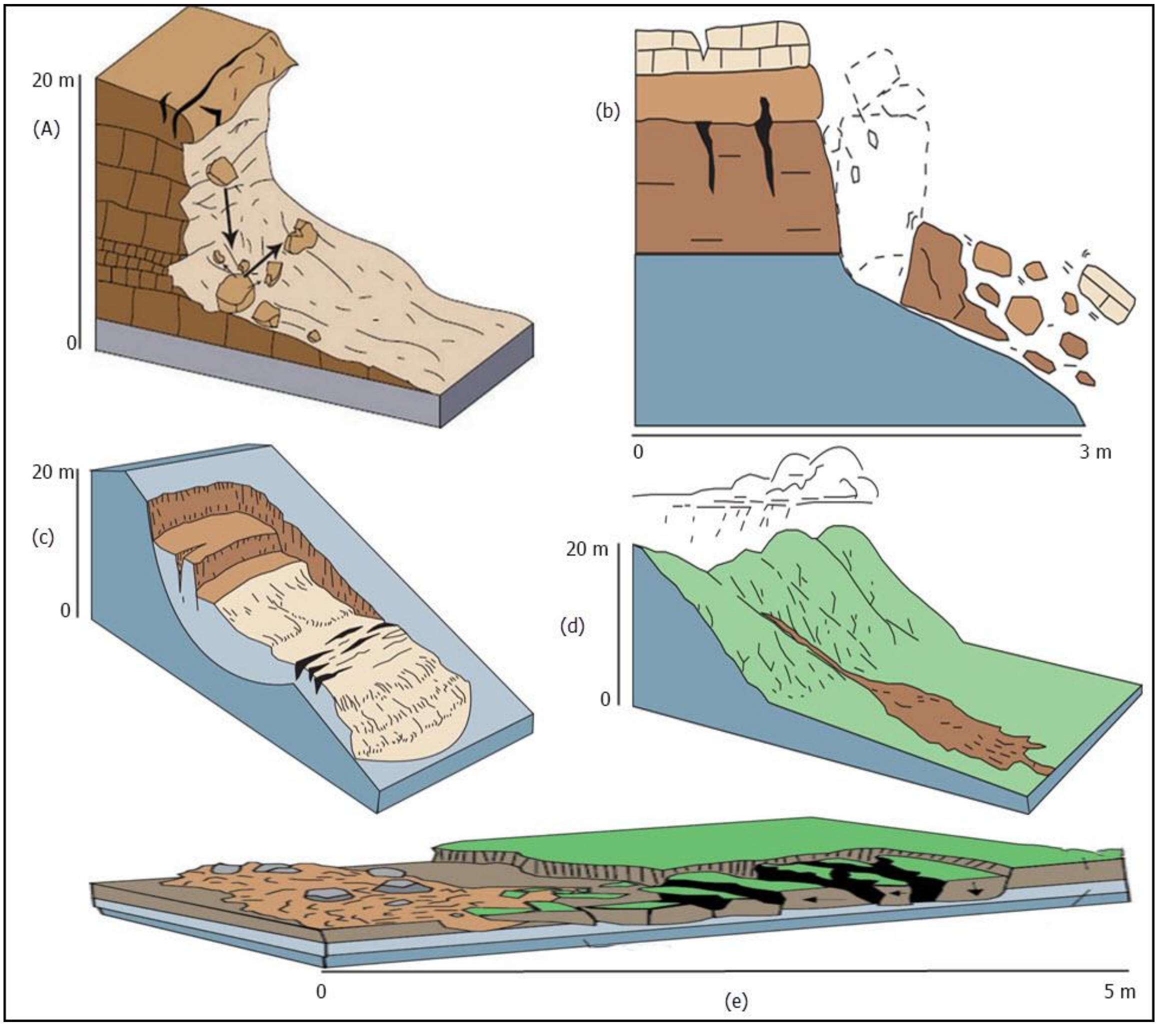

Figure 2.1 — Five fold classification of landslides types modified from Varnes, D. J. (1978) a) Fall b) Topple c) Slump d) c) Flow e) Lateral Spread (after Cruden, D. M. and Varnes, D. J., 1996)

Classification of landslides can be made on the basis of numerous factors including the type of movement, material involved, speed of movement, geometry of the slide area and the degree of development. (Cruden, D. M. and Varnes, D. J., 1996).

Type	**Rock**	**Debris**	**Soil**
Fall	Rock fall	Debris fall	Soil Fall
Topple	Rock Topple	Debris topple	Soil topple
Slump (rotational)	Dingle (Slump)	Single (slump)	Dingle (Slump)
Slide (translational)	Block slide	Block slide	Slab slide
Planar	Rock slide	Debris slide	Mudslide
Lateral spreading	Rock spreading	Debris spreading	Soil spreading
Flow	Rock flow	Debris flow	Mud flow
Complex	Rock avalanche	Flow slide	Slump-earthflow

Table 2.1 — Landslides classification derived from EPOCH project (Dikau, R. *et al.*, 1996)

This classification is based on EPOCH project that ran from 1991-1993 (Table 2.1) defines categories of mass movements based on the type of movement but there are further subdivided according to material subdivided involved on the failure.

In this study the focus will be only on slides since they were the most often landslides fond within Amzaz valley.

Slides were defined as *"a downslope movement of soil or rock mass occurring dominantly on the surface of rupture or on relatively thin zones of intense shear strain"* (Cruden, D. M. and Varnes, D. J., 1996), moreover, there are a couple of types of slides, 1) Rotational slides 2) Translational slides.

Rotational slide (slump) is a landslide on which the surface of rupture is curved upward (spoon-shaped) is a sliding of a mass of (homogeneous and usually cohesive) soil on a rotational rupture surface. Little internal deformation. Prominent main scarp and back-titled landslide head. Normally slow to rapid, but may be extremely rapid in sensitive or collapsive soils. The shape of the rupture surface usually departs to a certain degree from constant curvature, tending towards compound sliding. Rotational landslides occur in homogeneous massives clay deposits excavated by stream erosion or artificial earth works and in man-made fill slopes. The shear plan of shallow rotational slides is roughly circular spoon-like. In contrast with translational slides, where the planar surface often originates from a weakness zone, the circular shape of rotational slide is created by the failure itself and derives from the geometrical distribution of the shear stress (Fabio, V. D. B., 2011), The shear surface of shallow rotational landslides can be assumed as cylindrical shape, whose axis is parallel to the slope (Cruden, D. M. and Varnes, D. J., 1996; Henriques, C. d. S., 2014).

Translational slides known that the mass moves down and outward along a relatively planar surface with a little rotational movement or backward tilting. There is a couple of types of translational slides: translational slides with a composite shear plane (non-rotational) and translational slides occurring along a planar shear plane, the first type of landslides are controlled structurally, however the second type are controlled by surfaces weakness (Jones, K. A. and Lee, E. M., 1994) (flat stratification, contact between a debris cover and rocky substrate).

Landslides can be further subdivided depends on affected material in: rock slides, debris slides and mudslides, which generally occur in mountainous environment.

Debris slide/shallow translational slide, sheet slides, mudslide, mudflow, and slump-earthflow occur due to a complex process, generally most of them occur as a result of relatively loose material saturated with water (Jones, K. A. and Lee, E. M., 1994). In clay soil occur when the water content is higher than liquid limit whilst in rocks and debris material can flow due to trapped air or water or even through antiparticle impacts (Bromhead, E. N., 1992).

2.3. Landslides causes of occurrence: preparatory, triggering and predisposing factors

There are a variety of landslide causes compiled by a verity of authors.(Crozier, M. J., 1986; Dikau, R. *et al.*, 1996; Terzaghit, K., 1950) Those causes were divided into those that increased the shear stress, and those that resulted in a decreased shear strength, However some of them can influence both the shearing stress and shear strength (Varnes, D. J., 1978), Therefore it is important to think of landslides resulting from a complex interplay of preparatory and triggering factors (Shuster, R. L. and Weizorek, G. F., 2002).

Preparatory factors consist of the cumulative events which prepare the slope for failure (e.g. Heavy rainfall, toe erosion and earthquake) by reducing the factor of safety but do not necessarily produce movement.

Triggering factors reduce the factor of safety below unity and initiate the movement producing a slope that is actively unstable (Crozier, M. J., 1986).

Sustaining factors keep the material involved in motion, either intermittently or continuously

2.4. Landslides inventories of the study area

Landslide inventories map shows the location of mass movement that have left discernible features in an area (Guzzetti, F. *et al.*, 2000; 2012) and provide useful information for landslides to model landslides at a basin scale, and to train or validate landslide susceptibility or hazard models Landslides inventories (LI) are fundamental component for landslide susceptibility assessment (Soeters, R. and Westen, V., 1996).

Guzzetti, F. *et al.* (2012) indicate that landslide inventories can be prepared using different techniques, therefore, the selection of the appropriate technique depends on the purpose of the inventory, size of the area covered, time required, skills and experience of the investigators, in addition to the available resources (Guzzetti, F. *et al.*, 2000).

The main objective of this section is to produce landslides inventories based on the data available at *laboratoire public d'essais et d'etudes à Taounate* (LPEE) and *la direction provinciale de l'équipement et des transports de Taounate* (DPLT), in addition to landslides inventories from literature reviews and researches have been done on that area (Elfengour, M., 2008; Lelandais, F. and Fabre, G., 1975, 1996; Mesrar, H., 2011), however the data provided by these sources was not enough for the implementation of a model, then we used different techniques have been described by several authors.

The first method we used was aerial photos by following the processes and tools described by Dai, F. C. and Lee, C. F. (2003). The efficiency and accuracy of mapping surface elements particularly landslides scars are based on geomorphologist skills (Guzzetti, F. *et al.*, 2012)also the knowledge of the terrain (Zêzere, J. L. *et al.*, 2009) ,this stage of work was facilitated by a good knowledge of the terrain and combination of GIS tools and software.

The third method used for landslide inventories was a type of indirect mapping known as semi-automated (Guzzetti, F. *et al.*, 2012) for the identification and extraction of features in a satellite image using different wavelengths or a cluster of pixels as explained by Lakshmanan, V. (2012). However, due to the poor quality (resolution) of the satellite image that has been used, this semi-automated method for mapping landslide scars, overestimated the slope movements in many parts of the study areas, non-identificated in others and misrepresented in some cases. As a result, the process was rendered invalid. Thus the best options for reliable inventories were database available at (LPEE), (DPLT) and field survey.

To complete landslide inventories the Figure 2.2 illustrate deformation such as fractures and cracks in roads and houses and other types of structures, such instability indicators have a key role for defining some landslides boundaries.

Figure 2.2 — Types of structure damage or deformations used to define landslide boundaries: a) Vertically fractured house b) Damage in electric column c) Fracture parallel to a road c) Fracture parallel to a road with translation

According to agriculture nature of the study area it is difficult to observe shallow landslides because their evidences are constantly removed by agricultural activities which intensive and cover 50% of the study area.

The study area prone to different types of mass movement mainly landslides with their two types:

Rotational slides have a curved slip surfaces. The result is a pattern of scars and depositional features, of which most common is the spoon-shaped scar associated with shear failure along arcuate planes. This type of movement can cause a great deal of property damage if the slope has built upon (Smith, K., 2013). A good example is the landslide event which affected the community of Tisoufa (Figure 2.3) on the eastern side of Oudka mountain, this landslide triggered in the past (Maurer, G., 1968). The site of this landslide offer appropriate geo-environmental conditions for mass movement trigger, it is an area of weakness among three different geological structures which lead to faults activation. The top layer consists of Numidian limestone over a claystone layer.

Numidian limestone characterized by a high transmissivity allows the water to percolate through cracks and pores to get to the impermeable bedrock, thereby, landslide trigger under the pore-water pressure and the force of gravity. Furthermore, on the slipped mass there are several small lakes that retain rainfall water and saturate the soil, thus, reactivation of the slide frequently.

By analysing the morphology of this slide, there is a variety of units starting with a large main scarp for a landslide originated from the Quaternary (Maurer, G., 1968) followed by three new scarps , the first one was during 2009 and the second in 2013, the major short-term cause was an increase in pore-water pressure associated with heavy rainfall in the previous month, it caused losses to the road and 30 dwellings were damaged.

In addition to physical factor, there is the anthropogenic intervention by means of roadcuts in a relatively steep slope that lead to a change in geophysical characteristics and make it susceptible to mass movement. Also overloading of hillslopes by housing construction. This extra weight my increase the chance of slope failure; moreover, clear cutting of trees promotes soil erosion and weakens the support of soils by tree roots. It also reduces evapotranspiration and raises the water tables.

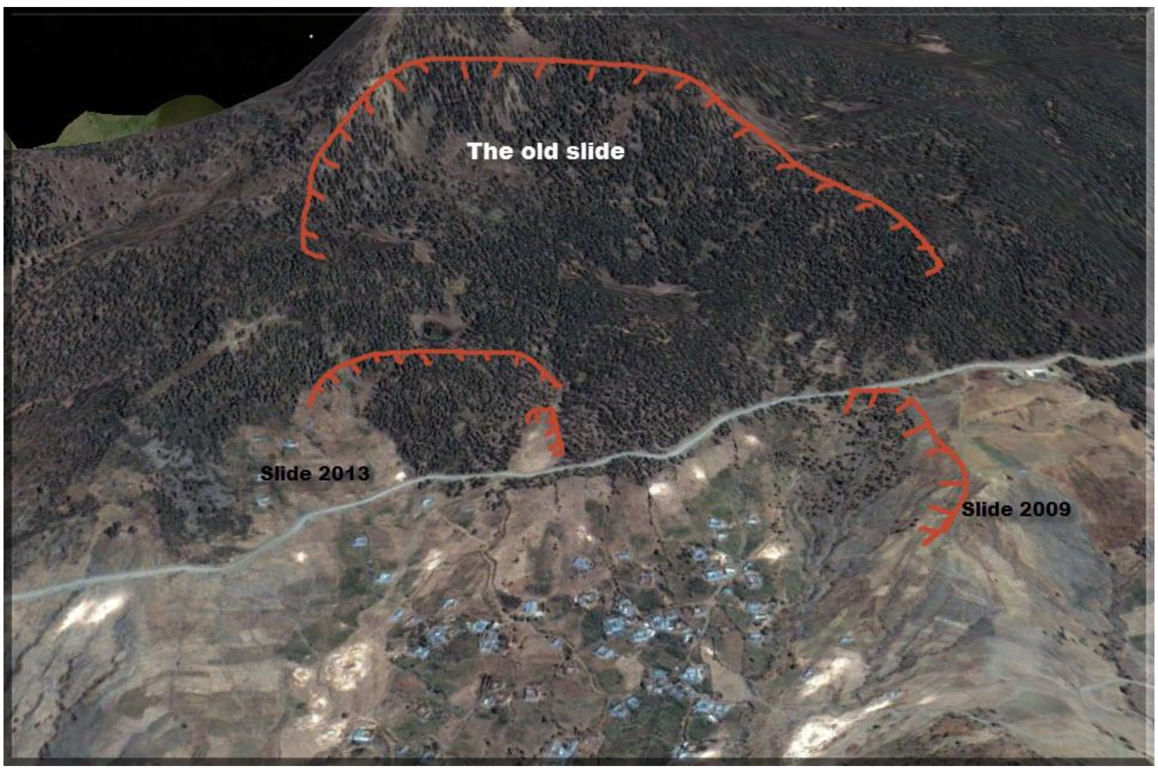

Figure 2.3 — Tisoufa landslide (google earth image)

The second type is translational slides, have relatively uniform, planar surface, of movement and are sometimes known as block glides and debris slides. Intersecting planar slip surfaces from wedges of rock (Bell, F. G., 2003). This kind of landslides is common in the study area in particular along the roads (Figure 2.4) due to the fact that soil vibration during road works and the excavation of slopes decrease the slope stability in addition to the removal of lateral support at the foot of a slope, moreover, deterioration of cut slope reduces the value of geotechnical parameters (intact rock strength, cohesion and friction) of slope material and mass, thus reducing factor of safety to unstable conditions.

Figure 2.4 Translational landslides that affect provincial road Nº 5308 (Source: DPLT, 2011)

it should be mentioned that a large number of landslides within the study area do not represent a clear behaviour, either sequence (complex movement) or simultaneously (composite movement).

According to EPOCH, E. C. P. (1993); Hutchinson, J. N. (1988) the classification schemes of landslides should be based on the morphology, the processes and type of material involved as well as the rate of movement. However, in this study the classification is only based on the morphology (rotational and translational) due to the lack of experience and knowledge of being able to estimate the depth using aerial photographic interpretation (API), even data available in resources doesn't involve enough details.

The first landslide inventories resulted in 29 scars from literature reviews for the period of time between 2006 and 2011, 17 landslides were classified as rotational and 12 as translational.

For the second landslide inventory was derived by orthophotomap interpretation, has been identified 89 landslides scars, 4 classified as rotational and 85 as translational landslides. The third inventory has been achieved by field investigation and resulted in 33 landslide scars, 12 of them identified as translational and 21 as rotational.

	Landslides types		
	Rotational	Translational	**Total**
Nº of landslides	217	145	**362**
Landslides density (n/km^2)	0.5651	0.3776	**0.9427**
Total affected area (Km^2)	0.1516	0.328	**0.4796**
Unstable (% of total area)	0.040	0.090	**0.1246**

Table 2.2 — Statistical analysis for the whole inventory

Based on statistical analysis of landslides (Table 2.2) that the most common type within the study area is rotational slides regarding the number. However translational slides are the larger type regarding the average size.

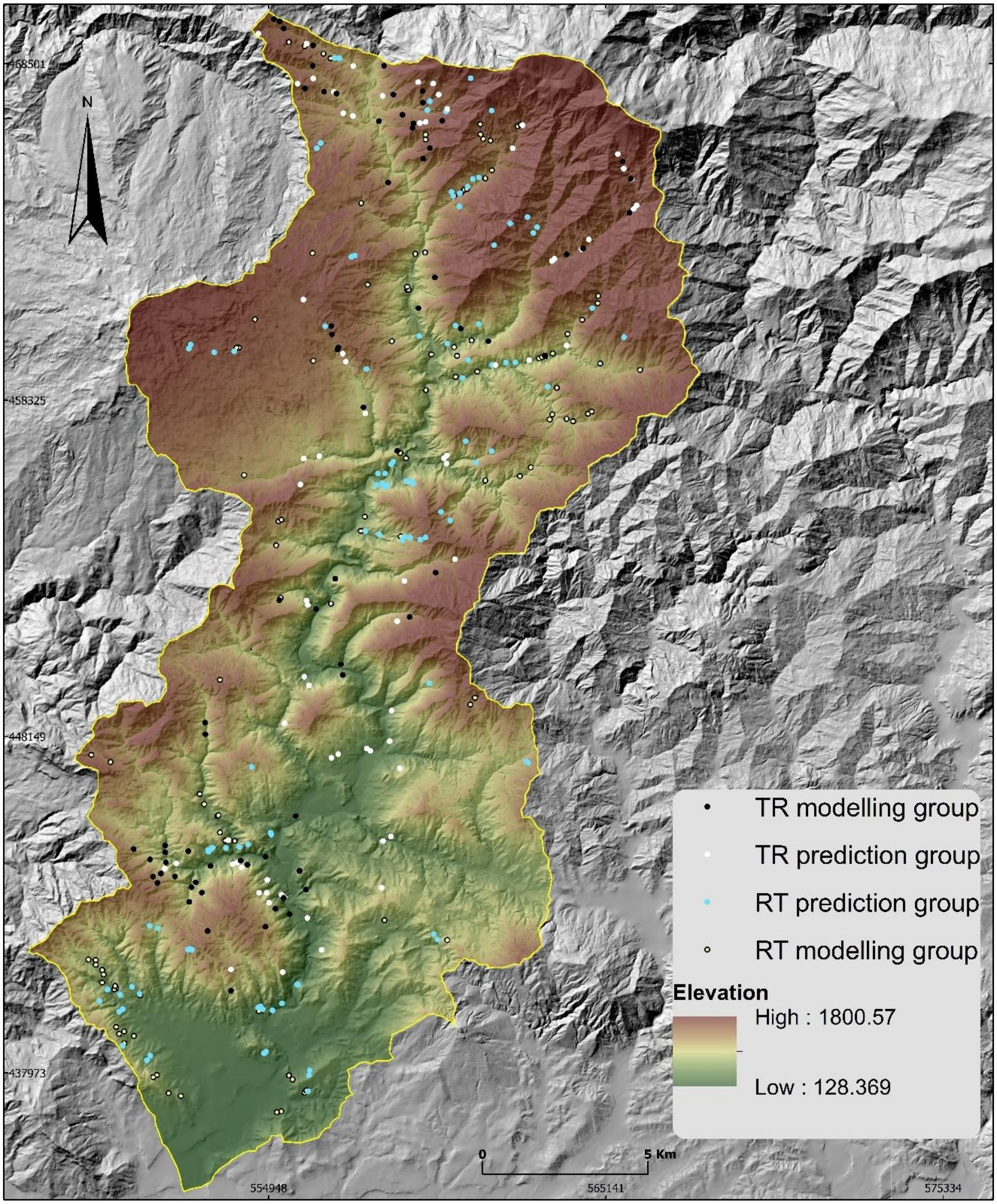

Figure 2.5 — Location of centroid of shallow landslides

To conclude, the majority of inventories were mapped based on orthophotomap interpretation. As it has been mentioned earlier in some areas, mapping landslide scares (Figure 2.5) becomes much more difficult, whether in areas where the typical geomorphological features of landslide have been eroded away or modified, for example by farming activities or the landslide is inactive or heavily vegetated. It requires more indirect interpretational skills. These facts are important to be mentioned because it affect statistical assessment of the landslide susceptibility.

CHAPTER 3: LANDSLIDES SUSCEPTIBILITY ASSESSMENT USING STATISTICAL APROACH (INFORMATION VALUE METHOD)

3. Landslides susceptibility assessment using information value method

Statistical analysis is the use of quantitative relationship between past landslides and the environmental conditions that led to them to indirectly predict future landslides in areas with similar environmental conditions under the assumption that "*the past and present are the keys to the feature*" (Soeters, R. and Westen, V., 1996). This indirect, quantitative method provides a spatial probability for landslides occurrence. Statistical analyses are popular because they provide a more quantitative analysis of slope instability and have the ability to examine the various effects of each factor on an individual basis. Statistical analysis of slope instability can include bivariate and multivariate methods. As an example for multivariate methods there are SVMs (Support Victor Machine regression), LR (Logistic Regression) and DTs (Decision Trees). While we can indicate these examples for bivariate methods, FR (Frequency Ratio), WOE (Weight of Evidence) and SI (statistical Index) IV (Informative Value) .(Yin, K. L. and Yan, T. Z., 1988).

Van Westen, C. J. (1994) define bivariate methods as a modified form of the quantitative map combination with the exception that weightings are assigned based upon statistical relationship between past landslides and various factor maps, individual factor maps (independent variable) or combination of factor maps are overlaid with a landslide map (dependent variable) to develop cross tabulations for each factor and class.

In this chapter the focus will be only on bivariate informative value which was chosen for landslides susceptibility assessment.by following numerous steps (Figure 3.1).

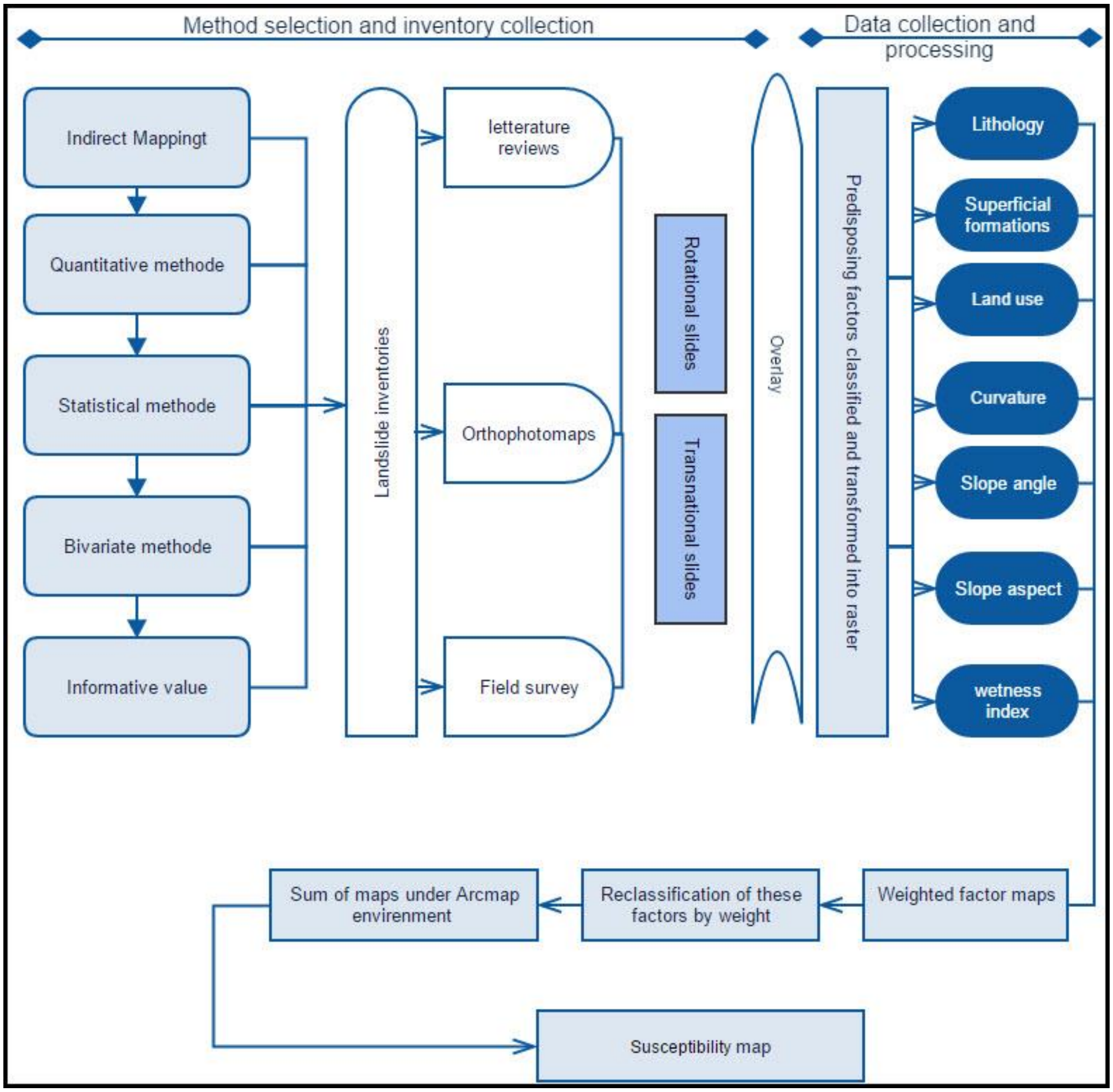

Figure 3.1 — Work flow overview of information value method

3.1. Informative value method

The information value method estimates the influence of each conditioning factor to mass wasting and it is able to differentiate between more and less impacted within a relevant layer. The method was originally proposed by (Yin, K. L. and Yan, T. Z., 1988) expressed as (Equation 3.1).

$$Ii = \log \frac{Si/Ni}{S/N}$$ Equation 3.1

Where,

- Si is the area with landslides belonging to modelling group and the presence of variable Xi.
- Ni is the number of pixels with variable Xi.
- The S is the total number of pixels with landslides belonging the modelling group.
- N is the total number of pixels.
- The S/N means a priori probability, the likelihood of each pixel to have a landslide without any consideration of predisposing factor.
- Si/Ni is the conditional probability to have 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 3.2)

$$IV_j = \sum_{i=1}^{m} X_{ij}\ IV_i$$ Equation 3.2

Where,

IVj is 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.

3.2. Preparation of landslides conditioning factors

In any slope instability analysis, the good knowledge of the mechanisms is required in order to identify the main factors for analysis. Landslide initiation is due to a variety of factors interacting in a complex way, because the process involved happen in a continuous manner from cause to affect (Varnes, D. J., 1978)

There is a wide set of thematic data that could be used on the information value method for landslide susceptibility assessment in the study area, in this chapter eight variables were considered as predisposing factors, which are manly related to lithology, soil type and morphology. Obtained either from exist maps or derived from digital elevation model (Figure 3.2).

3.2.1. Construction of Digital Elevation Model

Digital elevation model is a digital representation of earth's topography which is presently used in several applications such as hydrology, geomorphology, geology and risks mitigation. It is one of the most important imputes in modelling or simulating of landscape as well as dynamic natural phenomena such as flooding, soil erosion and landslide (Wilson, J. P. and Gallant, J. C., 2000). Due to the importance of DEM related with terrain researches and applications, it is required to build a high quality DEM in order to obtain a higher quality of models and its derivatives that come into account with the DEM.

In order to perform a detailed geomorphological analysis, a DEM 5m pixel size (Figure 3.2) of the study area was constructed. This model was generated from two types of data: contour lines and quoted points, altimetry data derived from National Agency of Land Conservation, Land Registry and Mapping (ANCFCC) at 1:50 000 scale (contours with 10m of interval and quoted points).

Digital elevation model will be used for derive several variables such as slope angle, slope aspect and curvature.

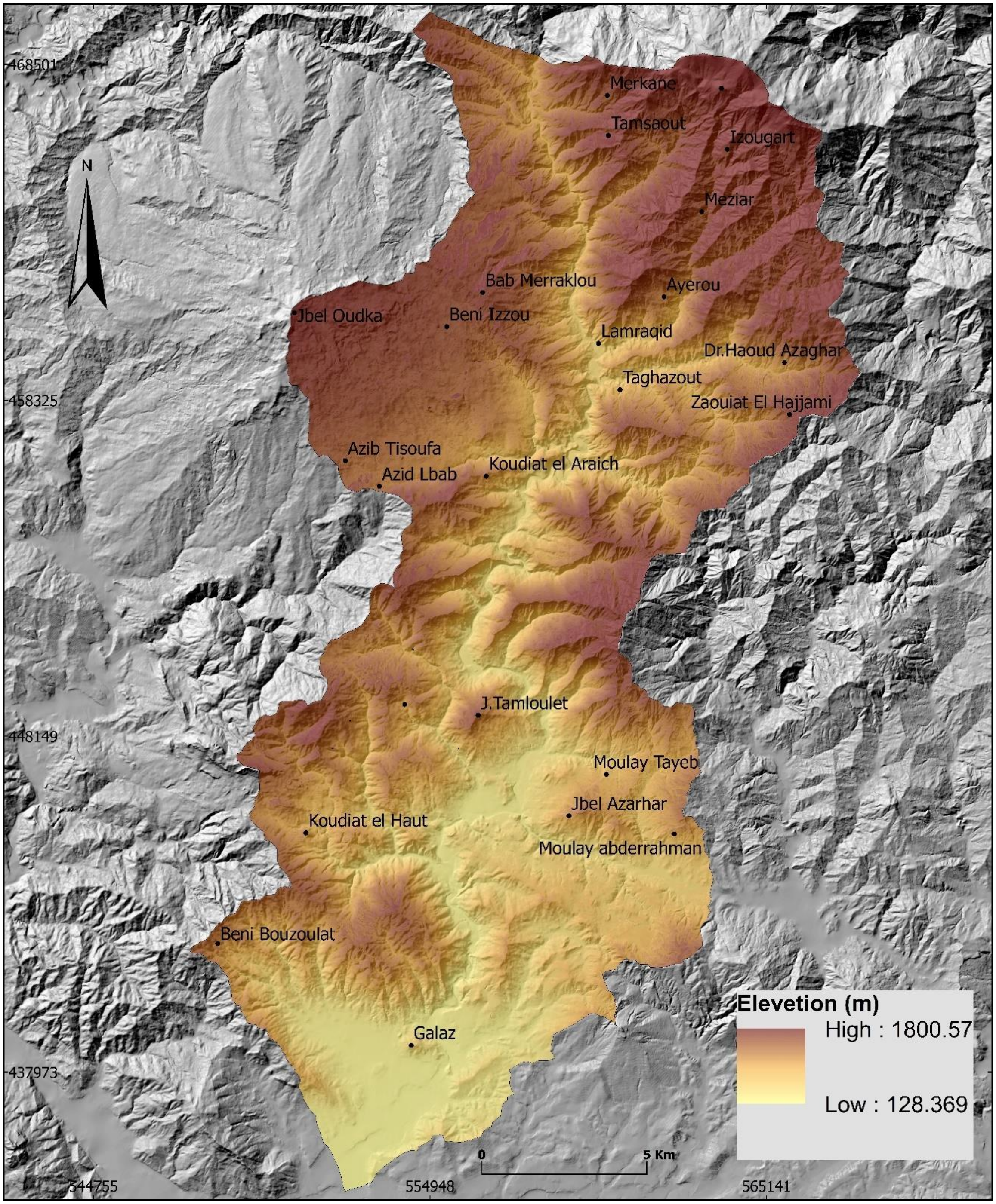

Figure 3.2 — Digital elevation model (DEM) of the study area

3.2.2. Lithology

It is widely recognized that geological parameters greatly influence the occurrence of landslides, due to the fact that lithological and structural variations often lead to a deference on strength and permeability of rocks and soils (Pradhan, B. *et al.*, 2010). Among predisposing factors (such as slope angle, slope aspect, distance to streams and roads, land use and land cover), lithology with respect to its type and mechanical characteristics play a significant role in controlling the nature and rate of geomorphological process taking place on the slopes.

Regarding landslide susceptibility mapping the lithological parameters such as lithology and tectonic structures are important parameters in landslide, this is because lithological and structural variations may often lead to different susceptibility to geomorphological processes, resistance against weathering and variation in geotechnical properties.(Dai, F. C. and Lee, C. F., 2002).

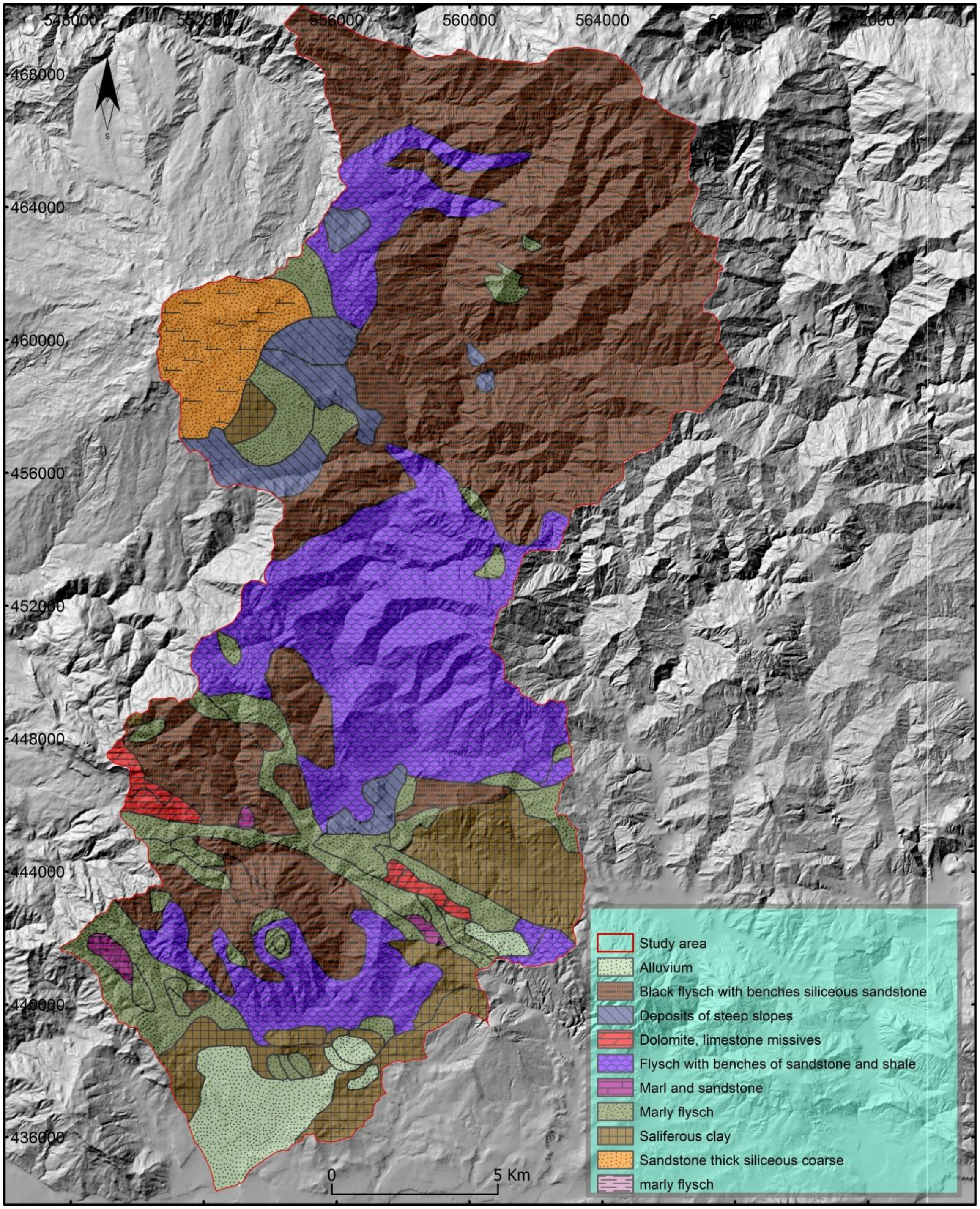

Figure 3.3 — Litho-stratigraphic map of the study area, extracted from: geological map of Rif, area of middle Ourgha, Taouunate – Ain Aicha (Sauter, G. and Mattauer, R., 1964)

Lithological facies	Area (km^2)	Area (%)
Alluvium	14.67420125	3.79
Black flysch with benches siliceous sandstone	168.93723826	43.65
Deposits of steep slopes	14.65828359	3.79
Dolomite, limestone missives	5.33674002	1.38
Flysch with benches of sandstone and shale	94.87717277	24.51
Marl and sandstone	1.73590717	0.45
Marly flysch	43.92546713	11.35
Saliferous clay	29.33322132	7.58
Sandstone thick siliceous coarse	13.564364	3.50
SUM	**387042595.20**	**100**

Table 3.1 — Areal distribution of lithological classes

Litho-stratigraphic map (Figure 3.3) and statistical detail (Table 3.1) shows that Black flysch with benches of siliceous sandstone (upper cretaceous) occupies 43.6 5% of the study area with 168.93 Km^2 especially on the north east and south east, while Flysch with benches of sandstone and shale (Middle cretaceous) occupies 24.51% with total area of 94.88 Km^2, in addition to marly flysch and saliferous clay which occupies respectively 7.58 % and 11.35%. Sandstone thick siliceous coarse, Marl and sandstone, Deposits of steep slopes, and Alluvium occupy all together 44.63 km^2 of the surface area, it is a narrow area but important in explaining the occurrence of landslides in the area.

3.2.3. Superficial formations

Superficial materials (Figure 3.4) were mapped based on the soils map of Morocco (COQUANT, S. o. J. M., 1996), ten classes were mapped and involved. However, a various types of superficial deposits represent small areas in addition to the less importance in slope instability found within the study area were combined under one layer. The table below shows the whole classes with their surface and characteristics (**Error! Reference source not found.**).

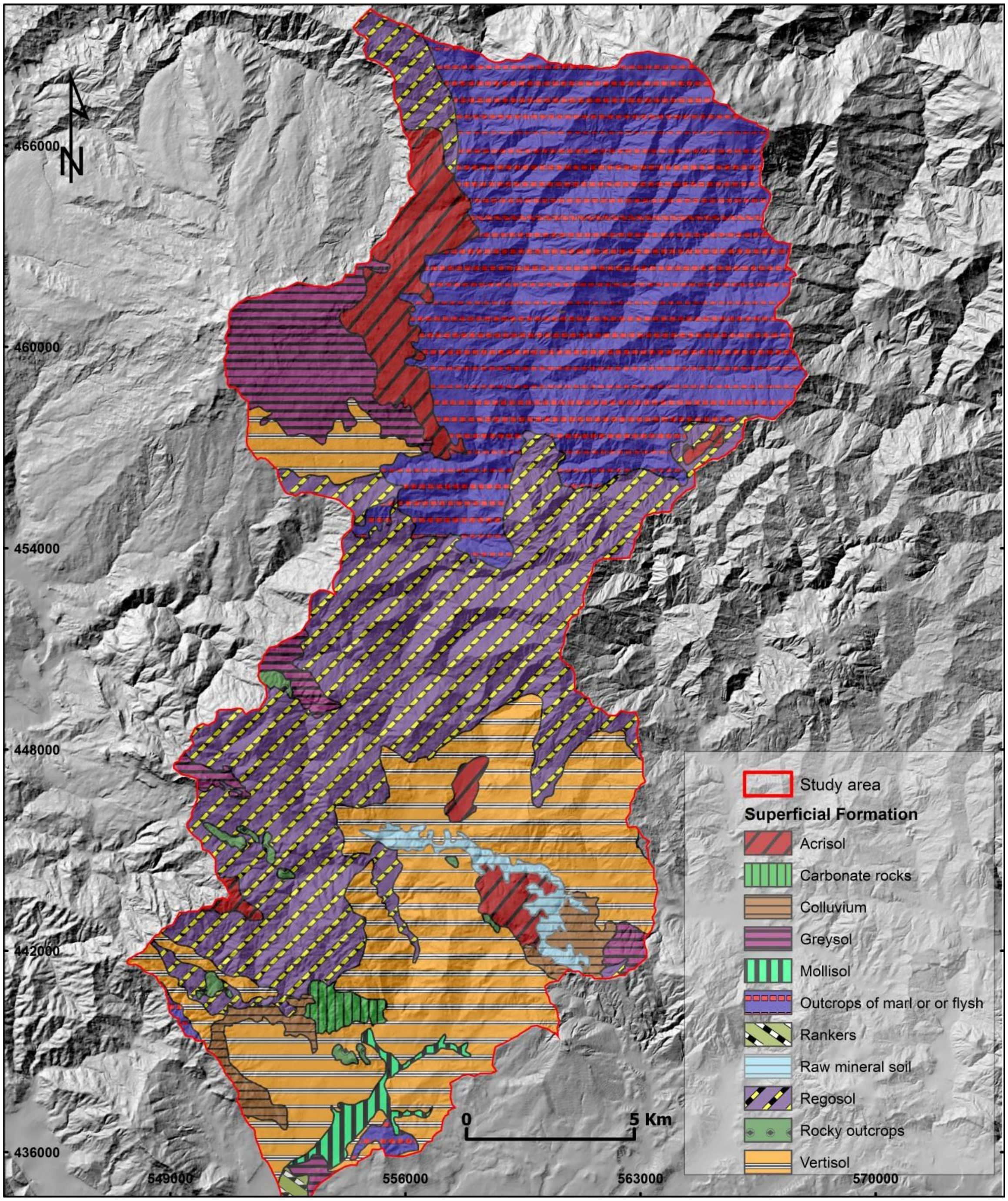

Figure 3.4 — Superficial formations map of the study area

Class	Area (Km^2)	Area (%)	Characteristics
Rankers	0.9501	0.24645	Non calcareous soils
Rocky outcrops	2.2806	0.5916	Rock material
Carbonate rocks	2.3465	0.60868	Sedimentary rocks
Mollisol	3.5373	0.91759	Rich in organic matter.
Raw mineral soil	4.6434	1.2045	Recent alluvium
Colluvium	8.3945	2.17754	sediments ranging from silt to rock fragments of various sizes
Acrisol	20.814	5.39919	Clay-rich material
Gleysol	23.5058	6.09745	Unconsolidated materials
Vertisol	82.842	21.4894	High content of expansive clay
Regosol	109.7318	28.4646	Very shallow soil extensive in eroding lands
Outcrops of marl or flysch	126.4563	32.803	Hilly relief consist of marl and flysch
SUM	**385.5021**	**100**	

3.2.4. Land use

A permanent forest removal or destruction resulting from planned conversion of forest to pasture, agriculture and possibly from continued shifting cultivation as practiced in many areas of Rif's chain have been influenced the stability of managed hillslopes within the study area. Widespread conversion of forest and brush land to managed grassland has accelerated soil mass movement in both areas and numbers of soil slips due to the reduction in root reinforcement because off root-wood deterioration, site disturbance, introduction of different plant species, temporarily increasing water inputs and soil moisture because of reduced evapotranspiration. The influence of conversion and shifting forest to pasture or agriculture on slope stability depends on the density of residual trees and understory vegetation, rate and type of regeneration and site characteristics.

High density of population and population growth in the area generates pressure on the food production and energy sources (i.e. firewood charcoal) which accelerates deforestation during nineties. A survey carried out by hydrological agency of Sebou river basin (ABHS) showed a mark change in the way the land is used, in 1975. Between 1975 and 1996 most of the area was a forest with some areas of arable land along the main streams. From 1975 onward (Figure 3.5) the large swaths of the forest have been cleaned for road and houses construction with intensive agriculture on steep slopes.

Tree crops, especially olive groves form the majority of the area with 7979 ha. The second largest crop consisted of cereal crops, mainly wheat which is considered the most widely cultivated plant in in the area, in addition to barely for feeding the livestock.

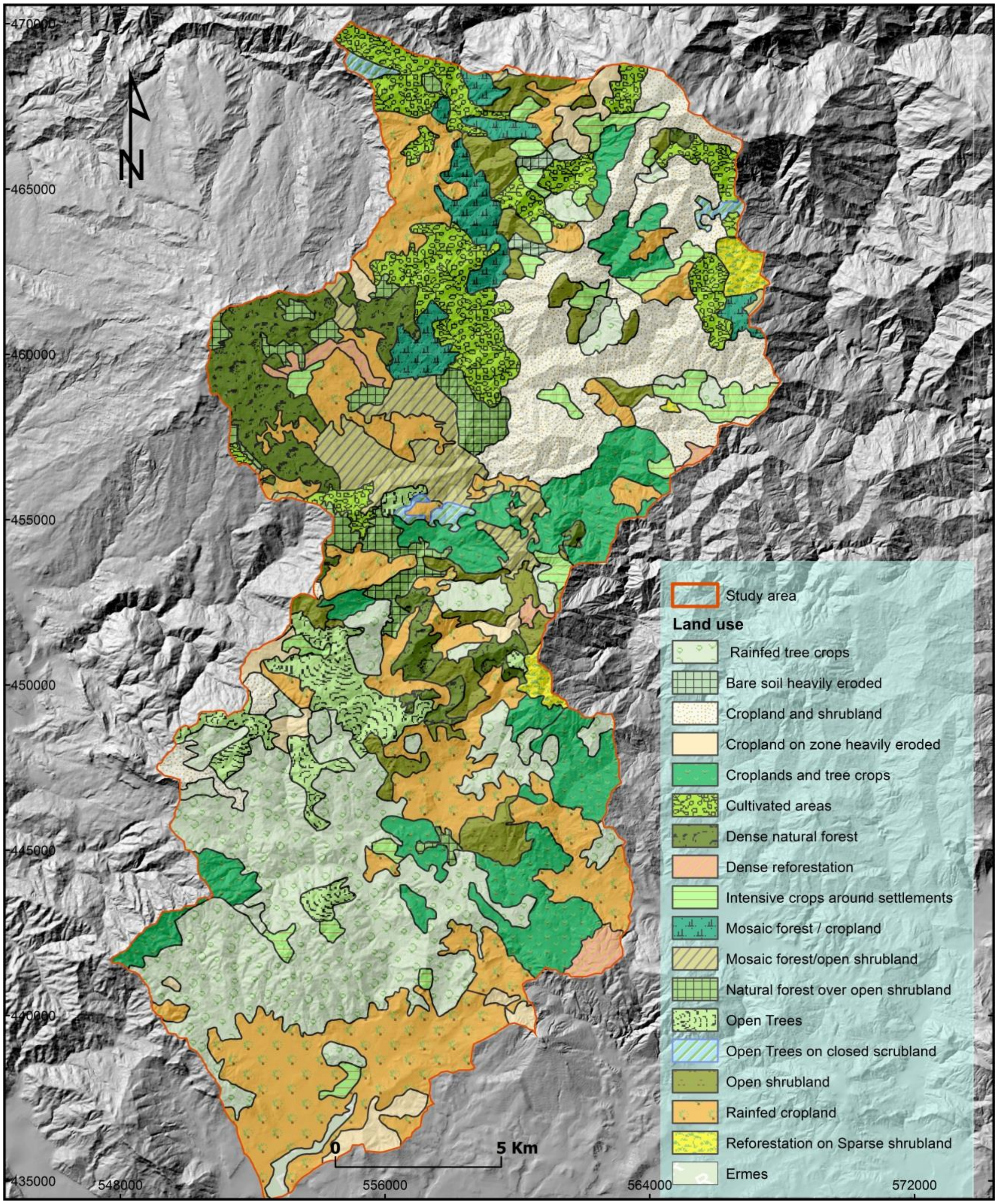

Figure 3.5 — Land use map of the study area (extracted and updated from Lelandais, F. and Fabre, G., 1996)

3.3. DEM derivatives

A large variety of DEM-derived variables can be can be computed, to model hydrological processes or local morphometry, known as secondary topographic attributes according to Wilson, J. P. and Gallant, J. C. (2000). DEM derived variables (i.e. aspect, slope) have an important effect on a various of ecological, hydrological and morphological, processes, Thereby the constructed DEM described in section 3.2.1 was used to derive the following variables: slope aspect, slope angle, curvature and topographic wetness index.

3.3.1. Slope orientation

Slope is defined by a plane tangent to a topographic surface, it describes the direction in which a slope faces and relates to the degree of solar exposure. Aspect influences the vegetation found on the slope and the daily range of temperature and relative humidity. These environmental influences should be taken into account. Thus, incorporating the aspect among predisposing factors for landslide susceptibility assessment through the statistically based model make much sense. Aspect is measured clockwise in degree from zero (due north) to 360 (again due north, coming full cycle). The value of each cell in an aspect grid indicates the direction in which the cell's slope faces. Flat slops have no direction and are given a value of -1 (Green, N., 1988).

Slope orientation within Amzaz valley are nearly equally as it shown in (Figure 3.6) and (Table 3.2). This factor could show important differences in terms of topo climatic characteristics of the drainage basin such as insolation, temperature and soil moisture.

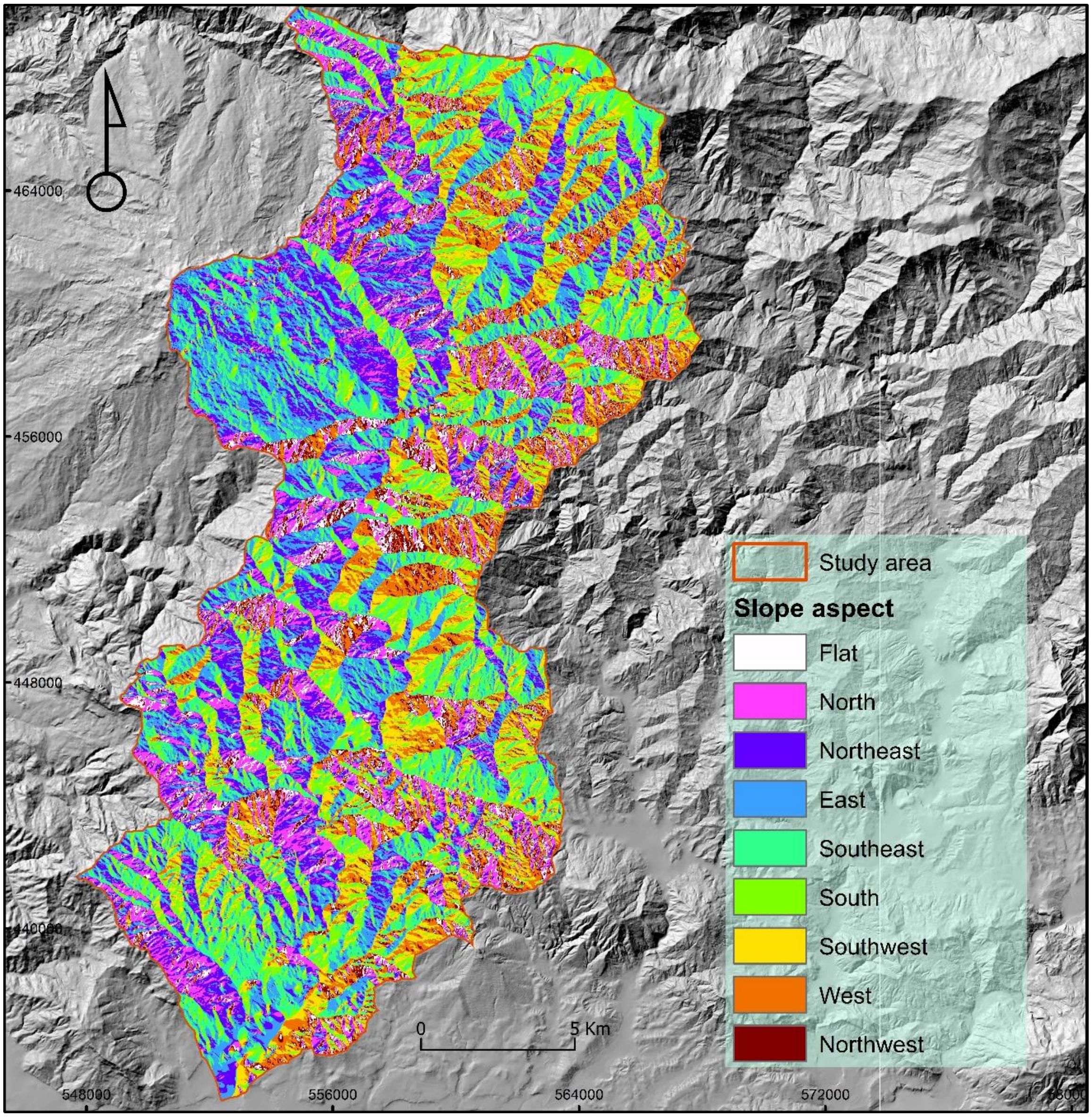

Figure 3.6 — Slope aspect map of the study area

Class	**Occupancy area**	
	(Km²)	**(%)**
North	166.8142	11.81
northwest	175.282	12.41
East	164.752	11.67
Southeast	180.131	12.75
South	199.1	14.10
Southwest	185.744	13.15
West	184.967	13.10
Southwest	185.744	13.15
Northeast	155.552	11.01
SUM	**1412.3422**	**100**

Table 3.2 — Reclassified aspect map of the study area

3.3.2. Slope gradient

Slope is the gradient of the land surface, it is a crucial parameter in several well-known predictive model used for environmental management, including the Universal Soil Loss Equation and landslide susceptibility assessment. There are two ways to express slope, whether as a percentage or slope angle or degree of slope (Dibiase, D. and John, A. D., 2014). In this study it was decided to classify slope angle map in 8 classes (Figure 3.7) using the degree (º) as a unit of measure.

A variety of authors and studies denote that there is a strong relationship between the angle of slope and the failure. As the slope angle increase, the shear stress along the slope increase due to added weight.

According to statistics of slope angle shown on the Table 3.3 it is noted that

72.67 percent of the study area is dominated by slope angle between 20 and 40 degrees, thus the topography of the study area is characterized by steepness.

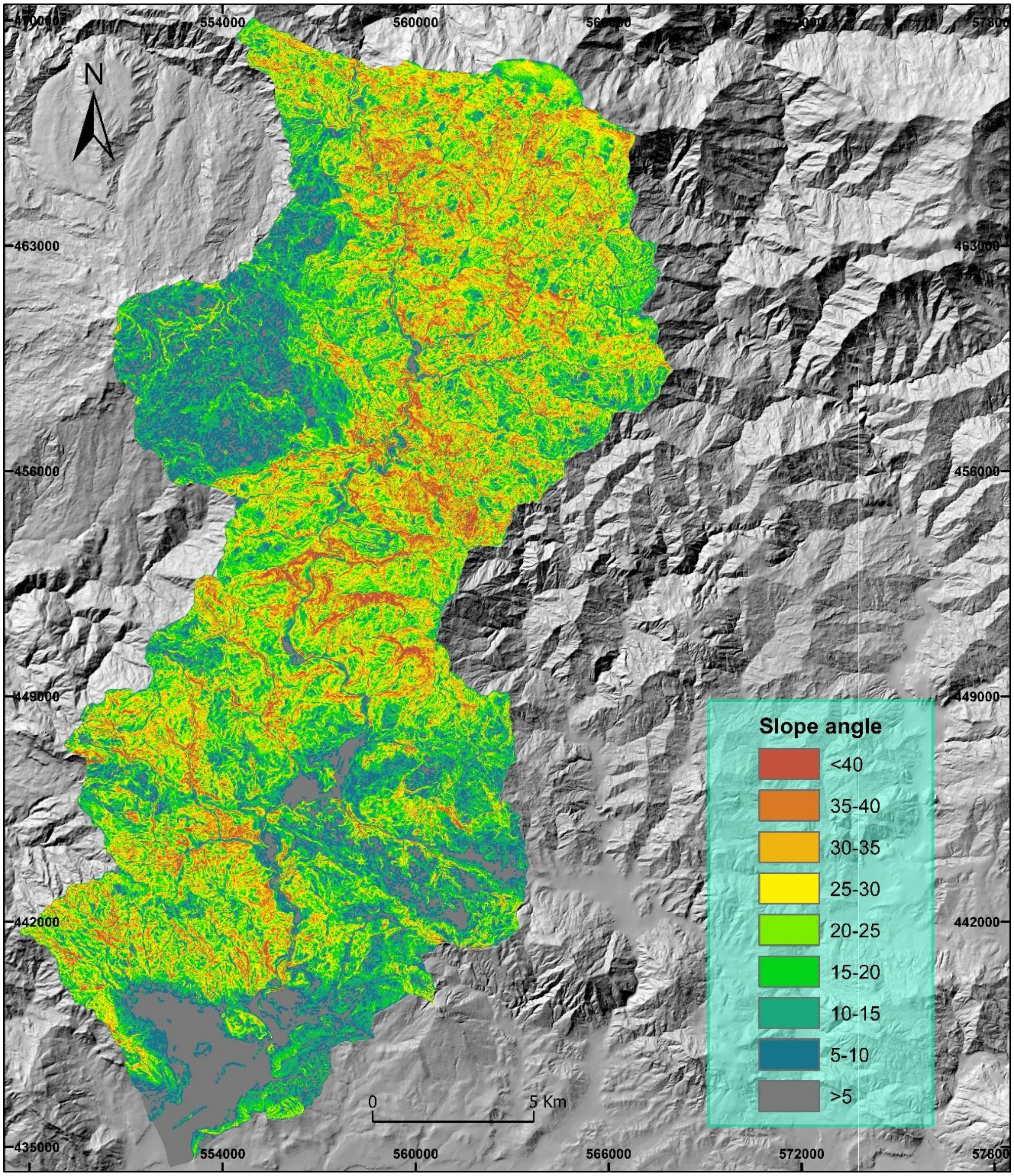

Figure 3.7 — Slope angle map of the study area.

Classes (º)	**Area**	
	(km²)	**(%)**
Greater than 40 º	251.064475	2.62
35 - 40	551.004625	5.75
30 - 35	1047.641725	10.93
25 - 30	1420.913	14.83
20 - 25	1546.717175	16.14
15 - 20	1501.16225	15.67
10 - 15	1375.19485	14.35
5 - 10	1137.3134	11.87
Less than 5º	750.739025	7.84
SUM	**9581.750525**	**100.00**

Table 3.3 — Reclassified slope angle map of the study area

Guzzetti, F. (2005) stated that there is a strong relationship between slope angle and landslide occurrence. Thus, relatively high values of slope angle, at least, up to certain value, tend to be related to an increase of landslide occurrence.

3.3.3. Topographic wetness index

Topographic wetness index (TWI) or compound topographic index (CTI), it is a steady state wetness index (Sørensen, R. *et al.*, 2006). It is commonly used to quantify topographic control on hydrological processes. tI is used to indicate the spatial distribution of soil moisture and surface saturation; it forms the key component of distributed hydrological model. TWI is an important index for modelling the topography-related geographical processes at hillslope or catchment scale.

TWI combines local upland contributing area, slope and a couple of geometric functions (Equation 3.4) develop by Beven, K. and Kirkby, M. J. (1979).

$$TWI = \ln\left(\frac{a}{Tan(\beta)}\right) \qquad \text{Equation 3.3}$$

Where,

a is contributing upland area (m^2) from flow accumulation raster,

β is the local slope angle (degree)

It is necessary to be mentioned that the conversion from degrees to radians is compulsory because the calculation process with degree on GIS environment leads to problems that can be solved with radians.

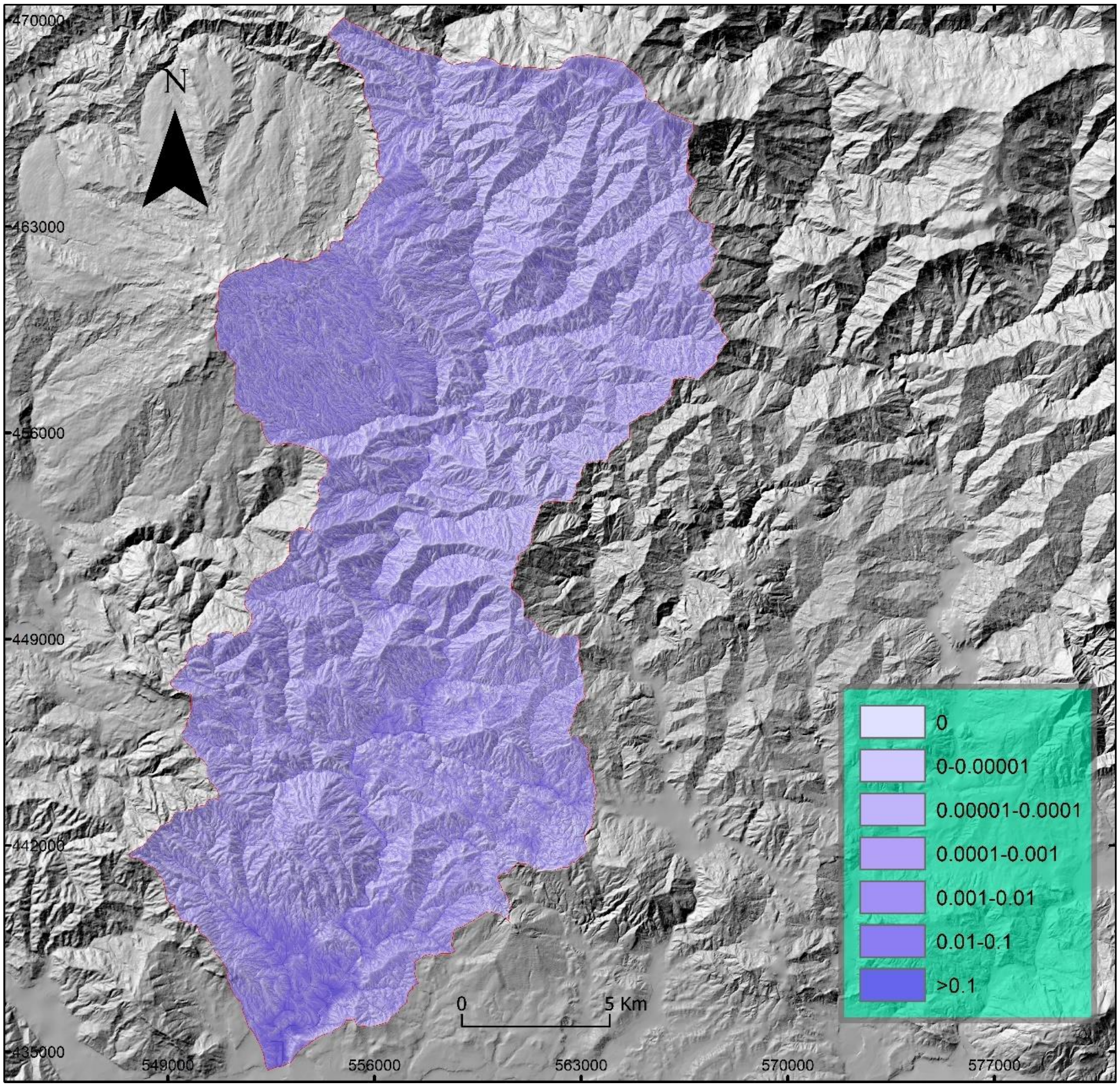

Figure 3.8 — Topographic wetness index of the study area

The map shows that in the flat and broad areas, the TWI has higher value than TWI of the nearing slope shoulder, which means that the terraces end toe slope areas have more potential to retain soil moisture than the nearby slope shoulders. The value of TWI reaches the highest in channels. This spatial distribution of TWI can reasonably indicate the spatial pattern of soil moisture in the study area. The first TWI class represents crests and ridges, whereas the last class represent drainage depressions.

Regarding the spatial distribution of water accumulation, it can be observing that TWI value increase due to the proximity of streams (TWI class 0.01 – and >0.1), these places represent the permanent or temporary water sources where water accumulates. Whereas TWI classes 0.0001 – 0.001 and 0 – 0.00001 mostly represent steep slopes and ridges.

3.3.4. Curvature

The curvature of the slopes is the inverse of the radius of circular tangent to the soil surface, hence, positive and negative curvature correspond respectively, to convergent and divergent topography and higher curvature corresponds to stronger convergence. Concave slopes may retain too much water and not drain properly, whereas convex slopes may cause water to run off the slope causing hydric erosion processes. Concave shapes are represented in blue, convex shapes are in red and uniform shapes are in yellow. Curvature is also a way to measure roughness of a terrain. The roughness of a DTM surface is the ratio of surface (S) and its projection onto a horizontal plane (A) (Eric, K. and Regis, H., 1989) (Equation 3.4).

$$\text{Roughness} = \frac{S}{A} \qquad \text{Equation 3.4}$$

The slope shapes map was classified into 3 classes and it expresses the variation between positive and negative values (Figure 3.9). A negative value indicates that the surface id upwardly convex at that cell. A positive profile indicates that the surface is upwardly concave at that cell. Value around zero (-0.05-0.05) indicate a linear slope (Zhou, Q. *et al.*, 2008).

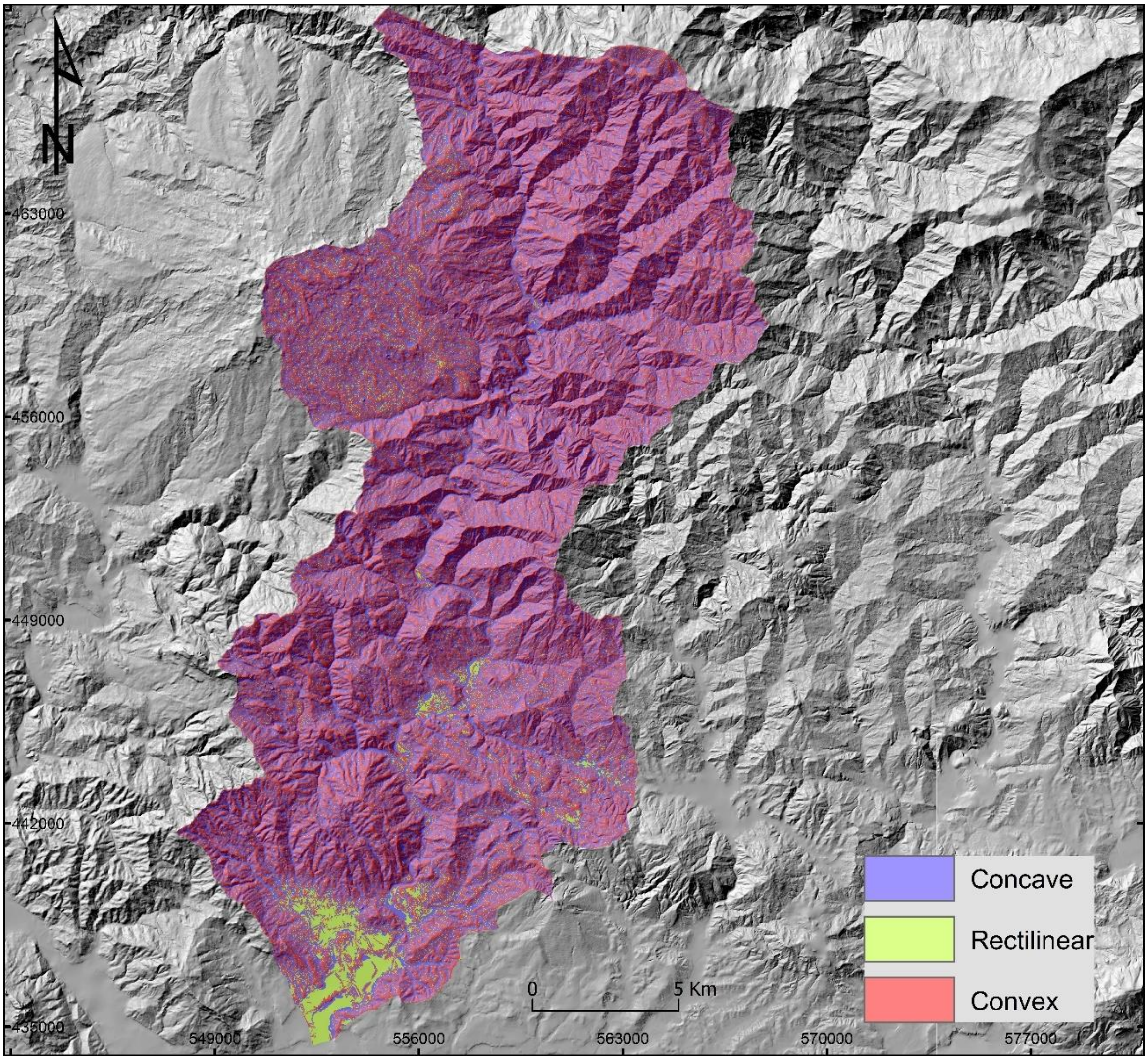

Figure 3.9 — Slope shape map of the study area

If a category is highly correlated to landslide, the area associated with this category will have a high positive IV. A negative IV for specific category is an indicator of low landslide density in this class (Yin, K. L. and Yan, T. Z., 1988) .

Thus, for predisposing factor to be useful for landslide susceptibility mapping, its categories should provide a range of Information values.

Table 3.4) shows the result of combination of spatial distribution of past mass movement with spatial patterns of the relevant conditioning factors of slope instability. The information value presents the relative susceptibility of terrain unit to the occurrence of a particular type of landslides. Informative value for each type of mass movement was calculated separately.

Predisposing factors	ID	Class	Rotational	Translational
Lithology	1	Alluvium	-0.6719	-0.7011
	2	Black flysch with benches 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 orientation	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 shrub land	**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 shrub land	**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 3.4 — Information values obtained for each class of each conditioning factor for each landslide type, significant values above zero are highlighted in bold.

Positive values of IV indicate that there is a positive relationship between the variable and landslide occurrence, the higher the score the stronger the relationship (Yin, K. L. and Yan, T. Z., 1988) , whereas negative values indicate that the variable is not favourable for landslide occurrence. A weight value (±0.1) contributes to neither presence nor absence of landslides (Van Westen, C. J. *et al.*, 2003).

Regarding lithological classes for each landslide type, the Flysch with benches of sandstone and shale followed by Marly flysch are the lithological classes more prone to shallow rotational slides. The flysch with benches of sandstone and shale class seemed to be the most unstable lithological class since it includes the majority of landslide occurrence. According to the Information Value, the marly flysch is very prone to rotational sliding. The area dominated by black flysch with benches siliceous sandstone is more prone to shallow translational slides.

According to slope angle we can notice that classes between 25 to 40 degrees are more prone to shallow translational and rotational slides, whereas the other classes are stable according to their Information Value.

Once the informative values were calculated, were assigned to the respective classes of its respective variable, then summed using raster calculator tool of ArcGis software. From this procedure resulted two maps of landslides susceptibility, one for shallow translational slides susceptibility (Figure 3.10.a) and the other for shallow rotational slides susceptibility (Figure 3.10.b).

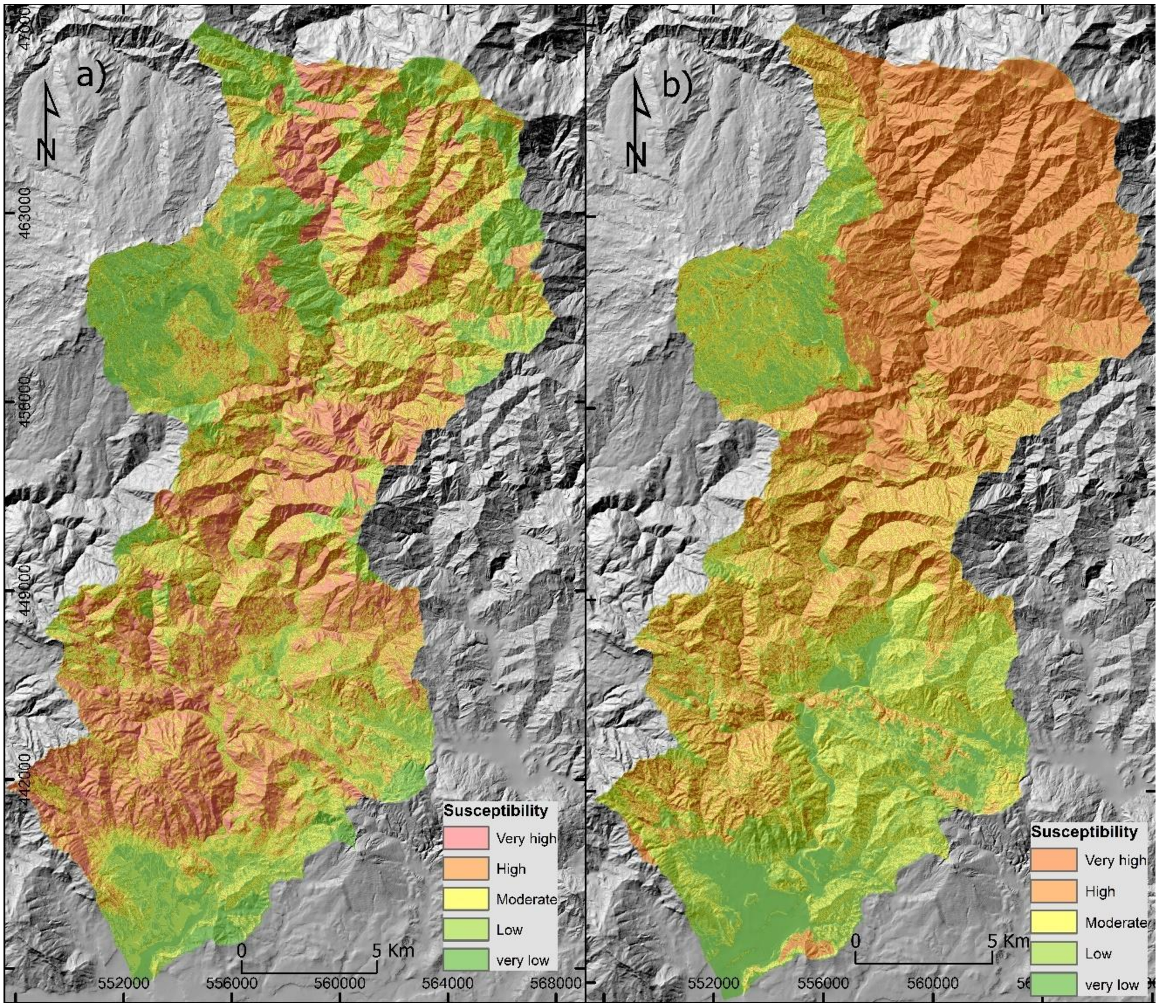

Figure 3.10 — Shallow landslide susceptibility models assessed through Information Value method a) translational b) rotational

By analysing the landslide susceptibility maps, it is possible to conclude that there are two distinct parts in the study area. Generally, the (Figure 3.10) identifies, the north eastern part of the study area as more susceptible to rotational landslides due to the fact that most slopes are grater or equal to 20º and the expansion of flysch and clayey formations lying upon an impermeable bedrock, whereas, the middle and south west parts are more prone to translational landslides. These parts of the study area characterised by the presence of artificial cut (roads), and moderate slope gradient that allows gradual percolation of water into the soil, thus reducing shear strength of materials through increased pore water pressure.

The calculated Information Values, generated from the analysis of seven parameter maps range from -2.8762 to 0.9891 for translational slides and from 0.9198 to -2.6817 for rotational slides, values were classified into four susceptibility classes (very low, low, moderate, high, very high), By employing natural breaks method in ArcGis. The classification was done automatically under ArcMap environment. The final map is shown in (Figure 3.10.a). Where the percentage of areas classified as very low, low, moderate, high, very high susceptibilities are 8.79, 18.48, 24.25, 30.08, and 18.40% respectively for rotational slides, and for translational slides the values are 9.79, 21.18, 26.10,29.58 and 23.36 (Table 3.5).

	Area %	
Susceptibility classes	**Rotational**	**Translational**
Very high	18.40	13.36
High	30.08	29.58
Moderate	24.25	26.10
Low	18.48	21.18
Very low	8.79	9.79

Table 3.5 — Percentage of areas prone to landslide

CHAPTER 4: LANDSLIDE SUSCEPTIBILITY ASSESSMENT MODEL VALIDATION, DISCUSSION AND CONCLUSION

4. Landslides susceptibility assessment model, discussion and conclusion

This chapter aims to validate the result of Information Value method applied to slope instability modelling, and present the discussion and a general conclusion, as well.

4.1. Model validation

Landslide susceptibility models without any validation are worthless and may not have any scientific significance (Chung, C.-J. F. and Fabbri, A. G., 2003). Validation is important in order to make sure the model can be applicable for practical purposes also to check its accuracy and reliability. A variety of methods have been developed to validate the quality of susceptibility map, are available in literature and were widely used (Chung, C.-J. F. and Fabbri, A. G., 2003; Fabbri, A. *et al.*, 2002; Frattini, P. *et al.*, 2010; Guzzetti, F. *et al.*, 2006; Liu, J.-K. and Shih, P. T., 2013)

In this study, the validation is based on the success and prediction rate curves (Van Westen, C. J. *et al.*, 2003) which explain how well the model and controlling factors predict landslides. In order to determine success rate, susceptibility map should be crossed with the same landslide inventory that was used to build the susceptibility model. For the predictive rate, the validation process requires that the susceptibility map should be crossed with a group of landslide independent from those that were used to generate the susceptibility model. In this study all landslide inventories were divided randomly into two groups (Figure 4.1) for both rotational or translational slides.

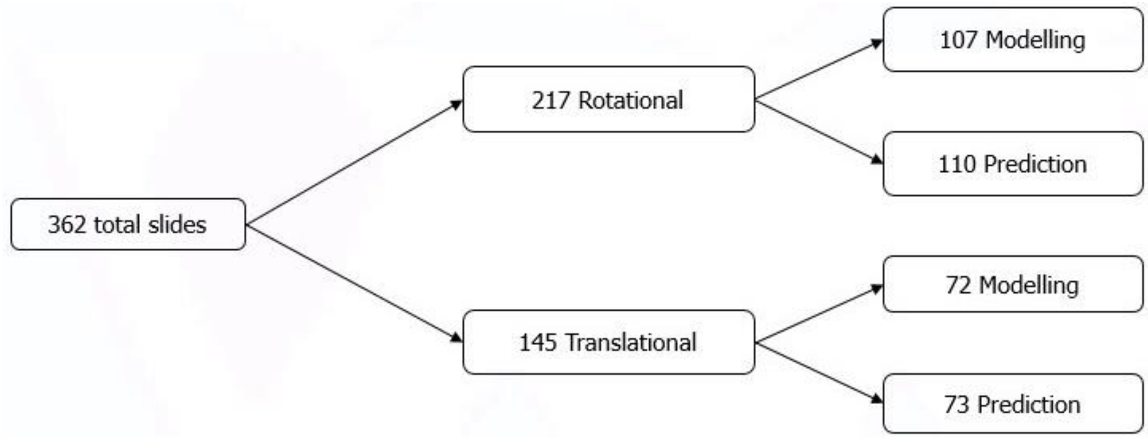

Figure 4.1 — Landslide groups division

To obtain the rate curves, the calculated landslide susceptibility index values of all grids in the study area were sorted in descending order with 1% cumulative intervals. The cumulative percentage of observed landslides is plotted against the cumulative percentage area of landslides susceptibility map. The validation in terms of success and prediction rate curves is shown graphically in percentage terms, and the scale ranging from 0 to 1. Success rate is graphically represented start from the origin of the graph shows a model with a degree of success, higher is its value, better is the model (Bennett, k. p. *et al.*, 2003).

Guzzetti, F. (2005) considered that Area Under Curve (Equation 3.4) values between 0.75 and 0.80 corresponds to an acceptable model, whereas AUC values between 0.8 and 0.9 indicate a good susceptibility model, finally, AUC values greater than 0.9 exemplify model.

$$\text{AUC} = \sum_{i=1}^{n} \left[(Lsi - Li) * \frac{ai + bi}{2} \right] \quad \text{Equation 4.1}$$

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 a success and prediction rate curves for both types of landslides separately. Cumulative frequency diagram for translational slides (Figure 4.2) illustrate the susceptibility of the study area ranked in a decreasing order (x-axis) and the ordinate axis is the cumulative distribution function of the landslide area. The area under curve of 0.76 for modelling group and 0.69 for prediction group concerning translational slides, was obtained from some of the predisposing factors (TWI, land use, superficial formations, slope aspect, slope angle and curvature) because the other factors do not have any influence on susceptibility. It gives an estimation of landslide occurrence in a highest susceptibility classes (van Westen, C. J. *et al.*, 2006).

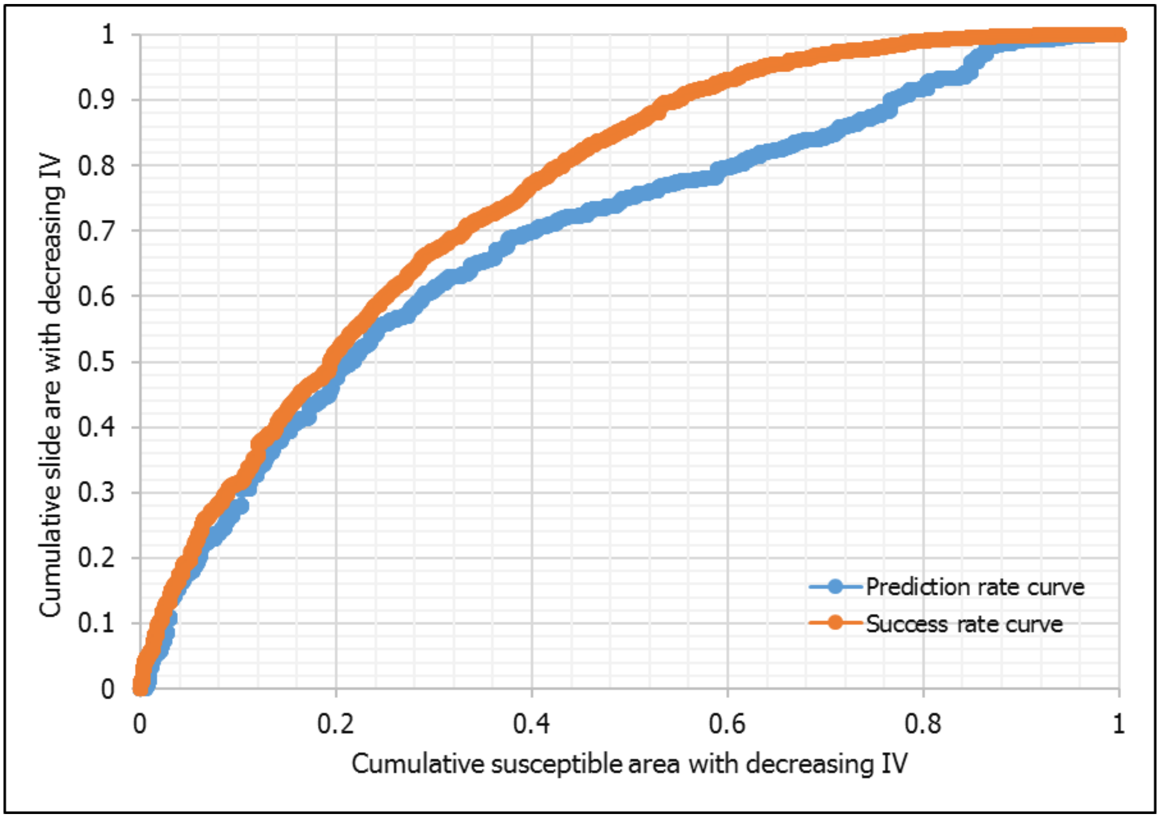

Figure 4.2 — Success and prediction rate curve for translational slides

The validation was the same for rotational slides (Figure 4.3), the area under curve value for generated landslide susceptibility pam is 0.75 for 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, D. W. and Lameshow, S. (2000) and indicate that the overall success rate is about 0.74.

It should be mentioned that not all predisposing factors were used for modelling rotational slides due to their lack of information or their small scale.

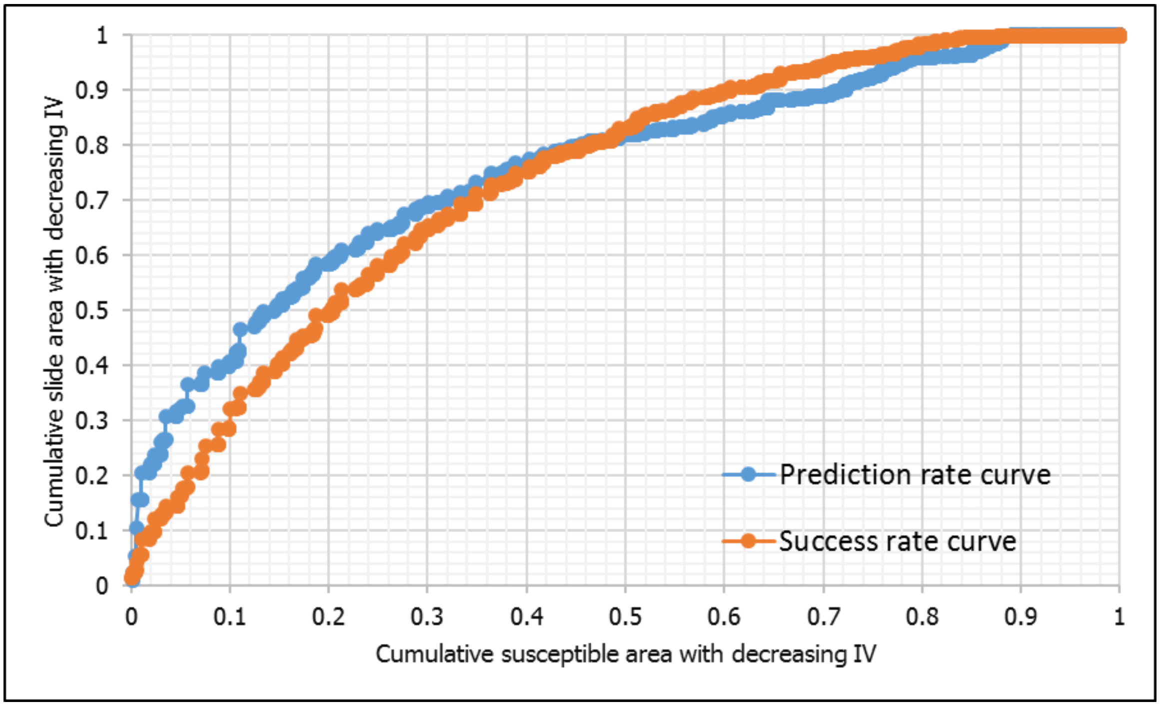

Figure 4.3 — Success and prediction rate curves for rotational slides

4.2. Discussion

The quality of landslide susceptibility map is largely relying on the quality of input parameters used in the analysis. The most important component is landslide inventories data. In this study landslide inventory prepared through satellite image interpretation (google earth images) and historical records obtained from local authorities (DPLT et LPEE). Details on landslide in Amzaz valley are very limited except landslides that resulted in infrastructures damages. Furthermore, there are several constraints that prevent the recognition of landslide evidences in the study area du to:

- Rapid disappearance because of vegetation growth;
- As a result of agricultural nature of the study area, landslide evidences are

constantly removed;

Based on land use map, landslides mostly occurred within cultivated areas (Rainfed tree crops, cropland in zone heavily eroded, cropland and tree crops, cultivated areas), this is due to fact that over exploitation of land, roads 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 exposed it to weathering agents. Some areas are relatively flat and thus not very prone to the landslides.

Regarding information value of slope angle classes, negative values are associated with slope gradient 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 slop class 20-25 degrees indicating a high probability of landslide occurrence within that slope class.

4.3. Conclusion

Natural hazard such as landslide are the biggest challenges for the development activities in mountain areas. Steep slopes, complex geology, random construction and heavy exploitation of agricultural land has contributed to landslide susceptibility on Rif mountains. Hence, landslides susceptibility modelling is quite important for planning and development work implementation. The main objective of this study is to prepare a Landslide Susceptibility map for Amzaz catchment area in central Rif.

Bivariate statistics information value method was used. Each predisposing factor was weighted on the basis of occurred former landslide, just like all bivariate statistical methods. Information Value is simple than complex mathematical analysis and yields scientifically reliable results.

Information Value Method (IV) has the advantage of assessing landslide susceptibility in an objective way. Each predisposing factor is crossed with the landslide distribution. The method allows the quantified prediction of susceptibility by means of a score even on terrain units that were not yet affected by landslide occurrence.

The landslide susceptibility assessment 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 probability of occurrence of damages and reduce their social and economic effects. Although quite an important vulnerable elements including population, roads, properties and economic activities exist in the threatened areas by landslide, local authorities do not give the attention required to such kind of problems.

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

Regarding spatial data, all maps (geology, superficial formations and land use) were with 1: 50 000 scale which means that several components are merged in one, thereby misrepresentation of the main factors controlling landslides occurrence.

In regard to future work, an effort should be done for finding a solution to the constraints pertaining to lithology, land use and superficial formations by using remote sensing technics to create more reliable data for modelling purposes, on the other hand, landslide inventories should be more robust and have more details.

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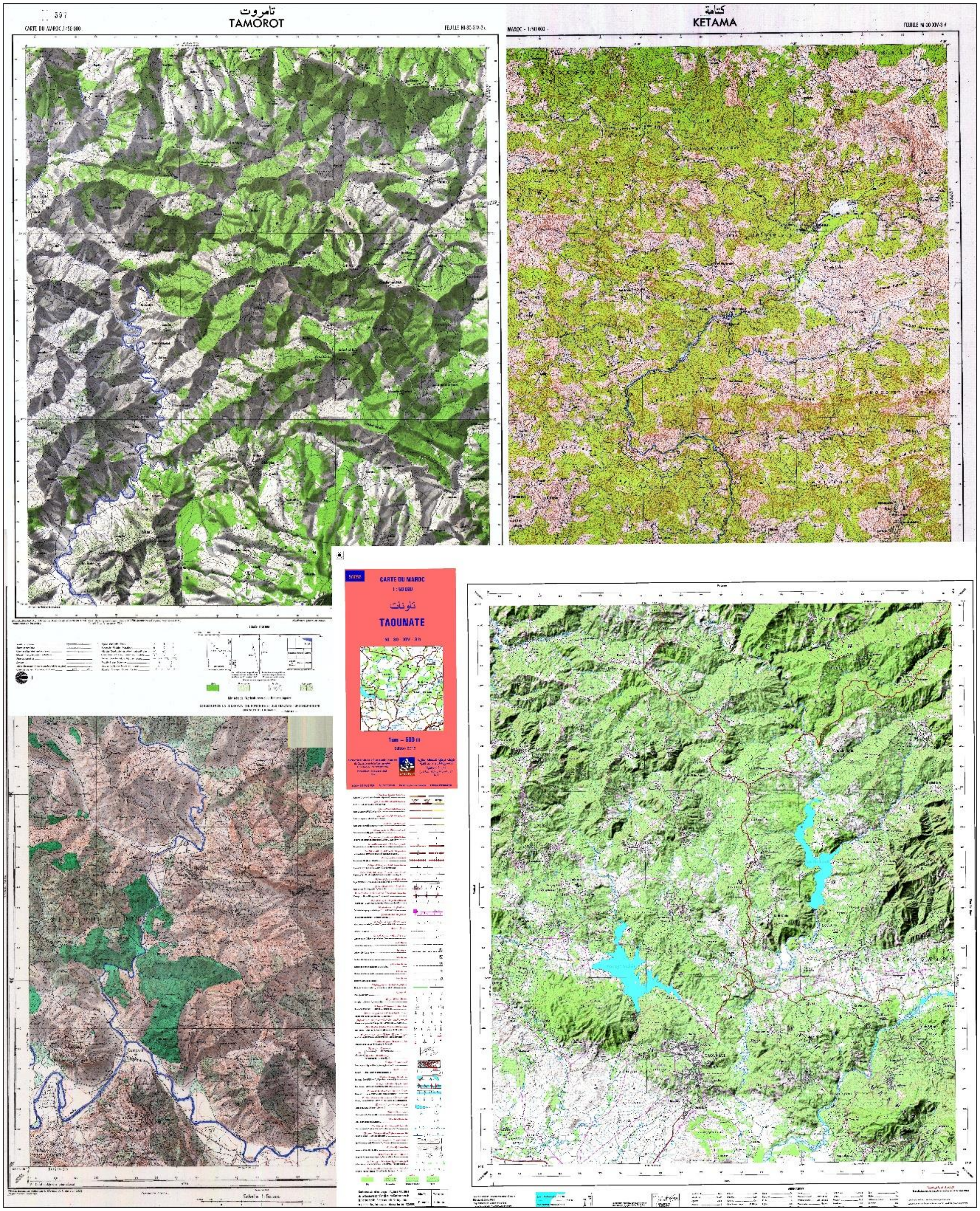
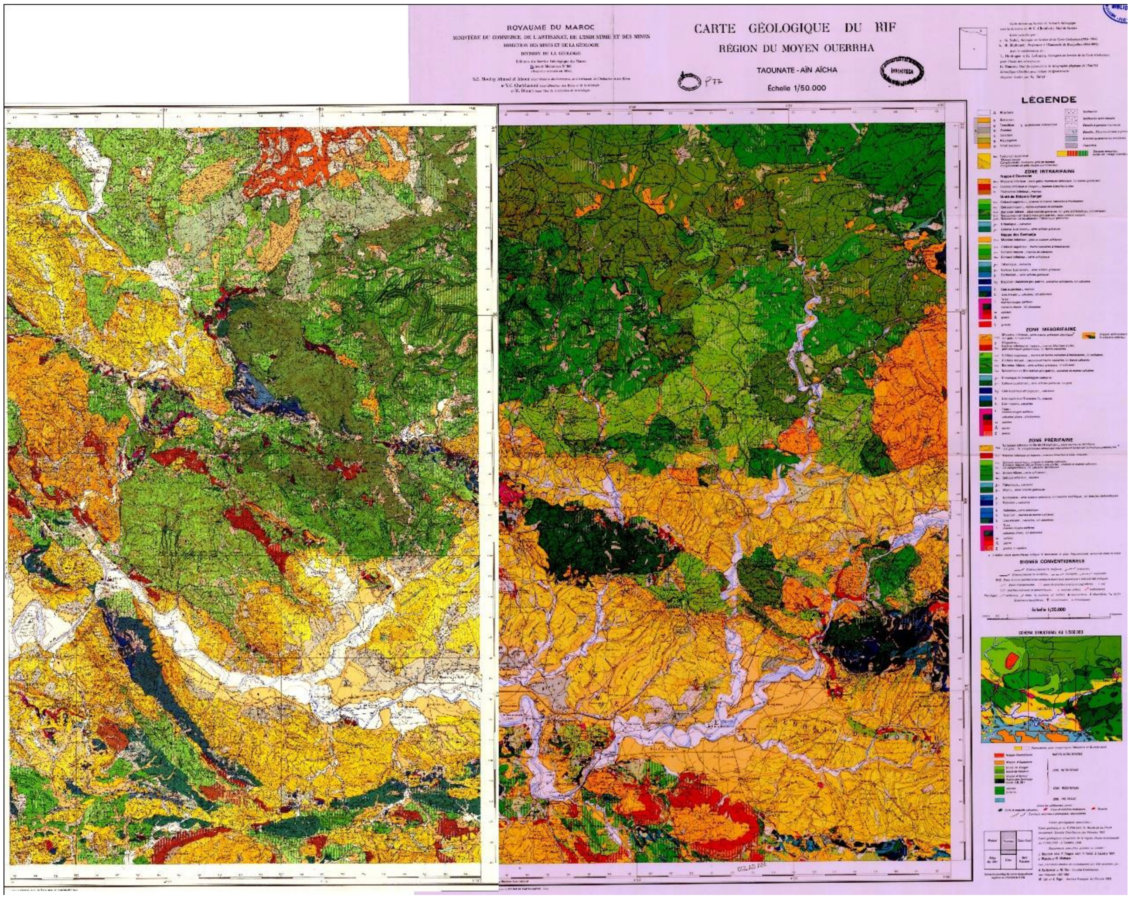
Appendices

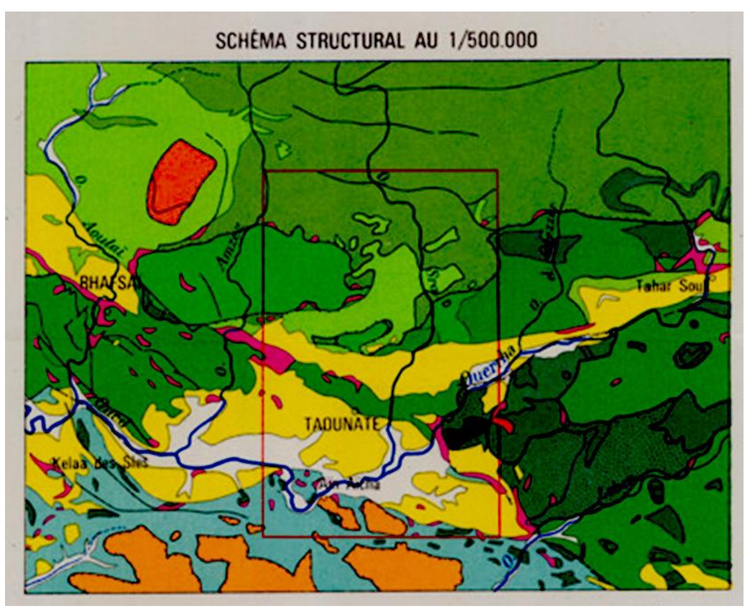
Appendix A. Topographic map sheets with scale 1/50 000 of Taounate, Ghafsai, Ketama, Tamorout region



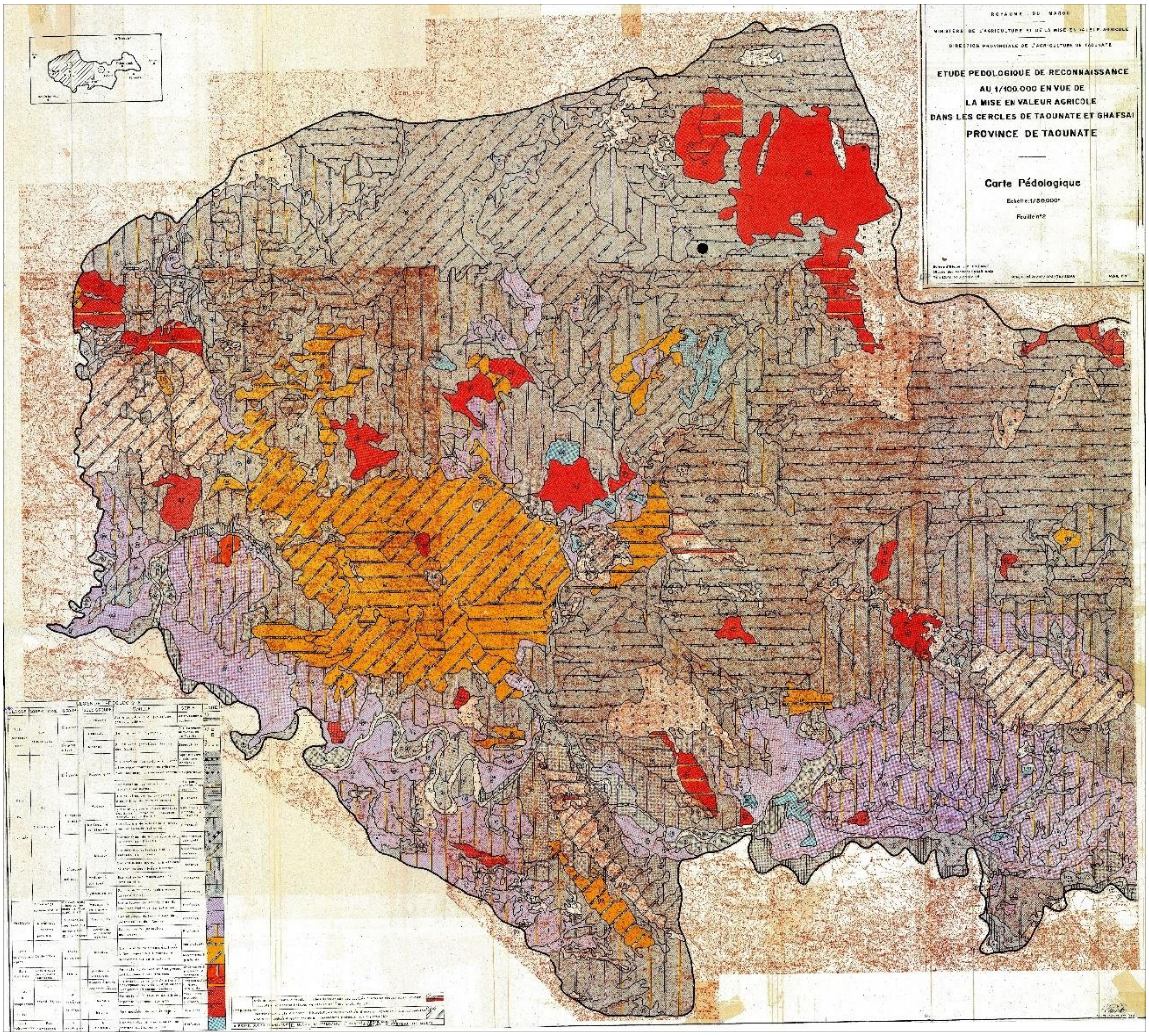
Appendix B. Lithological maps, regions middle Ourgha and Ghafsai



Appendix C. Structural scheme for Ain Aicha Taounate area



Appendix D. Soils map of Taounate province scale 1/50 000 sheet Nº2



Appendix E. Land use map