PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

DJILALI BOUNAAMA UNIVERSITY -KHEMIS MILIANA
Faculty of Nature and Life Sciences and Earth Sciences
DEPARTMENT OF EARTH SCIENCES

DISSERTATION OF ACADEMIC MASTER

Thesis Submitted in Fulfillment of the Requirements for the Degree of Master diploma

Specialty: Geotechnics

Use of geographic information system (GIS) for assessing and analyzing the landslide risks in the Algerian Sahel

Prepared by: SERBAH Khaled

Evaluated by the jury composed of:

Mr.	GADOURI Hamid	MCB	Examiner
Mr.	HENNIA Kaddour	MAA	Examiner
Mrs.	FILALI Mira	MAA	Supervisor

Academic Year: 2019/2020

Acknowledgements

First and foremost, I would like to Thank ALLAH for giving me the knowledge and the will to reach this level and to be able to accomplish this modest work.

I would like to express my full gratitude to my supervisor, Mrs. M. FILALI for her guidance, helps, and her fair criticisms and academic support which encouraged me to finish my work.

Also, I would like to express sincere thanks and appreciation to the members of jury for agreeing to review my work.

Thanks also go to all my teachers at KHEMIS MILIANA University for the through Education I received from them

Finally, I would like to thank my dear parents for all their support and encouragement. "I wouldn't be here today without your help".

Dedication

To my lovely parents

To all members of our families

To my closest friends

Abstract

Algerian Sahel region is prone to landslide problems due to the geological features combined with geotechnical characteristics and human activities. The present work was conducted to establish a landslide susceptibility map using a GIS-based spatial multicriteria approach. Five landslide-related factors, including slope, cohesion, friction angle, water content and distance to drainage network, were selected for the present assessment. Weight for each factor is assigned using Analytic Hierarchy Process (AHP) depending on its influence on the landslide occurrence. The landslide susceptibility map was derived using weighted overlay method and categorized into five susceptible classes namely, very low, low, moderate, high, very high.

The results revealed that 47.11% of the study area is at very low risk, 32.24% at low risk, 14.27% of moderate risk, 4.74% of high risk and 1.64% of very high risk area coverage.

The very high landslide vulnerability zones are more common within the river valleys on steep side slopes. Moreover, human activities namely the construction and the expansion of agricultural lands into forests intervene in inducing landslides through altering the slope stability along the river banks.

The landslide susceptibility map of the study area provides valuable information about future landslides probability. Such a map may be helpful for planners and decision makers to select the suitable locations and, consequently to ensure a better foundation for civil engineering projects.

Keywords: Algerian Sahel, Landslide susceptibility, GIS, AHP, Weighted overlay method.

ملخص

منطقة الساحل الجزائري عرضة لمشاكل الانزلاقات الأرضية بسبب الخصائص الجيولوجية المقترنة بالخصائص الجيوتقنية والأنشطة البشرية. تم إجراء العمل الحالي لإنشاء خريطة حساسية للانهيارات الأرضية باستخدام نهج متعدد المعايير المكاني القائم على نظام المعلومات الجغرافية. تم اختيار خمسة عوامل مرتبطة بالانهيارات الأرضية، بما في ذلك الانحدار والتماسك وزاوية الاحتكاك ومحتوى الماء والمسافة إلى شبكة الصرف من أجل التقييم الحالي. يخصص وزن لكل عامل باستخدام عملية التسلسل الهرمي التحليلي (AHP) تبعا لتأثيرها على حدوث الانزلاقات الأرضية. وقد اشتقت خريطة قابلية الانزلاقات الأرضية باستخدام طريقة التداخلية المرجحة وصنفت الى خمس فئات حساسة هي: منخفضة جدا، منخفضة، متوسطة، عالية وعالية جدا. وأظهرت النتائج أن 47.11٪ من منطقة الدراسة معرضة لخطر منخفض جدا، و32.24٪ في خطر منخفض، و14.27٪ في خطر متوسط، و4.74٪ في خطر عالي، و1.64٪ من المنطقة في خطورة شديدة. تعد المناطق المعرضة للانزلاقات الأرضية المرتفعة أكثر شيوعًا داخل أودية الأنهار على المنحدرات الجانبية شديدة الانحدار. علاوة على ذلك، تتسبب الأنشطة البشرية وهي البناء وتوسع الأراضي الزراعية في الغابات في إحداث الانهيارات الأرضية من خلال تغيير استقرار المنحدر على طول ضفاف النهر.

توفر خريطة الحساسية للانهيارات الأرضية في منطقة الدراسة معلومات قيمة حول احتمال حدوث انهيارات أرضية في المستقبل. قد تكون هذه الخريطة مفيدة للمخططين وصناع القرار لاختيار المواقع المناسبة، وبالتالي ضمان أساس أفضل لمشاريع الهندسة المدنية.

الكلمات المفتاحية: الساحل الجزائري، القابلية للانزلاقات الأرضية، AHP، GIS، طريقة التداخلات المرجحة.

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General Introduction

General Introduction

Landslides constitute one of the major hazards that cause losses in lives and property. Landslides are one of the complex analyses, involving multitude of factors and need to be studied systematically in order to evaluate the hazard. The increasing computer-based tools are found to be useful in the hazard mapping of landslides. One of such significant tools for hazard mapping of landslides is Geographic Information Systems (GIS). A GIS is defined as a powerful set of tools for collecting, storing, retrieving at will, displaying, and transforming spatial data from the real world (Burrough & McDonnell, 1998). One of the main advantages of the use of this technology is the possibility of improving hazard occurrence models, by evaluating their results and adjusting the input variables. An important aspect of landslide investigations is the possibilities to store, treat, and analyze spatiotemporal data that are available (Sivakumar Babu & Mukesh, 2009).

So, in order to help planners to select the suitable locations for the implementation of the civil engineering projects, a landslide risk zoning map is indispensable. And the planning for the future is necessary to reduce the loss caused by that disaster. One of the mitigation efforts is mapping of landslide hazard and risk potential zonation. This can be used by government as a tool to determine strategic planning in the future (Hanif & Ikhwanushova, 2017). The purposes of this study are the recognition of effective factors in landslide and the zonation of the study area which is a part of the marly Sahel of Algiers which is an area formed by marls of Piacenzian age which covers a large area to the south-west of Algiers in terms of the occurrence of this phenomenon using AHP model and GIS technique.

Geographic Information Systems (GIS) have become the promising tool for an effective analysis associated with the study of geologic hazards. GIS is an ideal tool for landslide modeling owing to its versatility in handling a large set of data, providing an efficient environment for analysis and display of results. This study demonstrates the ability of the GIS to incorporate the spatially varying data of ground morphology, soil properties, etc. in the engineering analysis of the slope stability (Sivakumar Babu & Mukesh, 2009).

The AHP method, suggested by Saaty (1980), has become a popular tool for multi-criteria decision-making. It supports decision-makers to make the best decision, by reducing complex decisions to a series of comparative pairs and synthesizing the results. The AHP disaggregates a complex decision problem into different hierarchical levels. This method allows quantifying opinions and transforming them into a coherent decision model (Saaty 1980). It was widely used by many authors worldwide (El Jazouli , et al., 2019).

Therefore, selection of criteria and standards, providing of factors raster layers, determining of relative and final weight of factors, overlaying of layers and preparing landslide hazard zonation map are the major objectives of this research to determine sensitive sites that have the maximum occurrence probability of landslide (Yazdadi & Ghanavati, 2016).

In this work, a landslide hazard zonation map has been produced for the study area as part of the Algerian Sahel region. For this purpose, some five major parameters were examined for integrated analysis of landslide hazard in the region, satellite imaging of the study area, and spatial analyses by using geographical information system (GIS). The produced factor maps were weighted with analytic hierarchy process (AHP) method and then classified. The data were first processed by weighting the parameters with the pairwise comparison matrix, and then did an evaluation of consistency. The result of each weighted parameter was overlaid with GIS. And finally, the study area was classified into five classes of relative landslide hazards: very low, low, moderate, high, and very high.

CHAPTER I

General information on landslides

CHAPTER I: General information on landslides

I. Introduction

Landslides are movements of soil and rocks under the effects of gravity (Cruden & Varnes, 1996). They are of very diverse origin such as intense precipitation, earthquake, volcanic activity, etc.

Landslides are present on all continents and play an important role in the evolution of landscapes. They also represent a serious danger in many parts of the world (Fausto, et al., 2012). By causing on average the death of 800 to 1000 people, Annually, and causing economic damage and very significant damages (Ameur, 2014).

II. The Landslides:

II.1 Definition of landslide:

A landslide is a generally slow movement (from a few millimeters per year to a few meters per day) of a coherent mass of land on a slope. The volume and thickness of the moving mass can vary from a few cubic meters in the case of a simple slide to a few million cubic meters in the case of a large-scale movement over the entire slope (christian , et al., 2010).

II.2 Main causes of landslides:

In sloping ground, the forces of friction and cohesion limit the effects of gravity. When the balance of these forces changes, the ground becomes unstable, under the combined effect of various factors, namely:

II.2.1 Natural factors:

- **The nature of the soil and subsoil (geological factors):**

  Geological factors are often intrinsic to massifs of soils or rocks, they affect its stability but also its resistance to degradation depending on the presence of fragile, altered, sheared or cracked materials which are called materials favorable to rupture.

  Weathering is a slow process that degrades materials. The primary reason for this alteration is the climatic conditions, in particular the role of water in all its forms. For example, the production of weathering clay in a rock mass has a negative impact on its stability (Pollet, 2004).

Regional tectonics induces significant stresses in the rock mass, especially in areas where there are large accidents of the overlapping type, or large fracture networks. The tectonic movements also caused many earthquakes, especially in mountainous environments. These earthquakes weaken the rock formations by the appearance of fractures. (Bruno, 2005).

- **The water:** During heavy rains or when the snow melts, the water entering the ground exerts a vertical thrust which can destabilize the ground. The situation is all the more dangerous if the amount of water entering the earth is greater than that which flows from it.

The increase in groundwater gradients induces a flow or infiltration inside the slope. And this adds a driving force (for example, the drawdown following the rapid decline of lakes or reservoirs at the foot of the slopes) (Timothy R H, 2014).

Fluctuations in groundwater influence pore pressures, which modify the effective normal stresses, and therefore the shear strength of the potential rupture surfaces.

Water saturation can change the inherent strength of materials (for example, soil saturation and swelling clays) (Timothy R H, 2014), also the increase in the amount of water in certain clay soils produce swelling (wet period).

- **Drought:** Too dry soil can lose its cohesion, crumble and slip (Les glissements de terrain, s.d.). and the decrease in the amount of water in certain clay soils produce settlement (dry period).

- **Erosion:** Eroded or exposed soil without vegetation (deforestation, fire, storm) will be more vulnerable to infiltration and therefore more likely to slip.

- **Seismic activity:** Each year, earthquakes are responsible for loss of human life and damage to buildings and infrastructure. Long considered as a side effect of earthquakes, the earth movements triggered by earthquakes, mainly falling rocks, landslides or rockslides, mud flows and rock avalanches, can be responsible for a significant part damage associated with earthquakes (juliet & julian, 2004). In the course of the twentieth century, nearly 80 earthquakes are the source of 100,000 to

1,000,000 earth movements that have claimed the lives of tens of thousands of people. (David, 1984).

Earthquakes generally trigger superficial ground movements. the volume thus destabilized can sometimes reach several million m3 as was the case during the earthquake of May 31, 1970 in Peru: the rocky avalanche of the Nevado Huascaran (Lliboutry, 1975), with an estimated volume of 50 million cubic meters of rock , of ice and snow, covered an exceptional distance of more than 16.5 km, at an estimated speed of 210-280 km/h.

During an earthquake, several phenomena can occur and contribute to the triggering of instability namely, (Bourdeau, 2018):

- Repeated earthquakes on a slope lead to deformation of the materials
- when the compression waves emitted by earthquakes propagate in less compact soils, they tend to compress the soils. When these soils are saturated with water, water occupies all of the pores (or interstices) between the soil grains. In response to soil compression, the pressure of the water in the soil pores increases and the water tries to escape from the soil, generally towards the surface. However, when the earthquake is rapid, sufficiently large or repeated in time in front of the time necessary for the drainage of the soil, water does not manage to escape from the soil. The more the water pressure increases in the soil, the more the mechanical resistance of the soil decreases and the more the rupture of the slope is likely. This can lead to a decrease in the intrinsic characteristics of the materials which tend to oppose the movement and thus facilitate the development of an overall rupture in the slope.

II.2.2 Anthropic factors:

- **Concentration of water towards the slope:** Some human interventions have the effect of concentrating water towards the slope. For example, directing rain, drainage, runoff or sewage into an embankment or at its top can cause gullying, vertical erosion or infiltration into the ground. In addition to the gullying problems that can be caused, such a concentration of water can affect the stability of the slope or even cause a landslide. These actions can change the geometry of the slope by increasing the slope and height of the slope and increase the water concentrations in the soil.

Thus, draining swimming pool water or channeling rainwater into drains or pipes at the top of the slope can be detrimental to its stability, especially when conditions are naturally critical, for example during spring melt. (The Ministry of Public Security, Government of Quebec, 2017)

Figure 1: *water infiltration into the soil due to a leaching field, (The Ministry of Public Security, Government of Quebec, 2017).*

- **Cutting or excavation at the base of the slope:** Cutting or excavating material at the base of the slope accentuates the slope or height of the slope. This type of intervention can cause a landslide during the intervention or affect the slope stability in the longer term. Leveling or enlarging its terrain at the base of an embankment has a significant impact on its stability (Figure 2). When the slope stability is precarious, even a small cut or excavation, such as digging for the maintenance of ditches, can cause a break (The Ministry of Public Security, Government of Quebec, 2017).

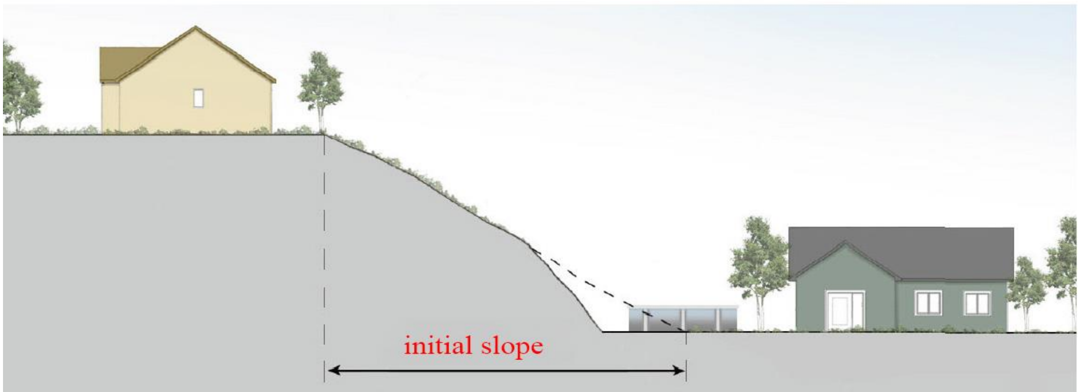


Figure 2: *Cutting that could affect the stability of an embankment.*

- **Embankment and overload at the top of the slope:** The act of adding additional weight to the top of a slope changes its equilibrium state and can therefore degrade its stability or directly cause a slip. This can include backfilling for earthmoving purposes, installing an above-ground pool or permanent or temporary storage of various materials such as excavation soil, scrap, etc.

  One of the most common harmful actions is the leveling of land by overloading the top of the slope to increase the usable area (Figure 3). These works, which may seem minor, increase the slope of the slope and decrease its safety factor. In addition, when the embankment is composed of clay, the water that infiltrates changes the groundwater conditions and, by the same token, the stability of the slope. (The Ministry of Public Security, Government of Quebec, 2017).

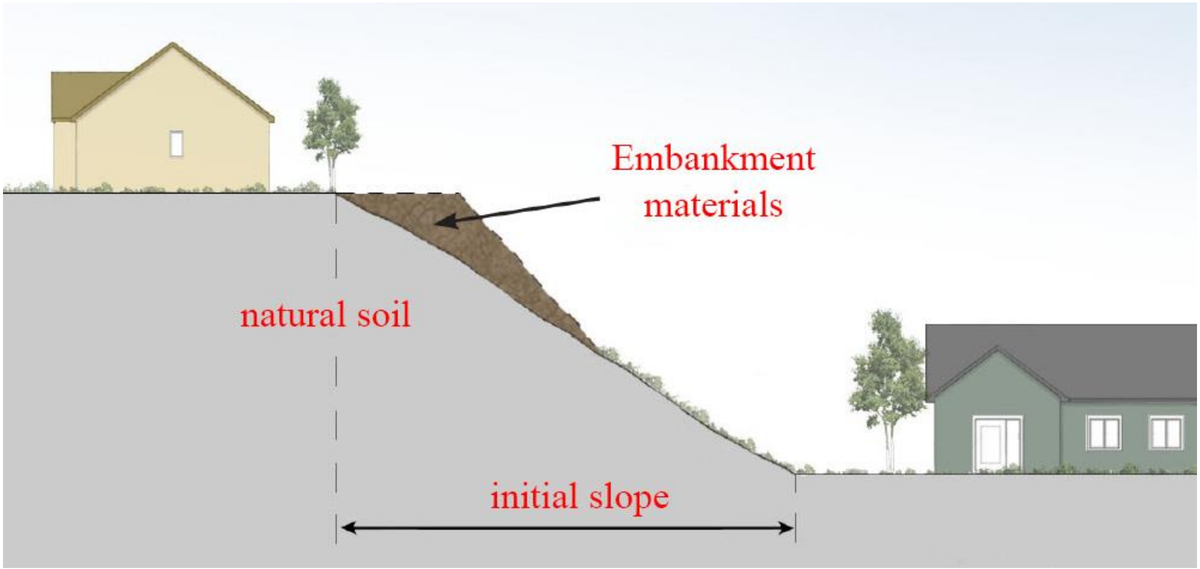


Figure 3: *Sketch representing an embankment that could be detrimental to the stability of an embankment.*

II.3 Types of ground movement:

II.3.1 Landslides:

Landslides are generally slow (less than 0.3 meters or 1 foot every 5 years), moderately rapid (1.5 meters or 5 feet per month) to rapid. (Highland & Bobrowsky, 2008). We distinguish:

II.3.1.1 Circular or rotational Landslide:

A landslide on which the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope. The displaced mass may, under certain circumstances, move as a relatively coherent mass

along the rupture surface with little internal deformation. The head of the displaced material may move almost vertically downward, and the upper surface of the displaced material may tilt backwards toward the scarp. If the slide is rotational and has several parallel curved planes of movement, it is called a slump.
Associated with slopes ranging from about 20 to 40 degrees. In soils, the surface of rupture generally has a depth-to-length ratio between 0.3 to 0.1. (Highland & Bobrowsky, 2008)

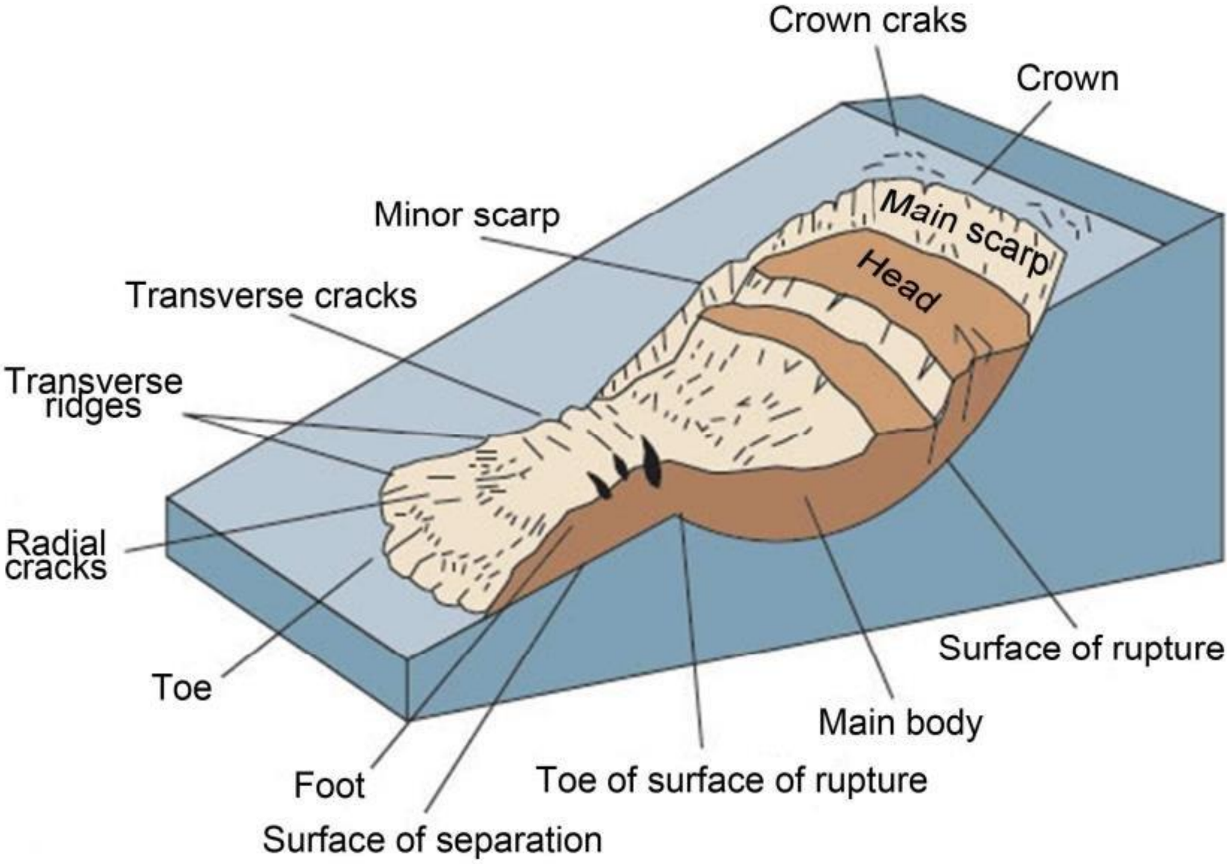


Figure 4: *Schematic of a rotational landslide, (Acharya, 2018).*

II.3.1.2 Translational Landslide:

The mass in a translational landslide moves out, or down and outward, along a relatively planar surface with little rotational movement or backward tilting. This type of slide may progress over considerable distances if the surface of rupture is sufficiently inclined, in contrast to rotational slides, which tend to restore the slide equilibrium. The material in the slide may range from loose, unconsolidated soils to extensive slabs of rock, or both. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between rock and soil. (Highland & Bobrowsky, 2008)

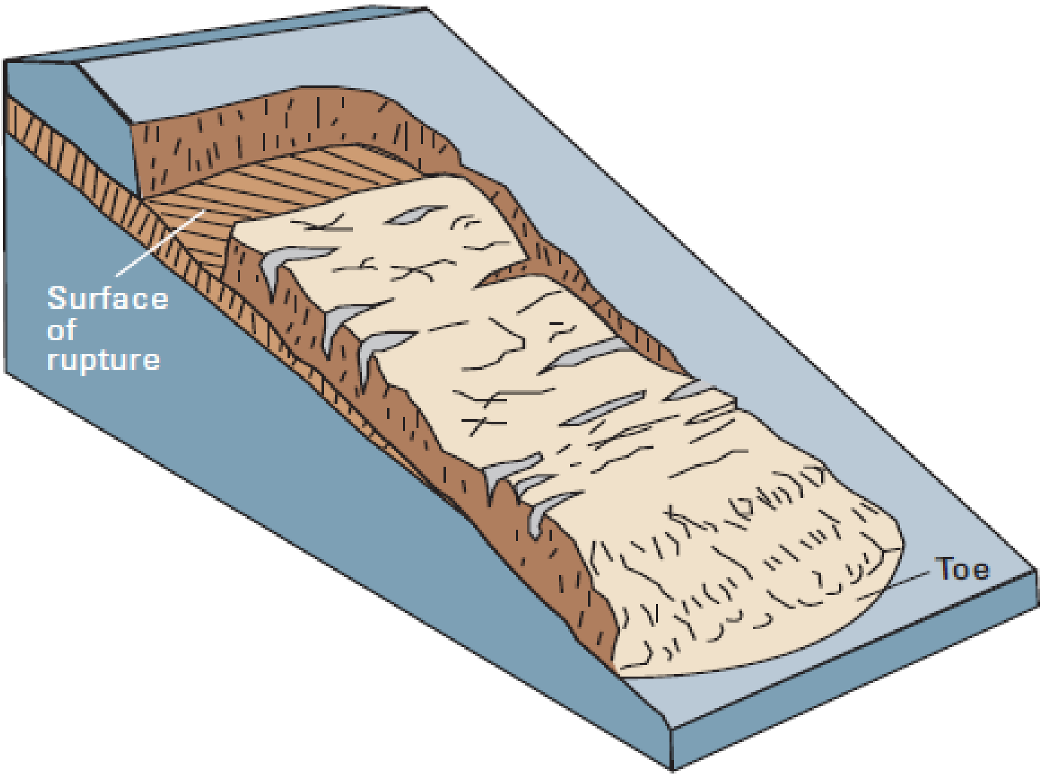


Figure 5: *Schematic of a translational landslide, (Highland & Bobrowsky, 2008).*

II.3.1.3 Composite or complex landslides:

The movement is very similar to the previous one in its external appearance, but the Surface (s) of rupture is (are) generally irregular in shape and passes through different levels of weakness of the massif. This is often a combination of flat and circular landslide.

III. Ground instabilities with diffuse rupture surfaces:

III.1 Rockfall:

In this type of movement (Figure 6), a rock mass generally overhanging collapses under its own weight or under the effects of a load at its top. Such rockfalls generate a fall of large rocks, which can later take with them other rubble, which leads to an avalanche of debris.

Generally, before the rockfall, small fractures and geometric variations appeared in the rock. If the recognition of risk areas can be identified, predicting the exact moment of the landslide is very complex, often impossible. Few measures exist to prevent falls. (Clément , et al., 2017)

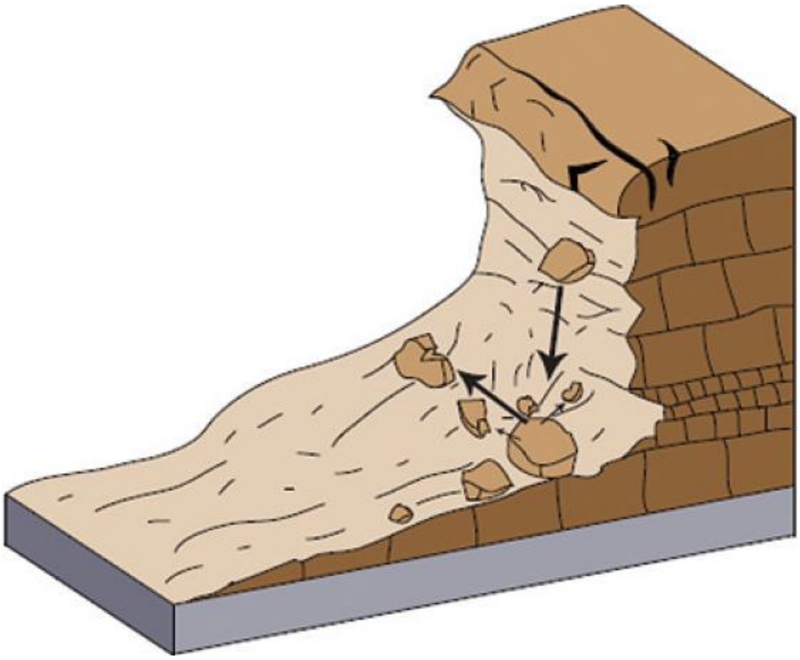


Figure 6: *Schematic of a rockfall, (Highland & Bobrowsky, 2008).*

III.2 Topple:

A topple consists of the simultaneous collapse of very large volumes of rock, of one or several million cubic meters, reaching speeds greater than 40 m / s (145 km / h). The strong interactions between the components can transform the material into fine rock powder, or even cause it to melt. The range of a collapse can reach several kilometers even with a slight slope. In mountain valleys, collapsed masses often form a dam on torrents and rivers, carrying the risk of a catastrophic wave and flooding of regions downstream. (Dangers naturels, s.d.)

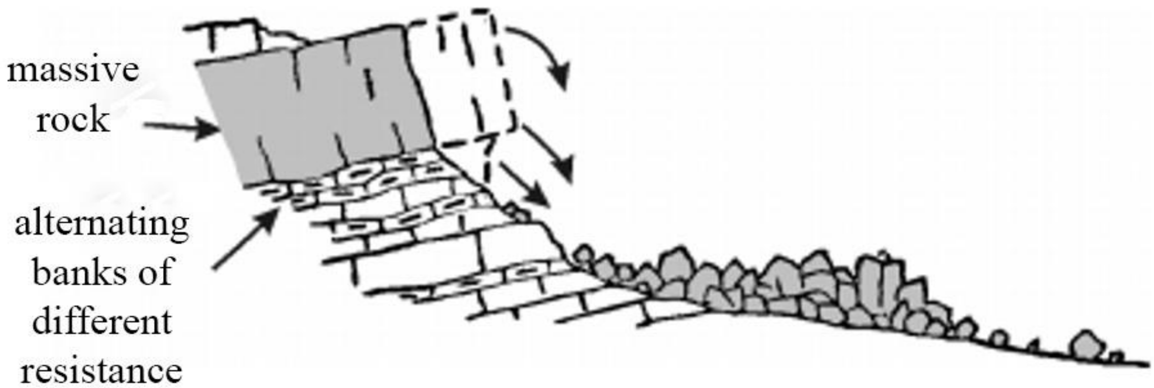


Figure 7: *Schematic of a topple.*

III.3 Earthflow:

Earthflows can occur on gentle to moderate slopes, generally in fine-grained soil, commonly clay or silt, but also in very weathered, clay-bearing bedrock. The mass in an earthflow moves as a plastic or viscous flow with strong internal deformation. Susceptible marine clay (quick clay) when disturbed is very vulnerable and may lose all shear strength with a change in its natural moisture content and suddenly liquefy, potentially destroying large areas and flowing for several kilometers. Size commonly increases through headscarp retrogression. Slides or lateral spreads may also evolve downslope into earthflows. Earthflows can range from very slow (creep) to rapid and catastrophic. (Highland & Bobrowsky, 2008)

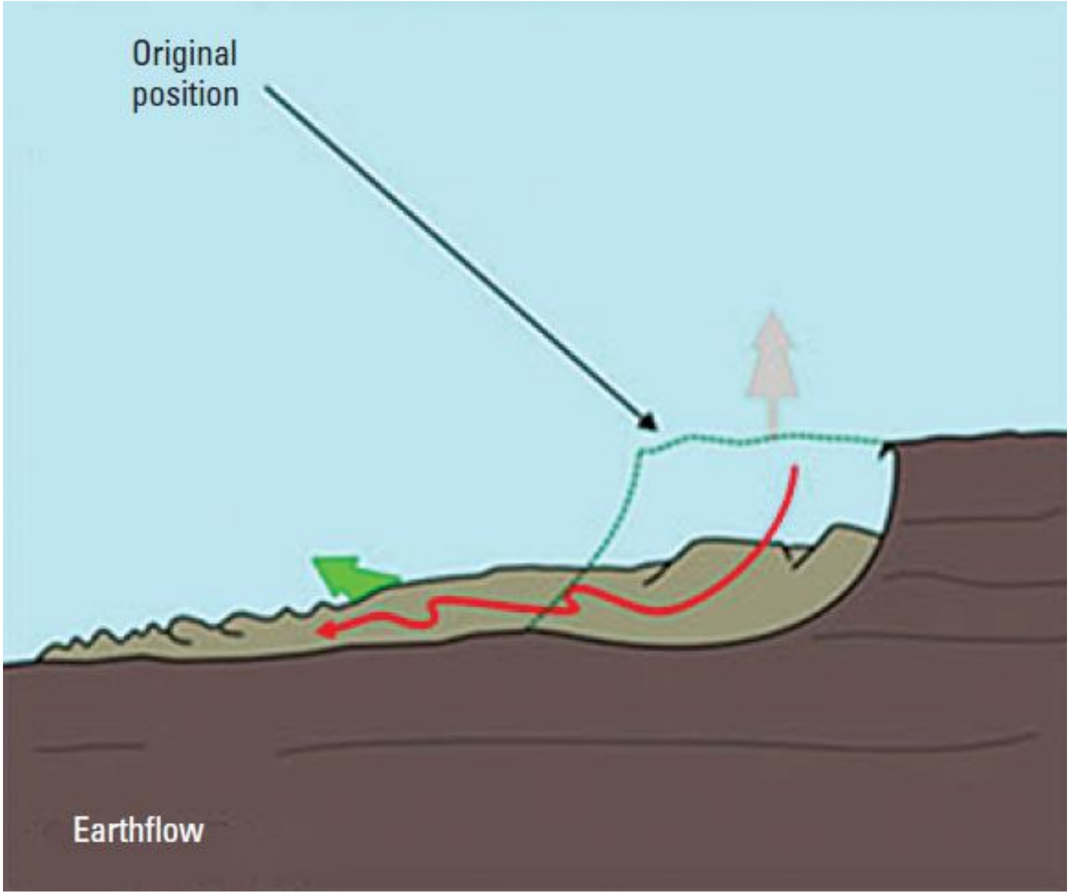


Figure 8: *Schematic of an earthflow, (Highland & Bobrowsky, 2008).*

III.4 Creep:

Creep is the informal name for a slow earthflow and consists of the imperceptibly slow, steady downward movement of slope-forming soil or rock. Movement is caused by internal shear stress sufficient to cause deformation but insufficient to cause failure, according to. (Highland & Bobrowsky, 2008). Generally, the three types of creep are:

(1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and temperature;

(2) continuous, where shear stress continuously exceeds the strength of the material;

(3) progressive, where slopes are reaching the point of failure for other types of mass movements. (Highland & Bobrowsky, 2008)

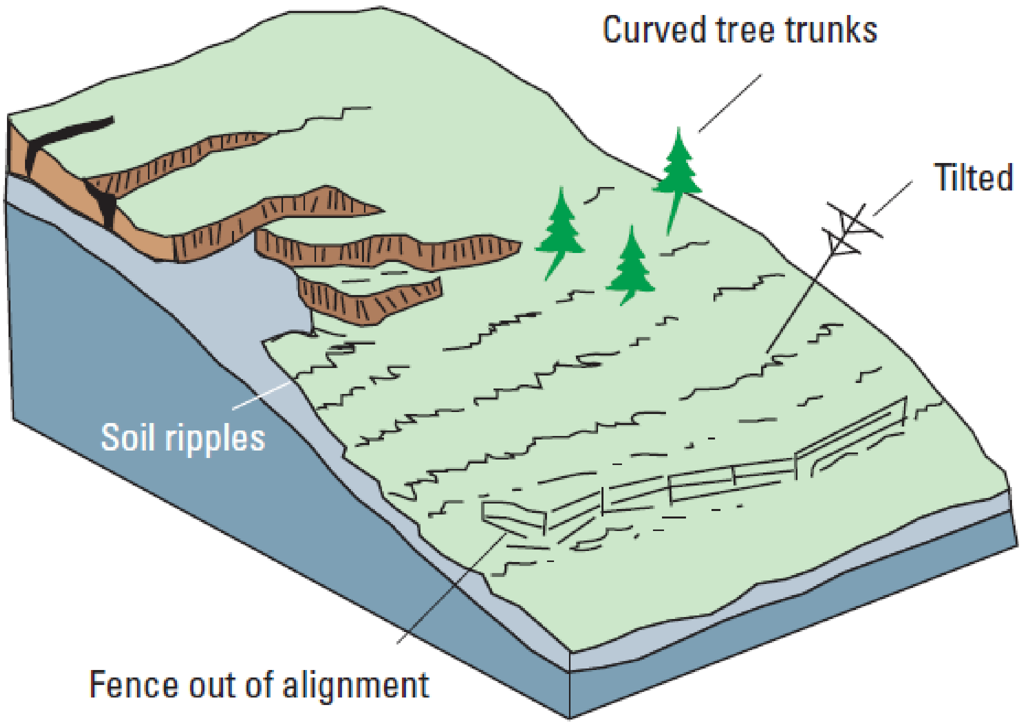


Figure 9: *Schematic of a slow earthflow, often called creep, image edited from, (Highland & Bobrowsky, 2008).*

IV. Methods of calculating landslides:

The usual methods of calculating slope stability are mostly based on a « limit equilibrium » reasoning, which consists in defining a potential failure surface of the structure and comparing:

- The contribution of driving forces (gravity, overloads, hydraulic flow, seismic stress, etc.) which tend to destabilize the part of the structure delimited by this surface.
- To the resistance contribution developed by the soil along this surface, taking into account its resistance characterized by its cohesion and its friction angle. (yves , et al., 2013).

Slope stability analysis is usually performed at failure using the slice method. This method gives, through the factor of safety, an idea of the equilibrium state of the slope studied with respect to the limit equilibrium. The expression of the safety coefficient is different depending on whether it is a plane, circular or any failure. In all cases, the stability calculations are made in short-term total stresses and / or in long-term effective stresses. The degree of precision of the calculations will however depend on the quality of determination of the shear parameters, but also on the calculation means implemented.

IV.1 Definition of the safety factor Fs:

Many formulas for calculating factor of safety are introduced to determine the degree of stability of the slope. The basic formula of Safety Factor (**FS**) (for soil material) was introduced by Fellenius, and later developed by many researchers such as Bishop, Janbu, Sarma and others.

The general formula for safety factor is:

$$F_s = \frac{\tau_{max}}{\tau}$$

In which $\boldsymbol{\tau_{max}}$ denotes the shear strength of the soil concerned by the slip and $\boldsymbol{\tau}$ the shear stress effectively mobilized along the failure curve.

Indeed, the safety factor is the comparison between the resistance force and the driving force. The safety factor reflects the slope conditions. In several studies on slope stability analysis, the FS (Safety Factor) plays an important role in determining the significance of slope stability. Based on several landslides, the adopted minimum safety factor FS is seldom less than 1.5. It can sometimes be equal to 2, or even to 2.5 for structures whose stability must be guaranteed at all costs (high risk for people, exceptional site), or for methods with high uncertainty (total stress analysis with risk of error on the value of the drained cohesion CD).

For some small sites or for some common structures, and when there is no risk to human life, lower values can be accepted for a very short time or for low frequencies: 1.2 or even 1.1.

The table below gives us the values of FS according to the importance of the structure and the particular conditions surrounding it:

Table 1: *FS value depending on the condition of the structure.*

Safety factor FS	State of the work
<1	Danger
1.0-1.25	Questionable security
1.25-1.4	Satisfactory safety for small works Questionable safety for dams, or when the rupture would be catastrophic
>1.4	Satisfactory for dams

IV.2 Classical methods for stability analysis:

IV.2.1 Case of plane ruptures (translational landslide):

This type of failure is encountered when the mass is made up of several layers with very different physicochemical and mechanical characteristics, or when the length of the potential sliding surface is very large compared to the thickness of the ground. The safety factor is given by the following expression:

$$F = \frac{C' L + (W \cos\alpha - U) tg\,\varphi'}{W \sin\alpha}$$

With:

L : Denotes the length of the embankment.

α : The slope angle.

W : The weight of the ground in motion.

U : The resultant of any pore pressures.

C': The effective cohesion.

φ' : The effective internal friction angle.

IV.2.2 Case of circular ruptures (Rotational landslides):

This type of rupture is encountered when the mass is homogeneous. Two calculation methods allow to deal with this problem:

a. Fellenius method:

In which it is assumed that the inter-slice external forces are equal. Hence the following expression for the safety factor:

$$F_f = \frac{\sum[c'b + (W\ cos^2\alpha - Ub\ )\ tg\ \varphi']/\cos\alpha}{\sum W \sin\alpha}$$

With:

b : Width of a slice.

b. Bishop's method:

In which it is assumed that only the horizontal components of the inter-slice external forces are balanced. Hence the following expression of the Safety factor:

$$F_b = \frac{\sum[c'b + (W - Ub)tg\ \varphi']/(cos\ \alpha + \sin\alpha\ tg\varphi'/F_f)}{\sum W \sin\alpha}$$

IV.2.3 Case of any ruptures (non-circular landslides):

This type of rupture is encountered when heterogeneities are evident. This problem is addressed by the perturbation method, in which it is considered that the normal stress is not constant along the failure curve as is the case with the two previous methods.

This method is global and applicable to any failure curve considered.

It is based on the simple resolution of the static equilibrium equations with automatic adjustment of the distribution of the normal stress obtained by a disturbance of the normal Fellenius stress along the failure curve.

IV.3 Some examples of landslides:

IV.3.1 In the world:

1- Shan Road landslide, Hong Kong, 1972

On 18 June 1972, near 14 Po Shan Road approximately 40 000 m3 of debris travelled some 270 m down slope and resulted in 67 deaths, 20 injuries, two buildings destroyed and one building severely damaged.

A construction site above the major part of the landslide was being redeveloped at the time of the landslide.

In late 1971 two landslides had occurred at the site.

This landslide occurred over a few days.

16 June 1972 cracks were noted

17 June 1972 a small slip occurred above the construction site.

18 June 1972 a major landslide travelled 270m down the slope

19 June 1972 another small failure occurred

20 June 1972 another small failure occurred.

Work on the construction site above the road, together with the exceptionally heavy rainfall in early 1972, caused this landslide.

About 1400 mm of rainfall was recorded between May and June 1972 and in particular more than 650 mm of rainfall was recorded from 16 to 18 June 1972 when the main landslide happened. (Landslides around the world, n.d.).

Figure 10: *Shan Road landslide, Hong Kong, 1972,* (Robert , et al., 2007).

2- Maiereto landslide Italy, Calabria, 2010:

On 15 Feb 2010, the side of a hillslope slipped past people whilst they stood and watched. A landslide had happened here before and geologists had seen signs that it would move again so people were evacuated and no one was hurt.

Gravity constantly tugs downward on a slope, but only when gravity's force exceeds the strength of the rocks, soils, and sediments making up the slope does land begin to slide downhill.

Heavy rainfall in the Maierato region is likely to have started this slide. (Landslides around the world, n.d.)

Figure 11: *Maiereto landslide Italy, Calabria, 2010, (Italie: des milliers d'habitants évacués après un spectaculaire glissement de terrain, 2010)*.

3- Quick clay landslide in Rissa, Norway, 1978:

On 29 April 1978 a landslide wiped away an area of 330 km2 (about the same as 47 football pitches) including 13 farms, two homes and the local community center.

The slide contained about 5 to 6 million m3 of material, about 2400 Olympic swimming pools and was the biggest slide in Norway in this century. Of the 40 people caught in the slide area, only one person died.

In this case the farmer dug a pit on his land and put the extra material on the edge of the lake. This extra weight was too much for the clay to cope with and so the landslide began.

The slide started at the lake shoreline and developed backwards and landwards taking with it people, farms and homes.
This type of landslide is rare and was caused by the special make-up of the clay material. Quick clay was laid down millions of years ago under the sea. Over the years, salt has been removed by water passing through it over time, leaving a clay crust with the salt-free marine clay underlying it.

When the clay has too much weight loaded on to it the strength fails, and collapses. It then becomes 'remoulded' and acts like a liquid.
Not only did the landslide travel backwards from the lake, it also caused great damage to the community of Leira when as a result of the clay sliding into the lake, a three meter high flood wave reached the opposite bank of Lake Botnen shortly after the main slide. (Landslides around the world, n.d.).

Figure 12: *Quick clay landslide in Rissa*, *Norway*, *1978,* (Norwegian Geotechnical Institute, 2008).

IV.3.2 In Algeria:

Algiers landslides:

1- El Biar landslide in Algiers:

Dating from at least 1785 and which still constitutes a real threat to an urban environment, despite the already completed comfort works.

Analyzes, between 1995 and 2007, as part of the study of the landslide at El Biar also known as the Saint-Raphaël landslide, revealed the presence of two zones: a moving peripheral zone at an average speed of approximately 5 cm per year and a central area in motion at an average speed of approximately 10 cm per year. The fact that all major displacements occurred during the winter strongly suggests a significant effect of groundwater pressure on the instability of the slope. (Abdallah , et al., 2014).

Figure 13: *Retaining wall collapsed along Bougara Road after heavy rain in February 2013*, (Abdallah , et al., 2014).

2- High winds landslide on the Algiers ring road:

The landslide concerns an embankment in the southern ring road of Algiers which links the city of Algiers to its western suburbs at a place called "the great winds". It is a high-traffic highway. The slip manifested as a mudslide that reached the pavement.

Figure 14: *View of expressway and mudslide, source :*(ARAB Rabah, ZERMANI Messaoud, TABTI Saïd; 2009).

3- Landslide in Constantine:

According to the Simecsol report, a set of 15,000 homes housing nearly 100,000 people are threatened by the landslide, and no less than 1,790 individual and collective constructions are condemned for demolition.

This means that the phenomenon of slippage has become an obsession for the inhabitants concerned and just as much concern for the local authorities who must take urgent measures. But since the phenomenon of slippage is not new, it must be admitted that much remains to be done to deal with it. It is thus, we learned that the new wali instructed his administration to engage as soon as possible an expertise on the phenomenon of landslides that he had to perceive at the level of the city of Constantine. (Le courrier d'Algérie newspaper).

Figure 15: *Hundreds of "Cnep" homes, erected on the Boussouf site, are declared uninhabitable, source:* (El Watan Newspaper).

4- The Aïn El Hammam landslide:

The landslide of Ain El Hammam is located on a hill slope of 30 to 40 ° inclination composed of mainly schistous and micaceous metamorphic terrains. The first appearance of this instability was recorded in December 1969 following heavy precipitation. The reactivations of the ground movement in 2009, 2012 and 2013 were marked by a clear evolution in surface and depth of the unstable zone. The geotechnical and geophysical study of the slope, conducted in 2009, showed that the latter is composed of saturated shales altered over a significant thickness surmounted by a surface covering composed of shale debris wrapped in a clay matrix. The landslide extends over an area greater than 23 ha and mobilizes a layer of soil with a thickness of 45m and more by implementing three deformation mechanisms. Several signs of instability were observed at the city and slope level (demolition of several buildings severely damaged by the movement). (BOUAZIZ & MELBOUCI)

Figure 16: *View of one of the landslide activities of Aïn El Hammam, source:* (L'expression Newspaper).

V. Conclusion:

Landslide is a general term used to describe the movement of soil and rocks under the effects of gravity and the shape of the landform that results from that movement.
In this chapter we have shown that the varying classifications of landslides are associated with specific slope failure mechanisms and the properties and characteristics of failure types.

Regardless of the exact definition used or the type of landslide under discussion, it is helpful to understand the basics of a typical landslide. (Highland & Bobrowsky, 2008).
For a ground movement to appear in a given place, it must be united in
This place a number of factors of instability which can be:

• permanent or very slowly variable factors, characterizing the predisposition,

The site's susceptibility to instabilities (relief, geological nature, hydrogeology, etc.);

• factors that vary over time (earthquakes, human activities, bad weather, etc.)

Who can play the role of trigger of movements.

CHAPTER II

Methods of analysis and assessment of landslide risks

CHAPTER II: Methods of analysis and assessment of landslide risks

I. Introduction

Recognizing areas at risk of landslides is a complicated task: the area to be covered is large, and only a detailed analysis can reveal their presence. Geographic Information Systems (GIS) allow efficient processing of information on a digital medium.

Once, the potential risk factors are identified, they are superimposed to deduce an overall level of risk, aggregating a maximum of factors. Some are easily accessible such as local precipitation, the degree of the slope, etc. It is a question of being able to indicate more precisely the level of danger. In addition to the precise study of the soils of a region, it is often necessary to rely on the archives to facilitate the work of geologists in the recognition of risk areas.

II. Vocabulary and concepts of the "RISKS" problem:

Risk is defined as the intersection between the hazard and the vulnerability of the issues. However, in the case of ground movements, the vulnerability is difficult to qualify because the interactions between the exposed elements and the phenomena which can damage them are complex. Thus, for most small-scale maps (beyond 1 / 100,000th), the assessment of ground movement risk results from the overlapping of the hazard with the issues without taking into account their vulnerability. (christian , et al., 2010)

Example which shows the evolution of the risk in the case of ground movements:

Figure 17: *Scheme representing the various components of natural risk, (christian , et al., 2010).*

III. Hazard mapping:

Risk mapping (or "hazard mapping") allows to analyze and query the risks in their spatial characteristics. It occurs on several scales and can represent either the spatial distribution of hazards, the distribution of issues (which is likely to be damaged), the distribution of vulnerabilities, or a combination of the three factors.

Examples of use:

• Spatial distribution of the different levels of dangerousness depending on the risk (s) taken into account;
• Implementation of risk prevention and management measures;
• Restriction of land use rights by an easement of public utility Risk Prevention Plan (RPP)

And so that we can make the hazard map. We have to go through certain stages:

1. 1. Definition of a reference area;
2. 2. Delimitation of the areas of hazard;
3. 3. Estimation of the occurrence of phenomena;
4. 4. Qualification of the hazard.

IV. Contribution of geographic information system (GIS):

The considerable development of GIS over the past ten years has made it possible to increase the power of techniques for assessing and mapping hazard at regional level. This development has been observed mainly in quantitative methods which require more sophisticated analyzes than qualitative methods. The first simple applications date from the 1970s (Aronoff, 1989). On the other hand, it was in the mid-1980s that the use of GIS became widespread thanks to the development of commercial applications and the availability of personal computers.

These geographic information systems which, at the beginning, only intervened in the automation of certain tasks of cartographic reproduction and computer-assisted drawing, are now tools which make it possible to carry out complex operations of spatial analysis such as slope, flow and identification calculations. (Magalie, 2003)

V. Risk assessment methods of « Landslide »:

The hazard assessment is currently the main component of the ground movement risk. It is based on the estimation of the probability of occurrence of the phenomenon within given time frames, and of the possible intensity of the phenomenon. The probability of occurrence can be assessed by estimating the site's predisposition to ground movements which depends on many factors of instability (geological nature, slope, hydrogeology, etc.) and the signs of activity observed. The intensity is most often evaluated indirectly depending on the importance of the measures to be implemented to treat the risk. (christian , et al., 2010).

Several methods exist to qualify the landslide hazard, but in general there are two main classes of landslide hazard analysis:

V.1 Qualitative or empirical Methods:

Qualitative (or empirical) methods fall into two categories with:

V.1.1 The « geomorphological » or so-called direct method:

The direct method is based on a geological and geomorphological analysis of the terrain. This type of method can be used for the regulatory cartographer. The assessment and / or zoning is carried out in the field by the expert who, on the basis of his observations and experience, will place the limits of the mapped areas and an estimated degree of hazard. Thus, the expert directly synthesizes the information and can integrate a large number of factors. The advantages of the method are its speed of implementation and the integration of the propagation of the lands slipped into the mapped envelopes. The major faults lie in an approach that is little explained with implicit rules that are difficult to reproduce by others (van Westen , et al., 2008). Geographic information systems (GIS) are used as a vectorization tool for the final hazard map (Thiery , et al., 2007).

V.1.2 Indirect methods:

Unlike the direct method, the expert tries to rationalize and explain his reasoning and to quantify each contributing factor, this type of method can be used for regulatory mapping. Several methods exist; all start from the same principle which consists in: (i) selecting the phenomena; (ii) select the contributing factors (in the form of spatial variables); (iii) assign a relative weight for each predisposition factor and respective class (each weight being proportional to the contribution expected by the expert to generate a type of phenomenon); (iv) combine the variables under GIS in order to obtain, after reclassification, homogeneous zones favorable or not to landslides. Several approaches are distinguished with: (i) the Boolean logic approach; (ii) the combination approach of index maps; (iii) multi-criteria systems (analysis by hierarchical process; Saaty, 1977). The last approach cited is in terms of combining variables and formalizing the most complete expert rules. In addition, it retains the flexibility of the geomorphological approach while being considered more objective by the formalist framework that it imposes on their application (Poiraud, 2012). For these methods, only susceptibility is assessed. (Yannick & Monique, 2019).

V.2 Quantitative Methods:

As opposed to qualitative methods, quantitative methods are considered objective. They are theoretically reproducible for similar environments by producing identical results with the same set of variables (Thiery , et al., 2007); (Fressard, 2014). Two main types of quantitative methods are differentiated:

V.2.1 statistical / probabilistic methods (or data-driven methods):

It is possible to use several approaches: bivariate approaches most often based on Bayes' theorem (Weight of Evidence, value of information, frequency ratio, etc.); multivariate approaches (logistic regression, discriminant analyzes, ...): approaches by artificial neural networks. The principle is the same for each one, it is based on the spatial distribution of the phenomena and a comparison with the different factors (in the form of a spatial variable). Thus, depending on the approach chosen, a weighting for each class of factor is obtained. The weightings are therefore defined in an objective manner, without intervention by the expert, then, as for the indirect qualitative methods, a combination under GIS is carried out. Zoning into homogeneous sectors favorable or not to landslides is carried out after reclassification of the models. While the results are robust and can be transposed to other similar sites (provided that the approaches are well aligned), these data-driven methods, as for the indirect methods, focus on the analysis of susceptibility and little integrate a temporal notion. When the latter is integrated, it is either in the form of a calculation of the spatial probability of return of the phenomena (Crovelli, 2000); (Coe, et al., 2004) or either by coupling statistical analyzes of the trigger factors (precipitation) and susceptibility (Zêzere , et al., 2004) which requires exhaustive inventories with the dates of the onset of the phenomena. (Yannick & Monique, 2019).

V.2.2 Physically based methods:

are based on limit equilibrium calculation models (safety factor calculation - FS). Two types of approach are generally used: static approaches and dynamic approaches. They are mostly based on infinite slope models, more rarely on complex failure models. For both approaches, the trigger factors (precipitation, saturation level of materials, seismic acceleration) are taken into account. For the dynamic approach, it is possible to make a forecast taking into account chronicles and temporal changes of the landscape and / or trigger factors. Thus, compared to the approaches described above, these methods require additional information such as hydrological (soil saturation, permeability, hydraulic conductivity, etc.) and geotechnical (material thickness, cohesion, angle of internal friction, specific weight, etc.) data.). Unlike statistical / probabilistic methods, these methods are considered to be more concrete and less exploratory, with physical processes being integrated and quantitative stability values calculated (Corominas , et al., 2014). However, in view of the large amount of information required, they are only applied to small watersheds or to a particular phenomenon, which makes them difficult to transpose. Indeed, a certain generalization of the input data would require approximations leading to imprecision of the results (Zizioli , et al., 2013); (Thiery , et al., 2019). Finally, their parameterization can be complex for the uninitiated. (Yannick & Monique, 2019).

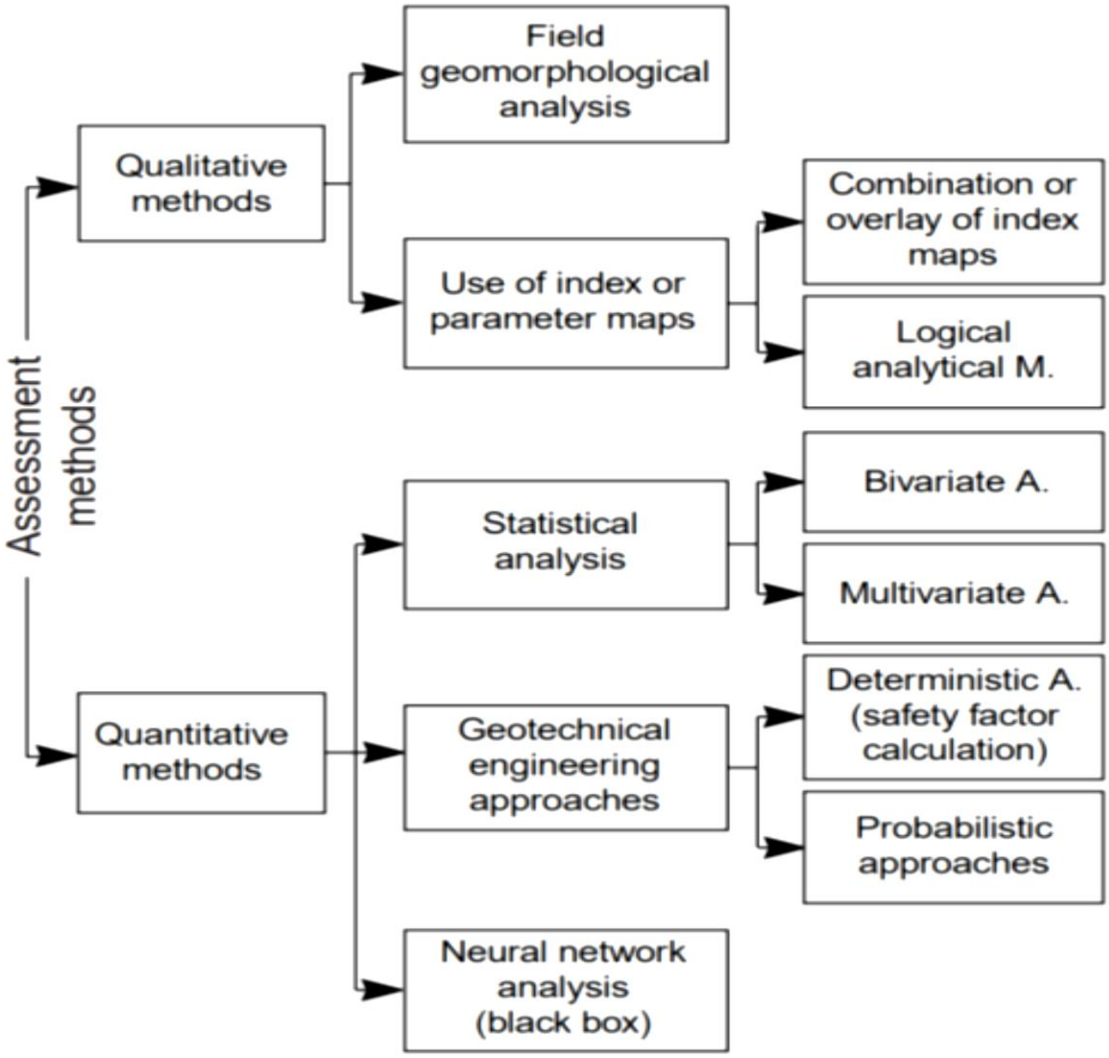
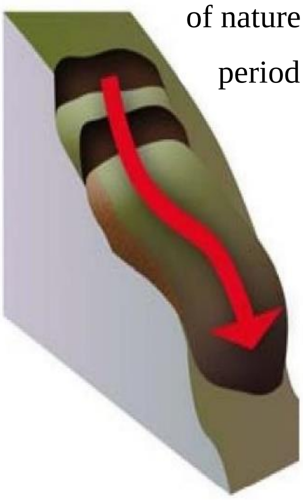
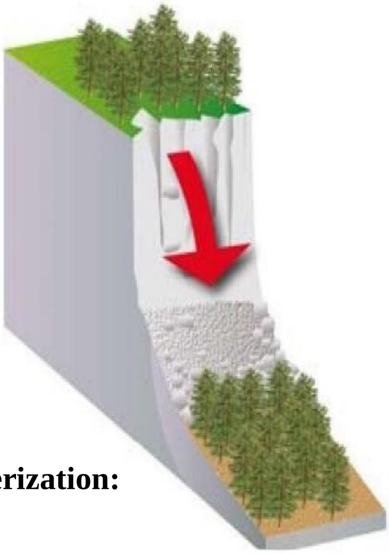


Figure 18: *Classification of the methods employed for landslide susceptibility assessments, (Kocaman & Gokceoglu, 2018).*

HAZARD ASSESSMENT

The ground movement hazard can be defined as the probability of occurrence of a phenomenon of nature and intensity given in a period of reference set





Hazard characterization:

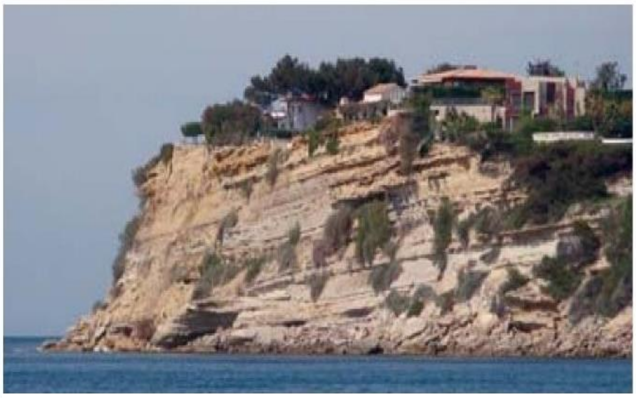
* its grip;

* its intensity;

* its frequency or recurrence or return period.

VULNERABILITY ASSESSMENT OF ISSUES

Vulnerability represents the degree of potential damage to an element exposed to a given phenomenon.



The exhibits bring together people, goods, activities, means, heritage likely to be affected by a natural phenomenon. The stakes represent the value attributed to the exposed elements according to the hazard. Assessing the vulnerability of issues involves:

- analysis of the natural and anthropic context
- identifying the issues;
- the estimation of the direct and indirect consequences of a ground movement on the different types of issues.

RISK ASSESSMENT

Figure 19: *A flowchart that shows the production of natural risk "ground movement", (christian , et al., 2010).*

VI. Conclusion:

Landslides occur in different forms, from individual rock falls to large creep failures depending on site conditions and the type of the triggering event (earthquake, precipitation, erosion, excavation, etc.). Based on their characteristics (number, timing, location, size, mobility, etc.), landslides can have significant consequences such as casualties, property damage or socioeconomic impacts, which constitute the ‘hazard’ and the ‘vulnerability’ of people, structures and infrastructure that exist or live in the potentially affected area. Such undesirable impacts can be prevented or reduced through various actions using ‘susceptibility mapping’ such that presented in this work.

CHAPTER III

Presentation of the study area

CHAPTER III: Presentation of the study area

I. Introduction

The north of Algeria is part of the alpine orogenesis; it currently corresponds to a geological field in compression attested by active inverse faults. This tectonic activity is the expression of the convergence of the Africa – Eurasia plates; and the Algiers region has a rather complex geological structure. It can be presented as a primary metamorphic Dome bordered by tertiary and quaternary sedimentary soils.

II. Presentation of the study area:

Areas susceptible to ground movement from Ouled Fayet - Dely Brahim - El Achour – Souidania - Baba Hassen – Douera - Khraicia; object of our study is undergoing intense urbanization. It is located in the south-western suburbs of Algiers in between Longitude and latitude **36°39'0''N** & **36°45'0'' N** and **2°55'0'' E** & **2°59'0'' E** on Piacenzian marly lands with sandstone-sandy Astian cover, very degraded, forming in particular the plateaus of El Achour and Ouled Fayet all the way to Douera. These zones correspond to the SE and NW flanks of an anticline fold, of plurikilometric scale, of direction N30 ° E (Aymé, 1956), with large radius of curvature.

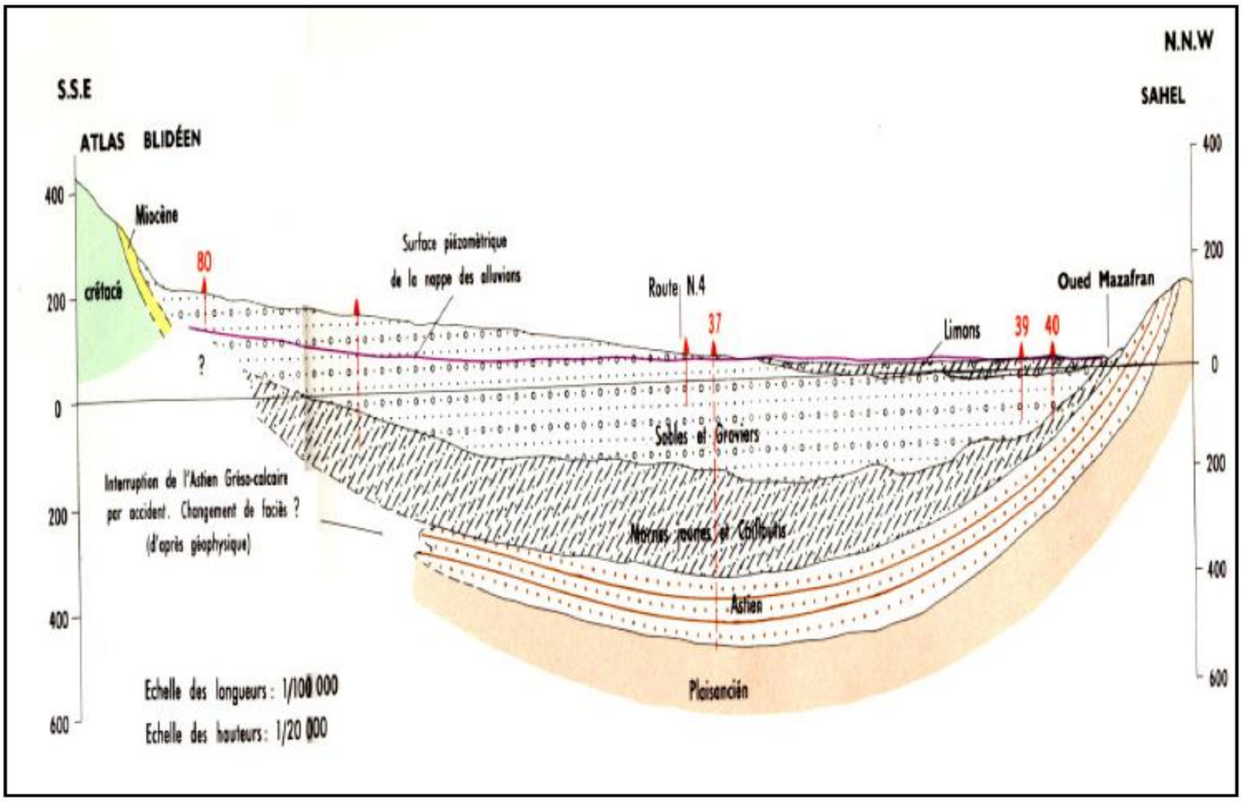


Figure 20: *Interpretative section of the Mitidja in the Mazafran basin showing the anticline fold, (Djoudar-Hallal & Toubal, 2014).*

III. Geographical situation of the marly sahel region:

The study area is located in the Algiers region (Figure 21), the vast majority of the region concerned is located in the Sahel (coastline) west and southwest of Algiers.

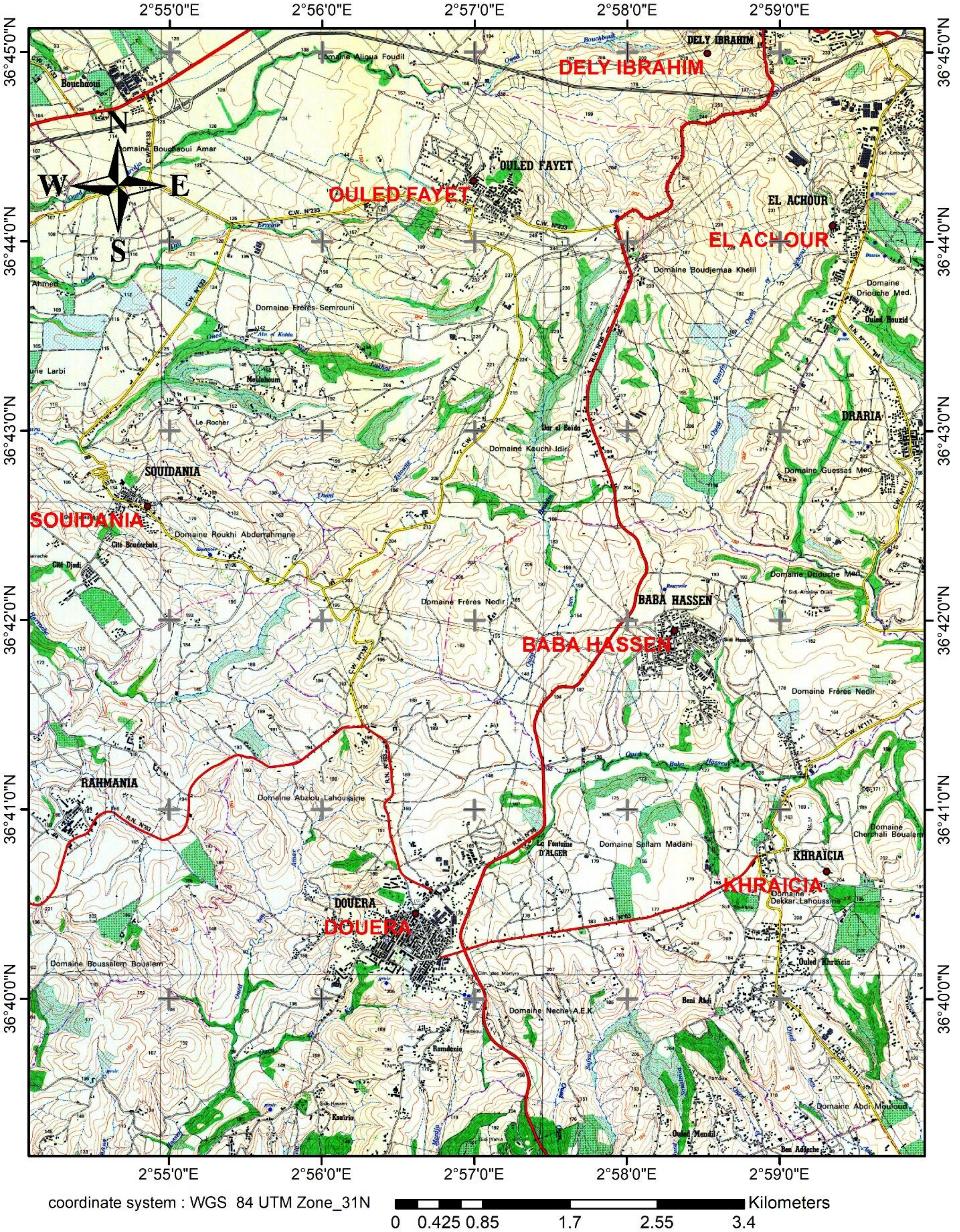


Figure 21: *Extract from the topographic map of the Algiers region (INCT).*

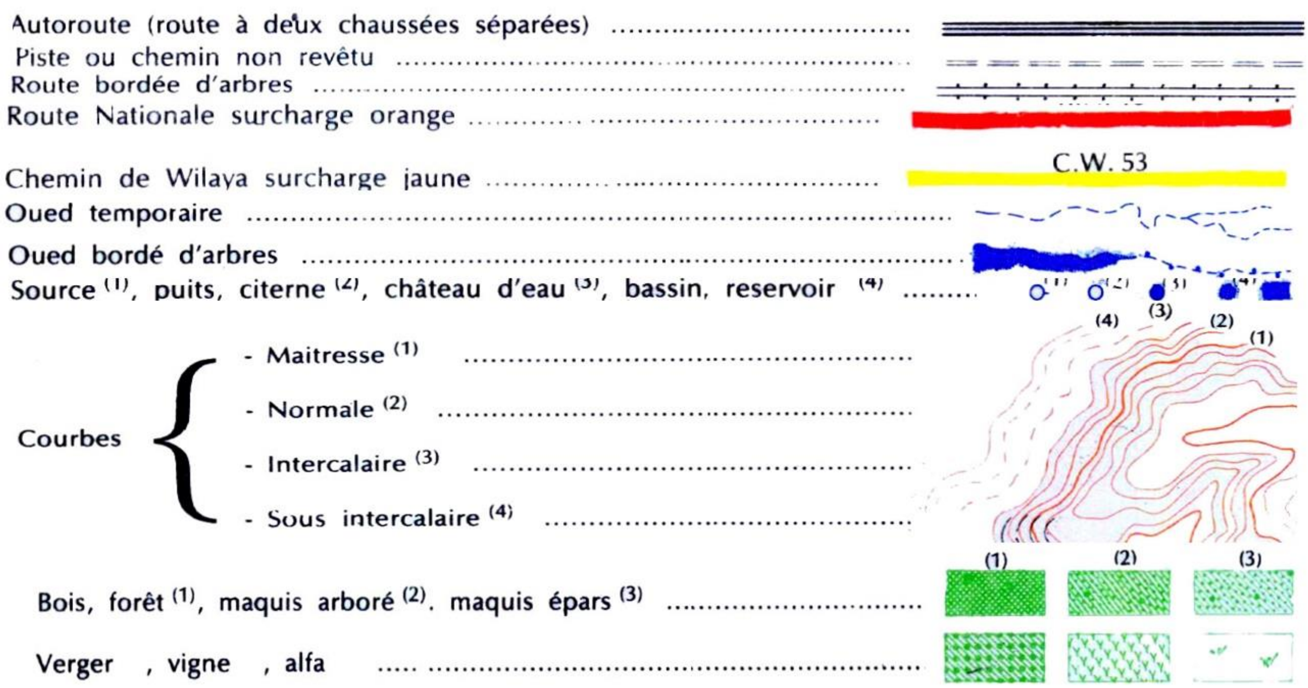


Figure 22: *The legend of the topographic map.*

IV. Geological and geomorphological framework:

IV.1 Regional geology of Algiers:

According to the geological map of Algeria, the geology of the Algiers region is varied from Primary to Quaternary.

We distinguish the following sets:

IV.1.1 The Paleozoic

It is represented by a metamorphic base made up of very tectonized crystallophyllian rocks. These rocks are exposed between Ain Benian, Bouzareah and the port of Algiers and reappear in the west at Sidi Fredj and in the east at Bordj El Bahri.

IV.1.2 The Mesozoic

The region is characterized by secondary stratigraphic gaps and the base of the Tertiary.

IV.1.3 The Cenozoic

It is marked by a gap in the Eocene and the Oligocene. It overlaps the metamorphic base. There are the floors:

- the lower Miocene which is made of sandstone and pudding. It is particularly tectonized and has reduced outcrop areas.

- the lower Pliocene which is clay-marly. It outcrops in the Sahel; its thickness exceeds 200 meters. It is covered by Astian sediments or by more recent formations.

IV.1.4 The Quaternary

It includes many lithological terms: sands, dune sandstones, silts, scree and slopes.
The Sahel is clayey, marly, and sand-limestone. In the plain a mound is sandy in nature. The plain is covered with a very large thickness of sediments and quaternary alluvium. (Derriche & Cheikh-Lounis, 2004).

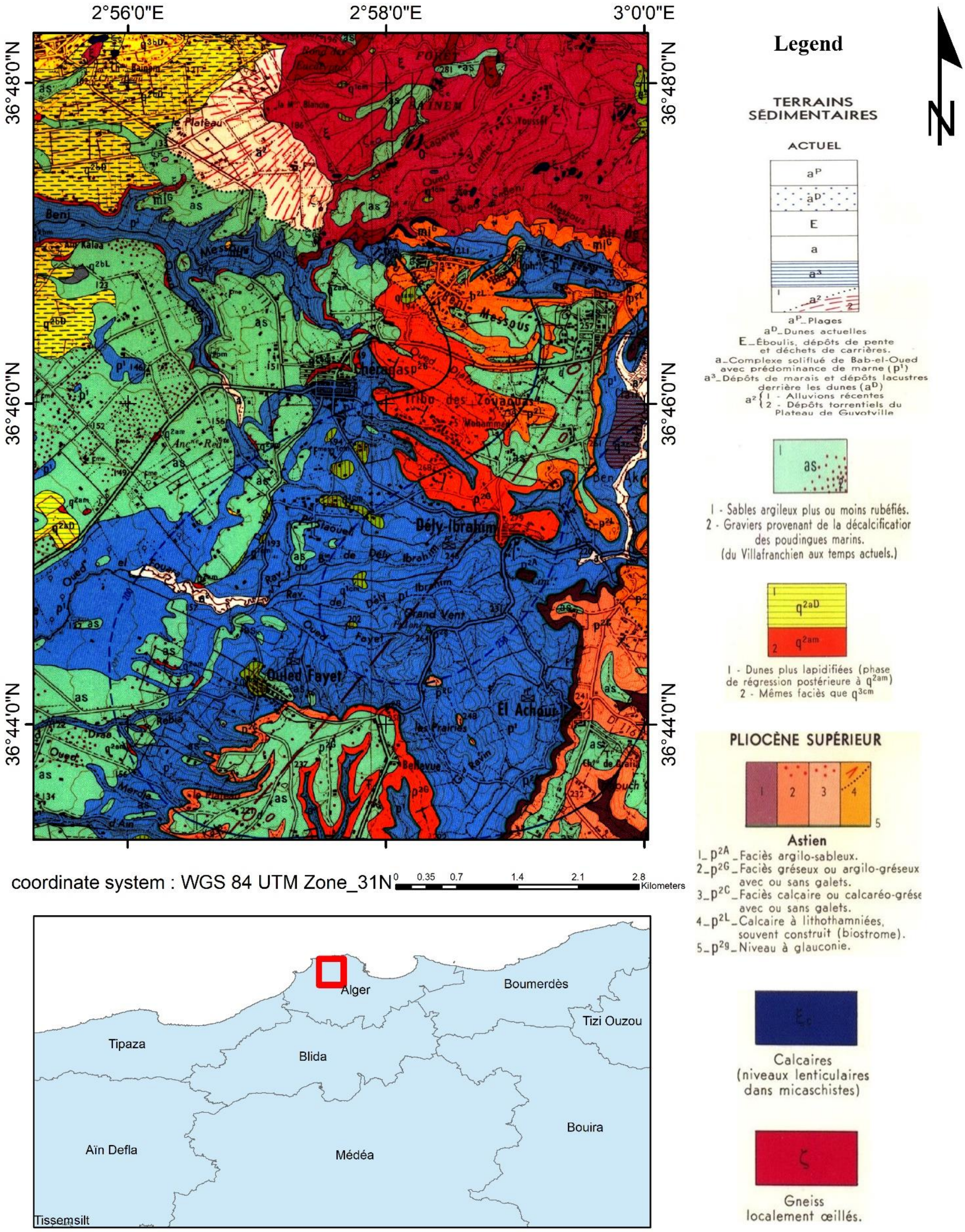


Figure 23: *Extract from the geological map of Algiers Cheragas (Sheet N ° 20 at 1 / 50,000th) after the engineer M.G BETIER, 1963.*

IV.2 Local geology:

According to the geological map of Algiers at 1 / 50,000th, the area of the Sahel of Algiers is made up from a geological point of view, with a dominance of land from the Lower Pliocene (Piacenzian) age, marly which outcrops in the Sahel and sometimes covered with Astian sediments.

From a lithological point of view, marls are deep marine deposits, very rich in microfossils. This base is very homogeneous and is found in all the mio-plio-quaternary coastal basins of Algeria. The Piacenzian marls with hilly topography and the presence of water form a ground very exposed to landslides.

IV.3 Geomorphology of the Algiers region:

Overall, the Algiers region can be subdivided into 5 major geographic areas (Figure24): (Derriche & Cheikh-Lounis, 2004)

IV.3.1 The Algiers massif or the Bouzaréa massif:

It is oriented in an east west direction. It is wooded and intersected by a network of deep thalwegs. It has a very rugged topography and its summit is the highest point in the region (407 m at Bouzaréa).

IV.3.2 The Sahel of Algiers:

It encompasses all the small reliefs that extend between, to the north, the Algiers massif, to the south, the Left Bank of the El Harrach river, and to the southeast, the Right Bank of the Oued Mazafran. We find in this set:

– The marly sahel

It is of Piacenzian age and has a hilly topography (hills and gentle slopes) and is traversed by a hairy hydrographic network typical of poorly permeable land.

– The molassic plateau

It overcomes in places the marly Sahel by large cliffs.

– The South Piedmont of the Sahel

It is formed by Clay-Stony deposits and forms quite strong slopes that testify to its low erosion.

IV.3.3 The eastern coastal plain:

Which is at an altitude of 2 to 15 meters.

IV.3.4 The dune coastline:

It develops in 2 zones. Between the right bank of El Harrach wadi and Bordj El Kiffan, it separates the maritime bank from the lower northern areas of Mitidja. In this area, it forms a small sand-sandstone barrier elongated parallel to the shore. West of Ain El Benian to Zeralda it forms the foothills of the marly Sahel. In this area it forms the dune plateau.

IV.3.5 The plain of Mitidja:

It is a WSW-ENE oriented syncline depression. It is the seat of accumulations of neogenic and quaternary formations. It has a flat topography which inspired the development despite the excellent agricultural quality of its soils and the irrigation perimeters that run through it.

In general, the Sahel forms a regular ridge, with a fairly steep slope (varying from 5 to more than 20%) towards the coast, surmounted by a slightly depressed plateau at its top, which descends in stages towards the Mitidja. This southern slope is hollowed out by multiple green ravines traversed by intermittent wadis despite the sources that give them birth. (Derriche & Cheikh-Lounis, 2004)

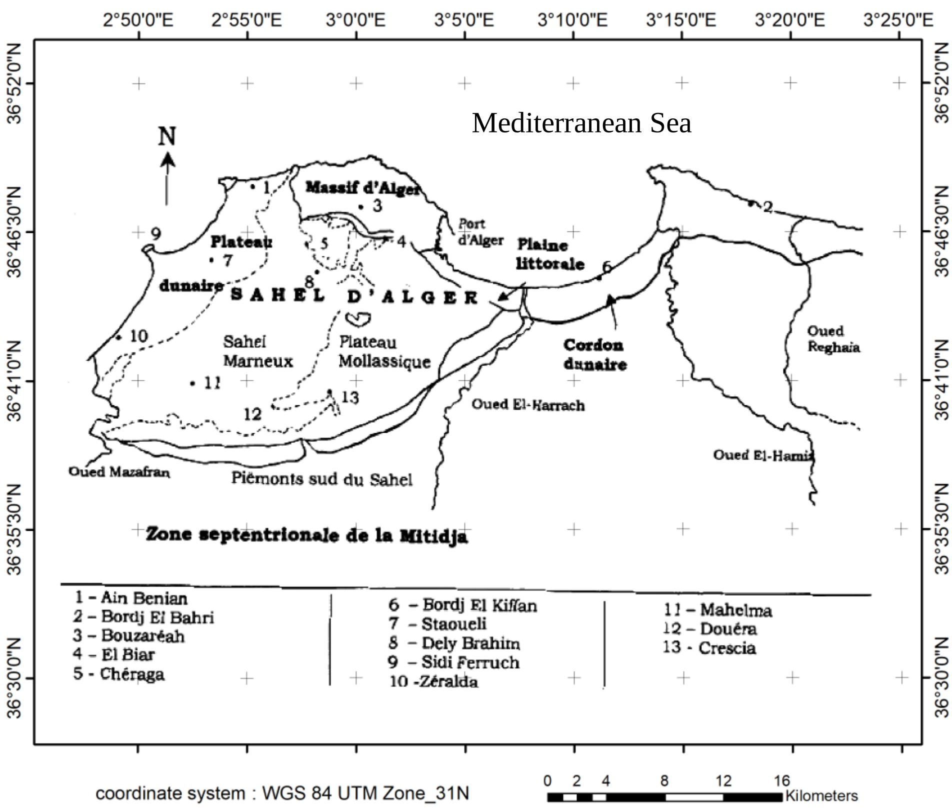


Figure 24: *The large geographic areas of the Algiers region, (Derriche & Cheikh-Lounis, 2004).*

V. Hydrogeology:

We distinguish in the Algerian region, in particular, two aquifers:

V.1 Piacenzian aquifer:

• It is in charge under the semi-waterproof yellow marl of El Harrach, except in the eastern part where it is in direct contact with the Mitidja aquifer.

• The hydrodynamic characteristics of the Piacenzian are poorly understood. The transmissivity estimates indicated by the company Geohydraulics (1968-1972), and the design office Bennie & Partners (1979-1980) vary from 90 to 2000m2 / day.

• The storage coefficient, estimated from short-term pumping tests (Bennie & Partners 1979-1980) is between 5.10-6 and 5.10-3. (Djoudar-Hallal & Toubal, 2014).

V.2 Mitidja quaternary aquifer:

- Separated from the Piacenzian aquifer by a thick layer of yellow marl, except east of Hamiz ("Rouiba pocket") where they are in direct contact.
- The free groundwater table extends over the entire Mitidja basin
- This aquifer is located in gravels and sands more or less consolidated and interbedded with clay, it is fed by:

• The rains; infiltration from El Harrach and Hamiz ...;

• The Astian aquifer by drainage**.** (Djoudar-Hallal & Toubal, 2014)

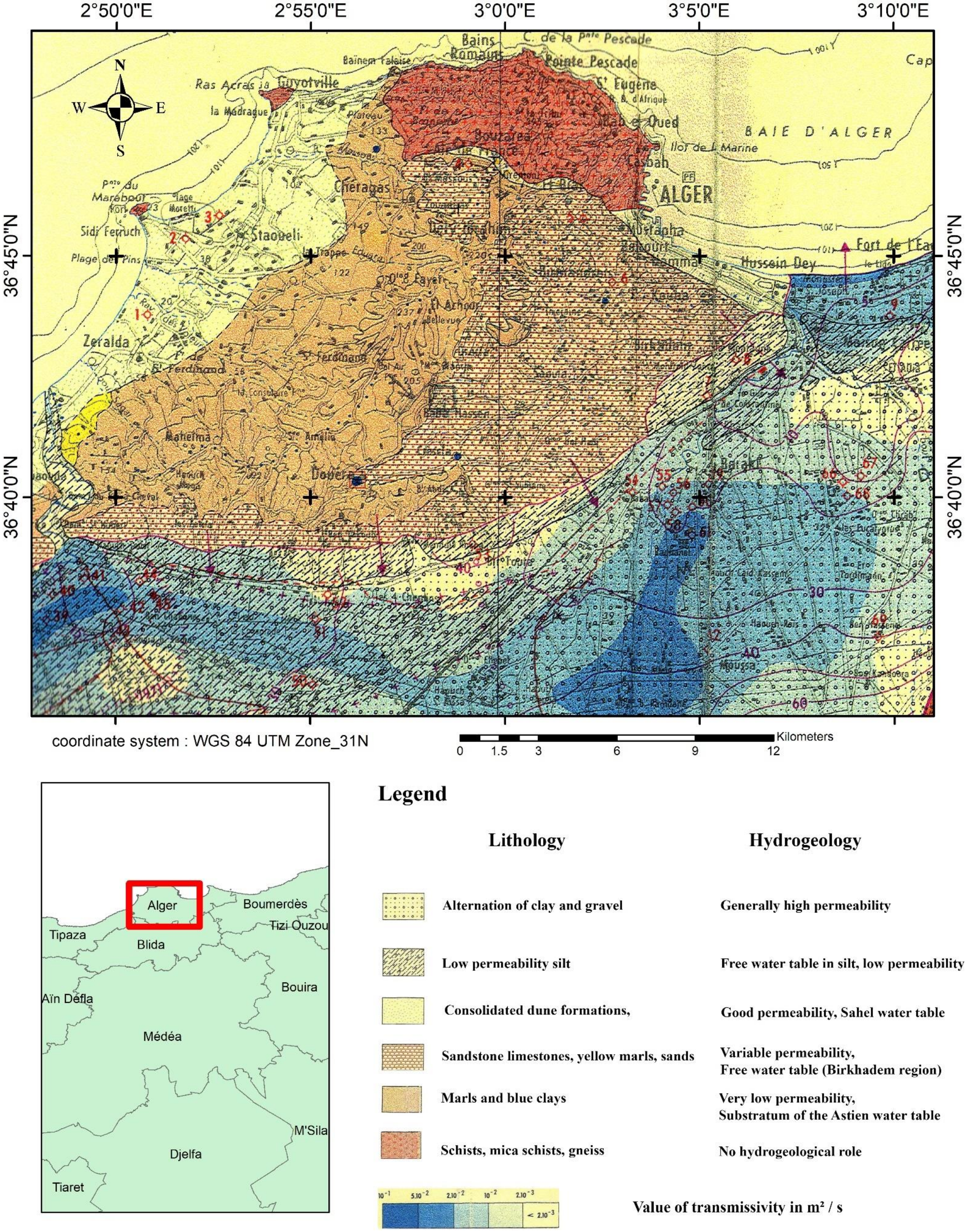


Figure 25: *Extract from the hydrogeological map of the region of Algiers (by K. ACHI, 1973).*

VI. The climate:

VI.1 Temperature:

In the Algerian Sahel region generally, there are two dominant seasons; a season which begins in December and ends in March, where the average temperatures vary between 13.7 ° C and 16.9 ° C with a minimum temperature in January. And another hot season which extends from June to October, where the average air temperatures vary between 22.9 ° C and 27.8 ° C with a maximum temperature in August and cool in November

In the following figure we can appreciate the average monthly variation in temperatures for the year 2019.

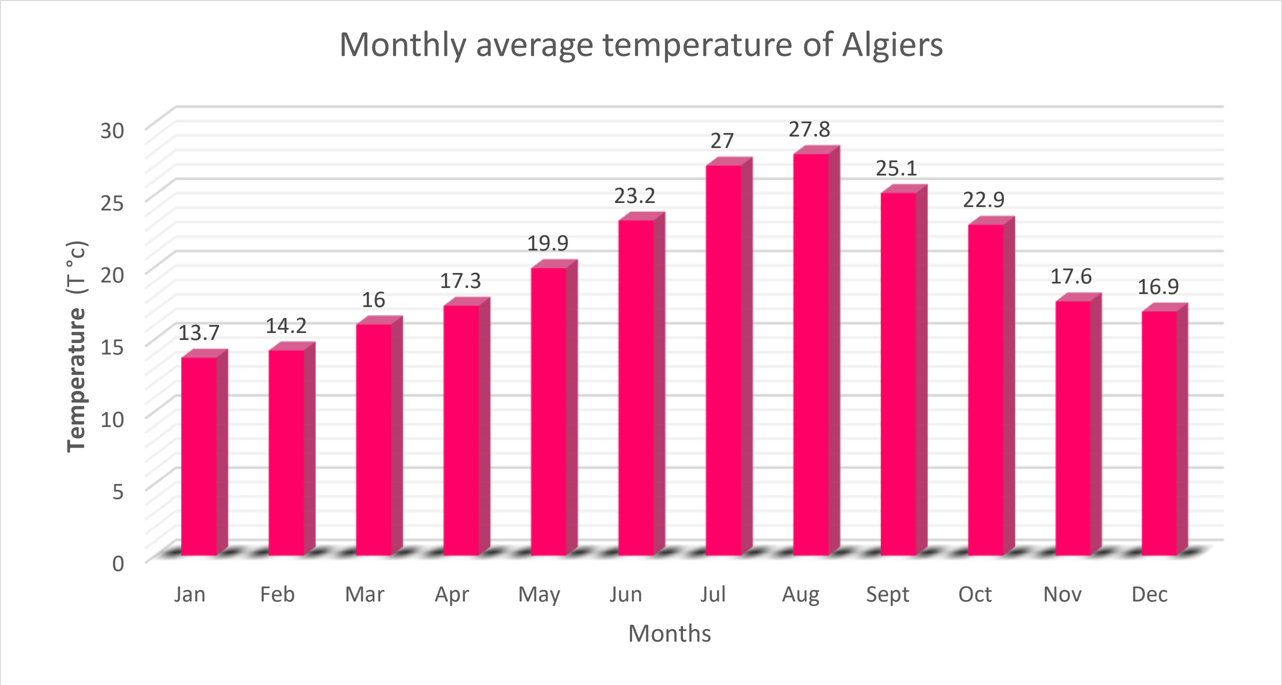


Figure 26: *Profile of variation of the average monthly air temperatures in the Algiers region for the year 2019 (according to Infoclimat, Algiers Port weather station).*

The warmest month of the year is August, with an average temperature of 27.8 ° C. and the coldest month of the year is January with an average temperature of 13.7 ° C.

VI.2 Rainfall:

Algiers in 2019, the rains are frequent in autumn and winter and decrease from the end of spring and become very weak in summer (Figure 27).

Two wet seasons stand out: one going from September to January where the maximum monthly average reaches 120.2 mm and the other rather dry going from May to August with a minimum of 1.2 mm.

There is, however, a transition period between February and April where the average precipitation varies between 28 and 46.3 mm.

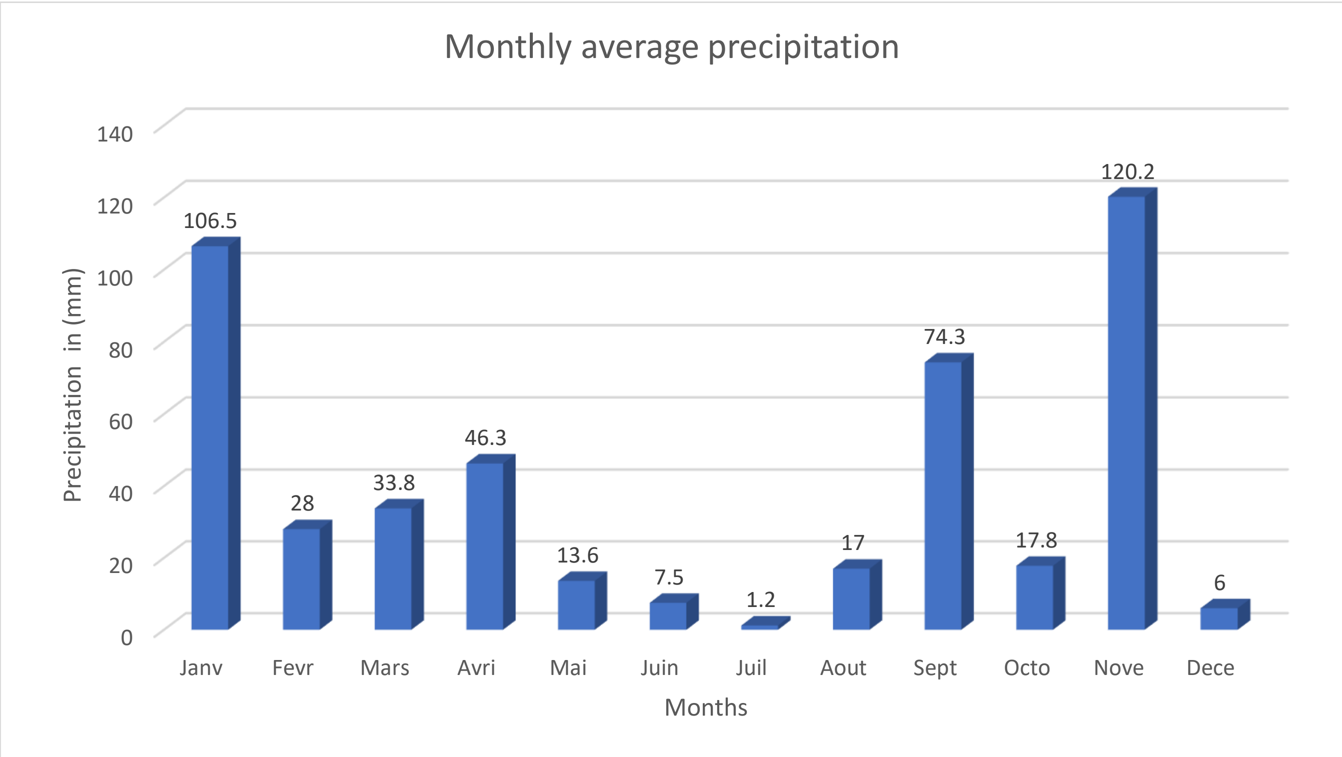


Figure 27: *Profile of variation of average monthly precipitation in the region of Algiers for the year 2019 (according to Infoclimat, Algiers weather station).*

VII. Seismicity:

The wilaya of Algiers is one of the regions conducive to seismic activities. Based on historical seismicity, Algeria has been subdivided into four macro-seismic zones. (RPA99 modified in 2003):

Zone III: high seismicity.

Zone IIb: medium seismicity.

Zone IIa: medium seismicity.

Zone I: low seismicity.

Zone 0: negligible seismicity.

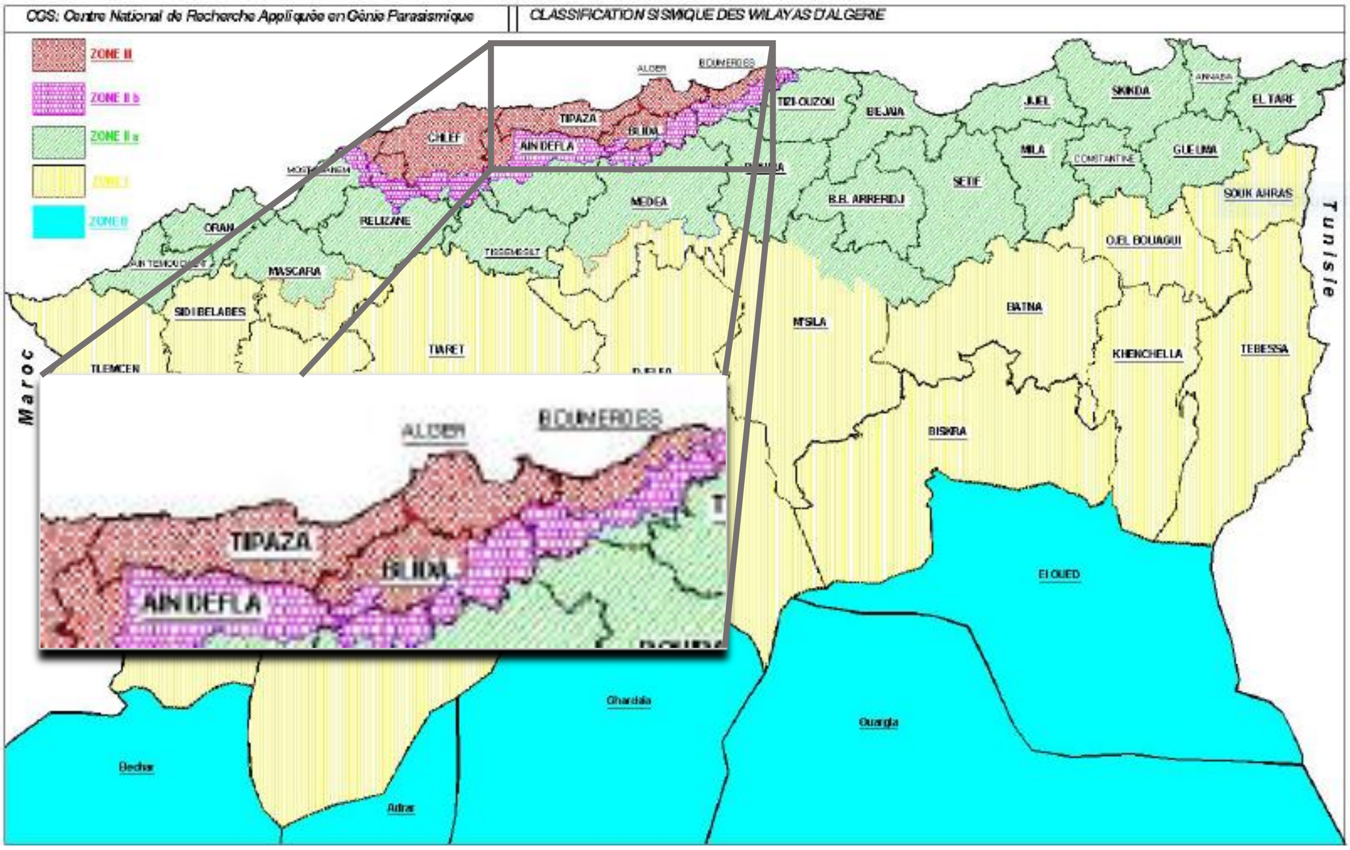


Figure 28: *Seismic zoning map of Algeria. (Source: RPA 2003).*

The Algerian Sahel region is classified in an area of high seismicity "ZONE III" according to the new seismic classification of the wilayas of Algeria carried out by the National Research Center for Earthquake Engineering C.G.S. (Figure 28).

VIII. Conclusion:

Through this chapter we deduce that the region of the Algerian Sahel is characterized by a much more recent geology little varied of different age and the seismicity of the region is high, therefore it is threatened by several types of instability. Such as the problems of instability of the slopes; these problems are mainly related to the lithological nature of the land, and to geomorphological and hydro-climatic conditions.

CHAPTER IV

General presentation of the work tools

CHAPTER IV: General presentation of the work tools

I. The AHP method

Many methods of multi-criteria decision support exist; their objective is to help decision-makers to formalize a problem, to clarify the decision context before assessing and comparing solutions. The AHP total aggregation method (or hierarchical multi criteria analysis) (Saaty, 1980), is one of the simplest to implement. It allows you to calculate a synthetic score (value between 0 and 1) aggregated on the basis of prioritization and weighting of all the criteria taken into account in the decision (Philippe , et al., 2018).

I.1 The principles of the AHP method (hierarchical multi criteria analysis):

AHP is recommended to solve complex problems with a multi-criteria decision. The strength of this approach (Al-Harbi, 2001) (Skibniewski & Chao, 1992) is that it organizes the factors in a structured manner while giving a relatively simple solution to decision-making problems. It makes it possible to dissect a problem in a logical way by passing from a higher level to a lower level until arriving at a simple comparison for each pair of criteria, thereafter one can go up to the higher level for the taking of decision.

In the application of the AHP, the relative importance or weight of the criteria is determined after consultation with the experts or the organization of interviews or group meetings. At this level the criteria must be compared in pairs separately using a qualitative or quantitative evaluation approach. In general, a nine-point numerical scale, called the Saaty scale, is recommended for comparison. This scale is detailed in (Table02): (BEN JEDDOU , et al., 2015).

Table 2: *Scale proposed by SAATY (1991).*

Degrees of importance of each characteristic	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor

		one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

In the hierarchical analysis process, the relative importance of the component or criterion i with respect to the component j is determined using the Saaty scale and is assigned to the (i, j) the position of the pairwise comparison matrix. Automatically, the reverse of the assigned number is associated with the (j, i) position according to the following rule. (Chang, et al., 2007):

$$a_{ij} \succ 0, \quad a_{ji} = \frac{1}{a_{ij}}, \quad a_{ii} = 1 \; \forall i$$

Hence the comparison matrix:

Table 3: *Comparison matrix and calculation of its own vector*, (RAMOS, et al., 2014).

Criteria	C_1	C_2	C_3	…	C_n	W_i
C_1	1/∑C1	W21/∑C2	W31/∑C3	…	Wn1/∑Cn	∑C1/n
C_2	W12/∑C1	1/∑C2	W32/∑C3	…	Wn2/∑Cn	∑C2/n
C_3	W13/∑C1	W23/∑C2	1/∑C3	…	Wn3/∑Cn	∑C3/n
…	…	…	…	…	…	…
C_n	W1n/∑C1	W2n/∑C2	W3n/∑C3	…	1/∑Cn	∑Cn/n
	∑C1	∑C2	∑C3	…	∑Cn	

When wij represents the quantitative judgment of the pair of characteristics Ci, Cj, it is defined by the following rules: (RAMOS, CUNHA, & CUNHA, 2014)

1. if Wij=α, so Wji=1/α, α≠0;

2. if C_i is considered to be of relative importance equal to that of C_j, so Wij=1, Wji=1 and Wii=1, for all i.

The eigenvector of the matrix can be found by the following formula:

$$w_i = (\Pi_{j-1}^{n} w_{ij})^{1/n}$$

In addition, it must be normalized so that the sum of its elements is equal to unity. For that, it is enough to calculate the proportion of each element compared to the addition.

T= [W1/∑Wi W2/∑Wi **…** Wn/∑Wi]

Let **T** be the normalized eigenvector used to quantify and assess the importance of each criterion.

In order to test the consistency of the response which indicates whether the data have a logical relationship between them, SAATY (1977) proposes to follow the following process:

$$\lambda_{max} = T \cdot W$$

Where **w** is calculated by adding the columns of the comparison matrix and $\boldsymbol{\lambda_{max}}$ maximum eigenvalue.

We calculate, then, the Consistency Index (**CI**):

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

n : number of criteria.

The Consistency Ratio (**CR**) is calculated by the equation:

$$CR = \frac{CI}{RI}$$

CR is the ratio between **CI** and a Random Consistency Index **(RI).** The **RI** index, presented in (Table04), comes from a sample of 500 reciprocal positive matrices managed at random, whose size reaches 11 by 11.

A consistency ratio of less than 0.10 is considered acceptable

Table 4: *Values of RI according to the order of the matrix*, (RAMOS, et al., 2014).

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

According to the work of (Yurdakul & Tansel, 2004), the value of **CR** must be less than 0.1 to conclude that the pairwise comparison judgments are consistent. On the other hand, if the value of **CR** is greater than 0.1, the coefficients of the matrix are incoherent and cannot be used for further analysis (Wong & Heng, 2008).

The AHP has been applied in several areas such as purchasing cars (Byun, 2001), selecting suppliers (Tam & Tummala, 2001) and selecting suppliers of computer software (Mamaghani, 2002). Also, (Yurdakul, 2004) adopted the AHP approach for the choice of production machines. This was also the case for the multi-criteria choice of the location of a factory by (Chan, et al., 2004).

I.2 The disadvantages of the AHP method:

This method remains simple to apply, but it is not free from bias which it is important to know before using it. Some of the known critics include:

- The possibility of compensation between criteria. If the weights are the same, a good evaluation on one criterion can indeed balance a bad one on another: we easily understand here the importance of determining preferences;
- The method of calculating the weights from subjective preferences;

Due to the method of aggregation of calculated weights (weighted sum), differences in performance on certain criteria between the alternatives evaluated may be hidden or misinterpreted. It should be remembered that even if the differences in assessment are minimal, a better score indicates a better solution, the value of the scores should not disturb the interpretation. In practice, if the method theoretically supports an infinite number of levels of criteria, experience shows that the human mind can validly compare only seven criteria at most by reasoning in pairs. Beyond this, it becomes difficult to compare two by two the criteria of the same matrix without avoiding inconsistencies. It is therefore necessary to limit the number of criteria of the same hierarchical level (the number of branches to a branch). A maximum number of sub-criteria between three and four is recommended. Finally, care should be taken to build a criteria tree that is as balanced as possible, that is to say with depths of equivalent criteria levels between the branches of the tree. The deeper a criterion is located in the tree, the less influence it will have on the final result. (Philippe, et al., 2018).

I.3 The advantages of the AHP method:

- Its ability to structure a complex, multi-criteria, multi-person and multi-period problem hierarchically,
- Binary comparison of elements (alternatives, criteria and sub-criteria),
- And the ease of its IT support, Expert Choice software.

II. General presentation of GIS and the ArcGIS work tool:

GIS "Geographic Information System" can be designed as a computer system managing geolocated information. Its primary function is to produce geographical maps from a wide variety of data: field survey, aerial photography, satellite image, old topographic map, etc. then to automate their analysis. (Yves, 2018).

II.1 Definition of GIS:

GIS is considered one of the most successful information technologies because it aims to integrate knowledge from multiple sources and creates an ideal multi-sector environment for collaboration.

In addition, GIS appeals to new users with its intuitive and cognitive side. It brings together a powerful visualization environment and a powerful analysis and modeling infrastructure specially adapted to the geography. (Antoine, 2012).

II.2 Reference coordinate system:

The reference coordinate system (RCS) defines the parameters useful for calculating the position of objects located on the surface of the Earth. The position of objects can be defined in a geographic coordinate system in latitude / longitude or in a cartographic coordinate system projected in a plane. The RCS is made up of two elements. (Yves, 2018) :

- **the geodetic system**

It models the shape of the Earth by an ellipsoid. The model of the ellipsoid can be improved by the geoid which takes into account the equipotential of the Earth's gravity field coinciding with the mean level of the oceans;

- **the projection system**

Is a transformation necessary for the representation in a plane, objects located on the surface of the Earth commonly modeled by an ellipsoid.

The coordinates of a point are expressed in units of length (meter) in cartographic marks and in units of angle (degree, radians, grade) in geographic marks. The cartographic marks define a position, in a projected space, by the triplet abscissa, ordinate and altitude (x, y, z). Geographic landmarks use the triplet angle to the prime meridian, angle to the equator, and altitude (λ, φ, h) to represent a point on the ellipsoid. (Yves, 2018).

II.3 ArcGIS software overview:

II.3.1 Definition of ArcGIS:

ArcGIS is software from ESRI, the world leader in GIS. The simplest version of the software is « ArcGIS desktop », comprising the « ArcCatalog », « ArcMap » and «ArcToolbox » applications.

ArcGIS Desktop (literally « ArcGIS Desktop ») includes a suite of applications integrated into each other (Antoine, 2012) :

II.3.1.1 ArcCatalog:

Facilitates the organization and management of all GIS data (maps, datasets, models, etc.).

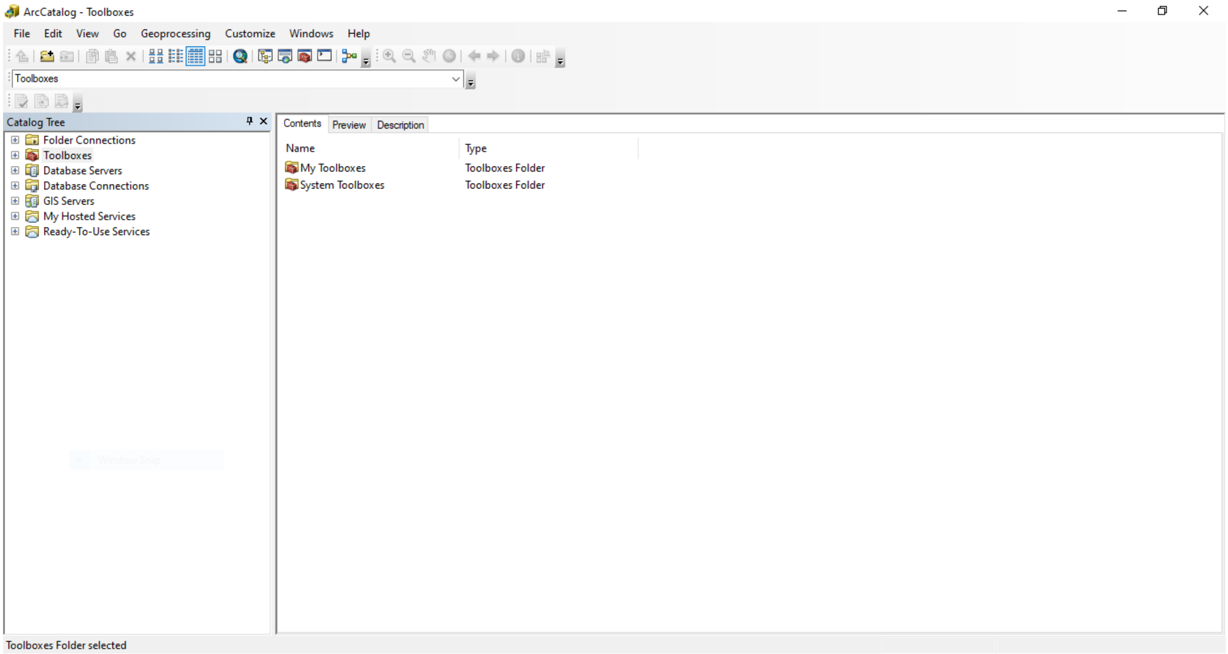


Figure 29: *The main ArcCatalog window.*

II.3.1.2 ArcMap:

Is the central application of ArcGIS Desktop. It is subdivided into two interfaces: visualization and processing (analysis, edition, etc.) of geographic data in the “data view” window and layout of maps in the « layout view » window.

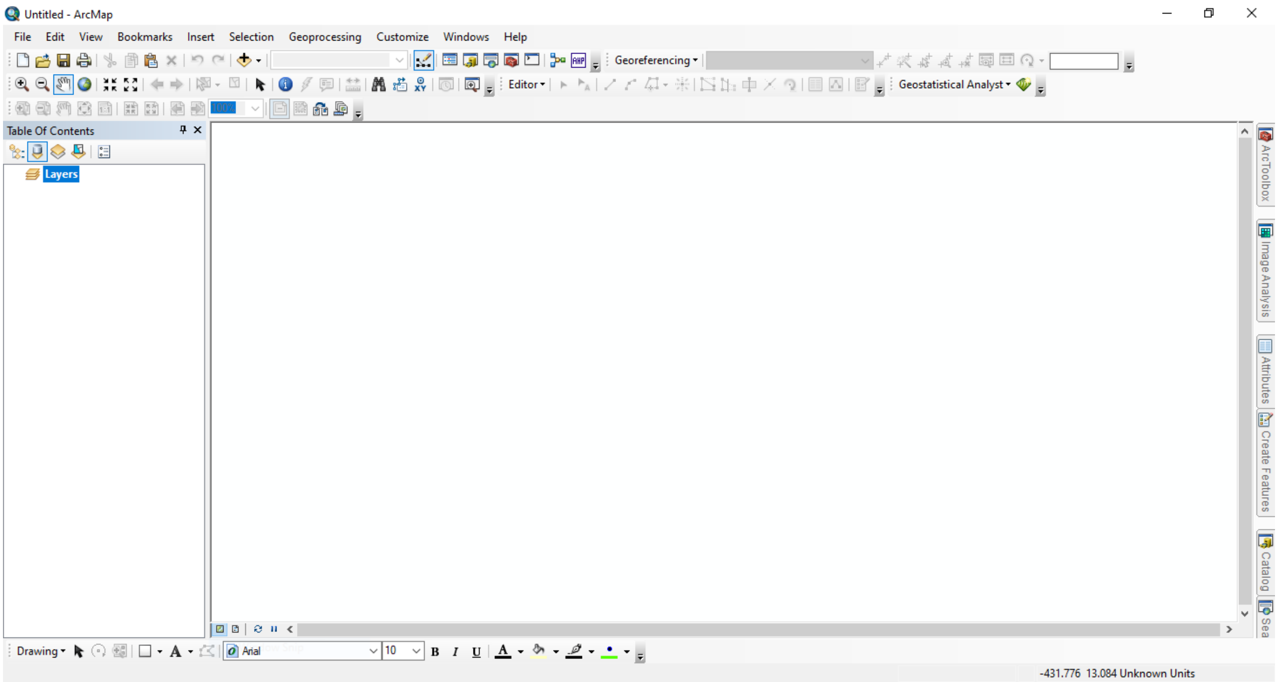


Figure 30: *The main ArcMap window in « data view » mode.*

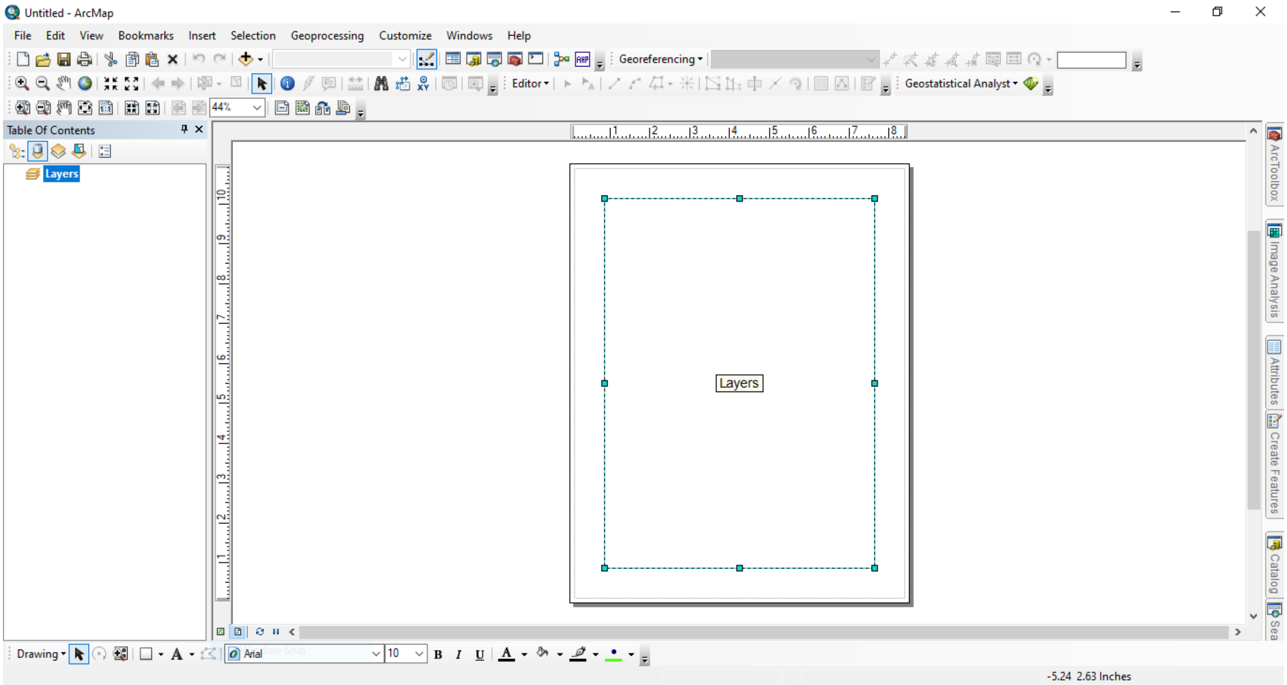


Figure 31: *The main ArcMap window in « layout view » mode.*

II.3.1.3 ArcGlobe:

Is similar to ArcMap but allows 3D visualization of the data you are working on.

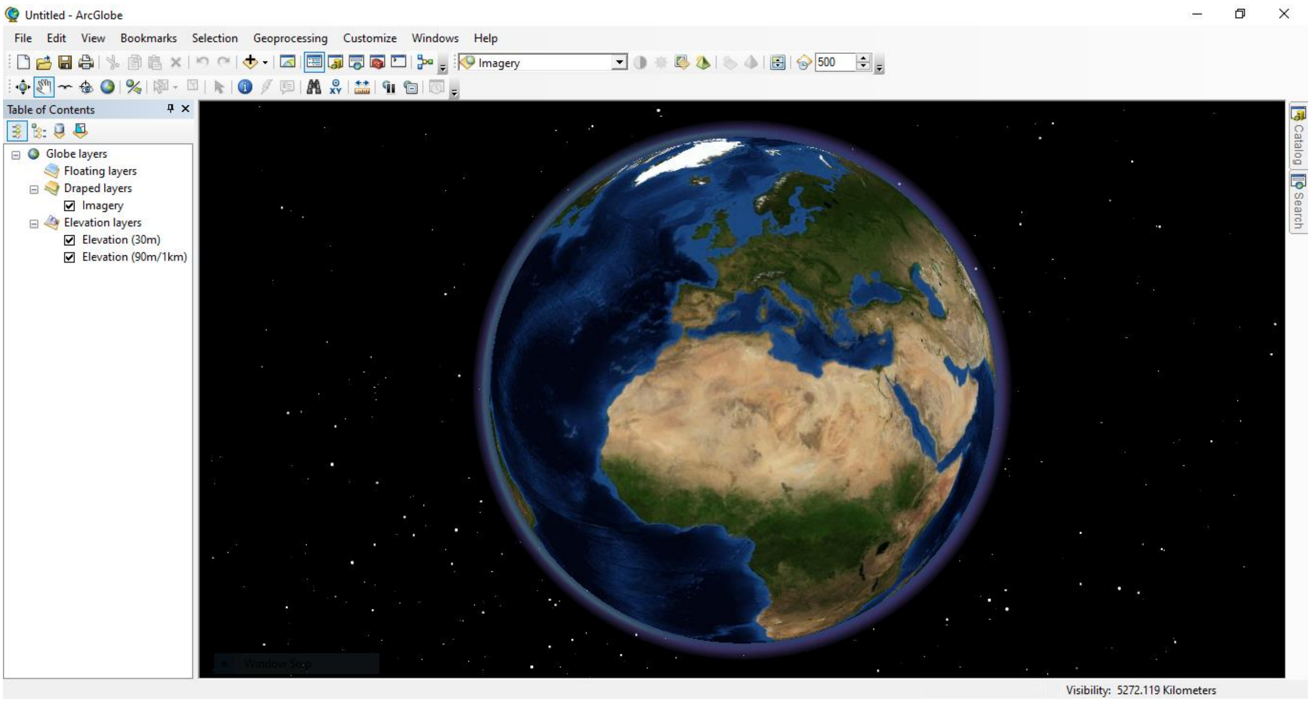


Figure 32: *The main ArcGlobe window.*

II.3.1.4 ArcToolbox:

(literally, the ArcGIS « toolbox »), groups together all the geoprocessing tools useful for performing operations on geographic data. ArcToolbox includes the « Builder Model », a visual and easy-to-use programming language, to automate a suite of geoprocessing.

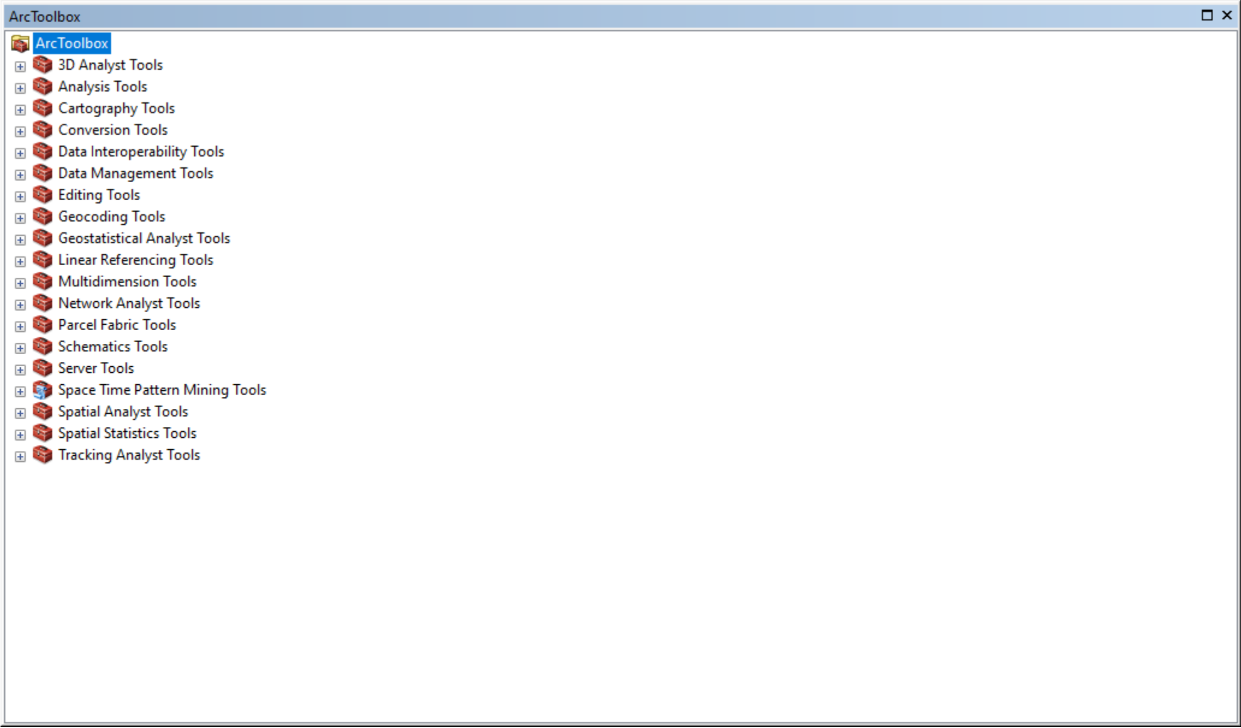


Figure 33: *The ArcToolbox window.*

By jointly using these applications and interfaces, ArcGIS makes it possible to perform all kinds of GIS tasks, including cartography, geographic analysis, data editing (creation, update, etc.), data management, visualization and geoprocessing. (Antoine, 2012).

It is available at three functional levels, from the simplest to the most sophisticated:

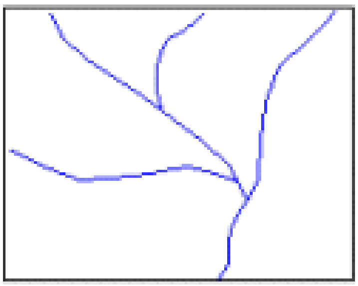
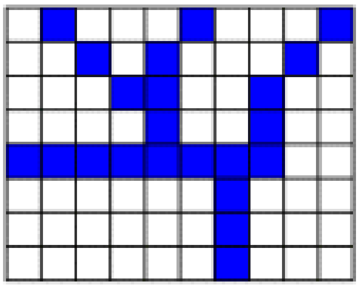
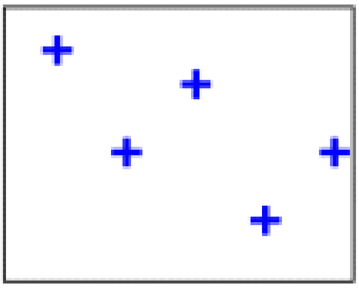
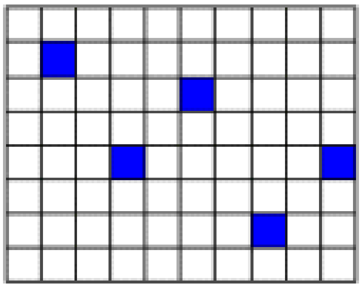
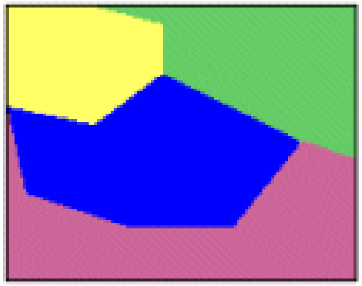
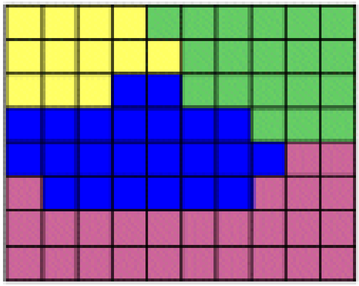
1. **ArcView** is a comprehensive GIS tool dedicated to data usage, mapping and analysis.
2. **ArcEditor** enables advanced creation and updating of geographic data.
3. **ArcInfo** is a professional and comprehensive office GIS tool, which offers comprehensive GIS functions and many geoprocessing tools.

Additional functionality is available by activating a series of extensions. Users also have the option of developing their own extensions. (Antoine, 2012).

II.4 The main types of geographic data models: Raster / Vector:

There are 2 main types of geographic data in GIS: « Raster Data Model » and « Vector Data Model ».

Table 5: *Types of geographic data: Vector versus Raster.*

Vector Data Model	Raster Data Model	Example in reality
		**Linear data:** watercourses, roads, ...
		**Point data:** trees, weather stations, GPS points, …
		**Polygonal data:** lakes, administrative boundaries (country boundaries, municipal boundaries, etc.), natural parks, etc.

II.4.1 Raster Data Model:

Raster Data Model, more often called « Raster », correspond to grids made up of cells. Each cell contains a value which often represents a geographic phenomenon, for example, altitude or land use. It can be scanned map, aerial photograph, satellite image, digital photo,… (Antoine, 2012).

II.4.2 Vector Data Model:

In the Vector model, objects are modeled by geometric elements. Point objects are represented by a single point. Linear objects (road, river, etc.) are made up of lines. Surface objects (geographic territory, parcel, etc.) are summarized in the form of polygons. The properties of these objects are stored in an attached attribute table. (Yves, 2018).

II.5 Geographic data and associated tables:

GIS makes it possible to easily associate / integrate spatial type data with « tabular » (or « attribute ») type data (Figure 34). To each spatial entity corresponds one or more attribute information (s) organized in a "table".

Figure 34 represents some wilayas of Algeria, taken in the form of spatial entities of the « polygon » type, to which is associated a whole series of information organized in a table called "table of attributes". 1 line or « record » contains all the information concerning 1 wilaya. 1 column or 1 « field » corresponds to 1 type of information, for example, the name of the wilaya, its area, the male and female population, etc.

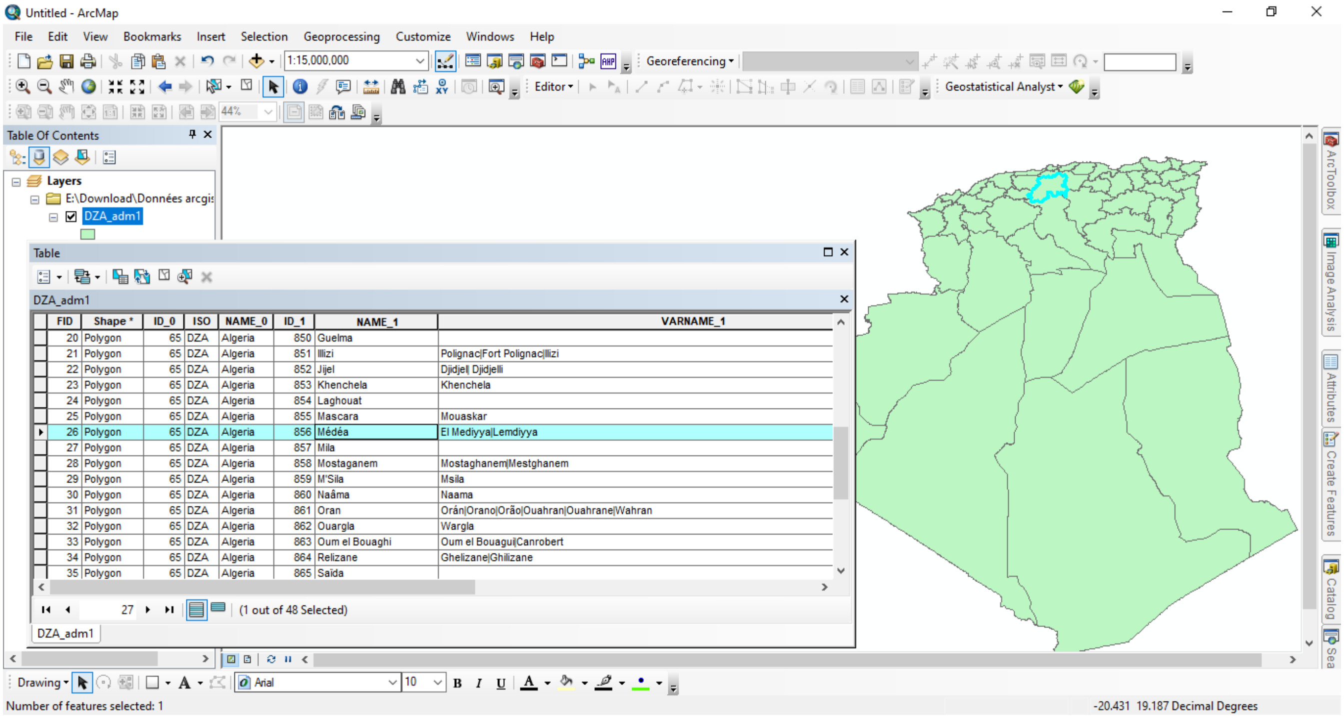


Figure 34: *Geographic data and associated attribute table.*

II.6 The themes « Layered structure »:

Before the advent of GIS, cartographers used layers to separate themes. They took care to use graphic codes for each layer which, by superimposition, made it possible to visualize the spatial relationships between themes.

McHarg (1969) theorized this method for the purposes of planning natural systems. (Yves, 2018).

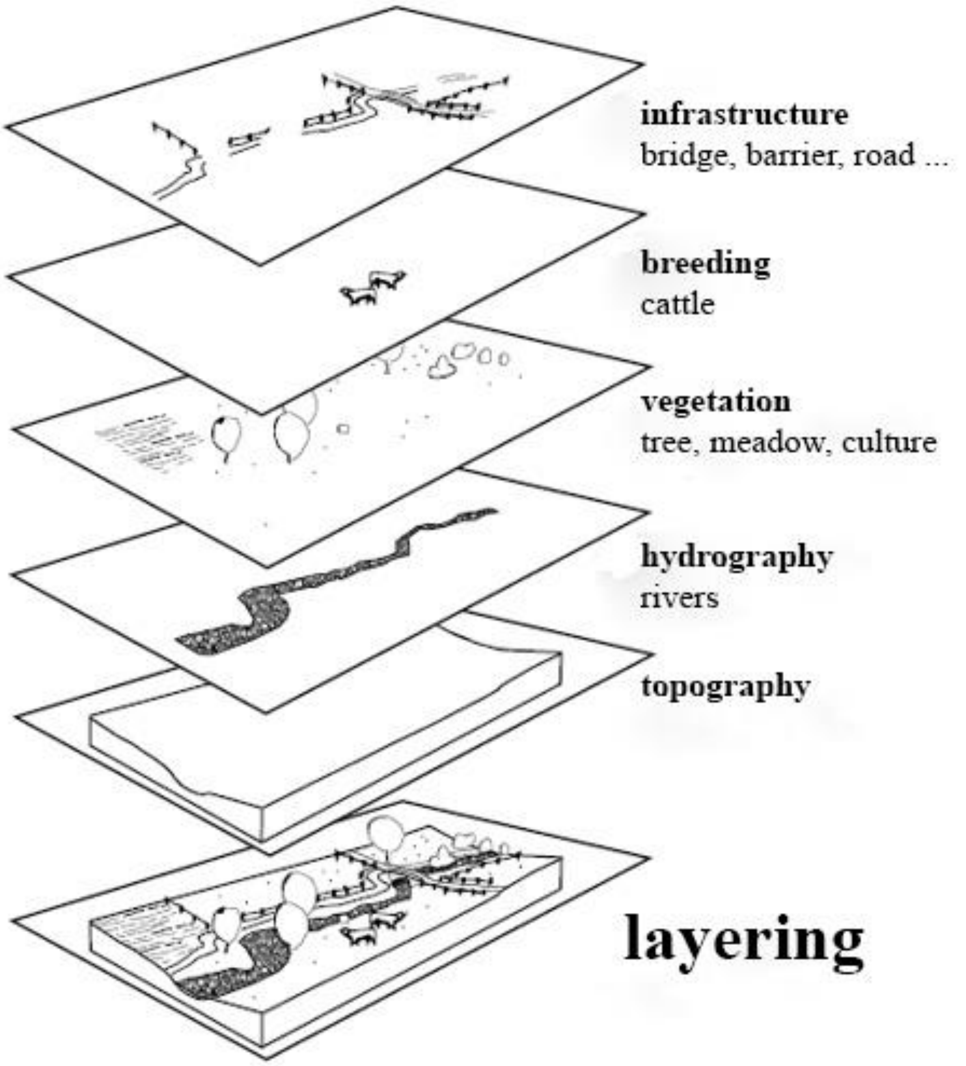


Figure 35: *Layered structuring of GIS data, (Yves, 2018).*

This organization in superimposed layers results in GIS by an organization of the data in layers (Figure 35). Each layer can only contain one data model, Vector or Raster. The data of a layer usually corresponds to a single theme: geology, land use, rivers, roads, etc. The map is built by Superposition of the layers describing the objects useful for its realization. For layering to make sense, all layers must represent objects in the same spatial frame of reference, that is, use the same coordinate reference system. (Yves, 2018).

III. Conclusion:

Landslides are considered to be one of the major risks in the Algiers Sahel; for better risk management, decision-makers must be able to have susceptibility maps, allowing them to identify areas of their territory where new landslides will have a higher probability of triggering in the future and this can only be possible with the computer tool in order to make a predictive mapping of the susceptibility to landslides in the Sahel area using a probabilistic approach based on a spatial analysis model. And to be able to apply this method we have to switch to software such as ArcGIS, which is one of the best programs for collecting, organizing, managing, analyzing, communicating and disseminating geographic information. As the world's leading platform for the development and use of geographic information systems (GIS).

One of the most useful features of GIS is the ability to overlay different layers or maps. However, the superposition procedure does not take into account the fact that the variables do not have the same importance (Janssen & Rietveld, 1990). One approach that can help overcome these limitations is multi-criteria analysis (Carver, 1991). We mention the AHP method.

The objective of using multi-criteria analysis models is to find solutions to decision-making problems characterized by multiple variants, which can be evaluated using decision criteria (Jankowski, et al., 2001).

CHAPTER V

Elaboration of the risk map

CHAPTER IV: Elaboration of the risk map

I. Materials and methods:

In order to develop the landslide probability map, we followed the AHP (Analytic Hierarchy Process) method. This method, created by SAATY (1991), is a multicriteria analysis method that can be used in the quantification of qualitative characteristics, through its weighting.

The method is based on the comparison of the different characteristics, two by two. From the construction of a square matrix, we assess the relative importance of one characteristic compared to another, using for this, an appropriate scale. SAATY (1991) suggests using the scale shown in (Table 2, CHAPTER IV). Once the comparison matrix is filled, we calculate the eigenvalue of each and the eigenvector corresponding to it. The eigenvector indicates the order of priority or the hierarchy of the characteristics studied. This result is important for the assessment of probability, as it will be used to indicate the relative importance of each operative criterion. The eigenvalue is the measure which will allow the consistency or the quality of the solution obtained to be evaluated, thus representing another advantage of this method.

Five landslide affecting factors namely slope, cohesion, friction angle, water content and distance to drainage network were used for landslide analysis in the present study. These factors selected either intervene in the stability of slopes and rocky massifs or are exposed to a landslide hazard risk. The various thematic layers relative to these factors were generated and then were combined.

Using weights of factors determined by AHP method to generate the landslide susceptibility map. The combination of all thematic layers in agreement with the AHP results was carried out in a GIS environment. So, the method used in this study is a qualitative indirect method.

II. Preparing landslide factor layers:

The main data required for landslide susceptibility and risk assessment in this study were collected from various sources such as the geotechnical study reports (Boreholes data) carried out by several laboratories like LNHC, LCTP and constructed of a spatial database.

Location map of the study area showing the borehole locations was created on a built-in ArcMap background of a satellite image.

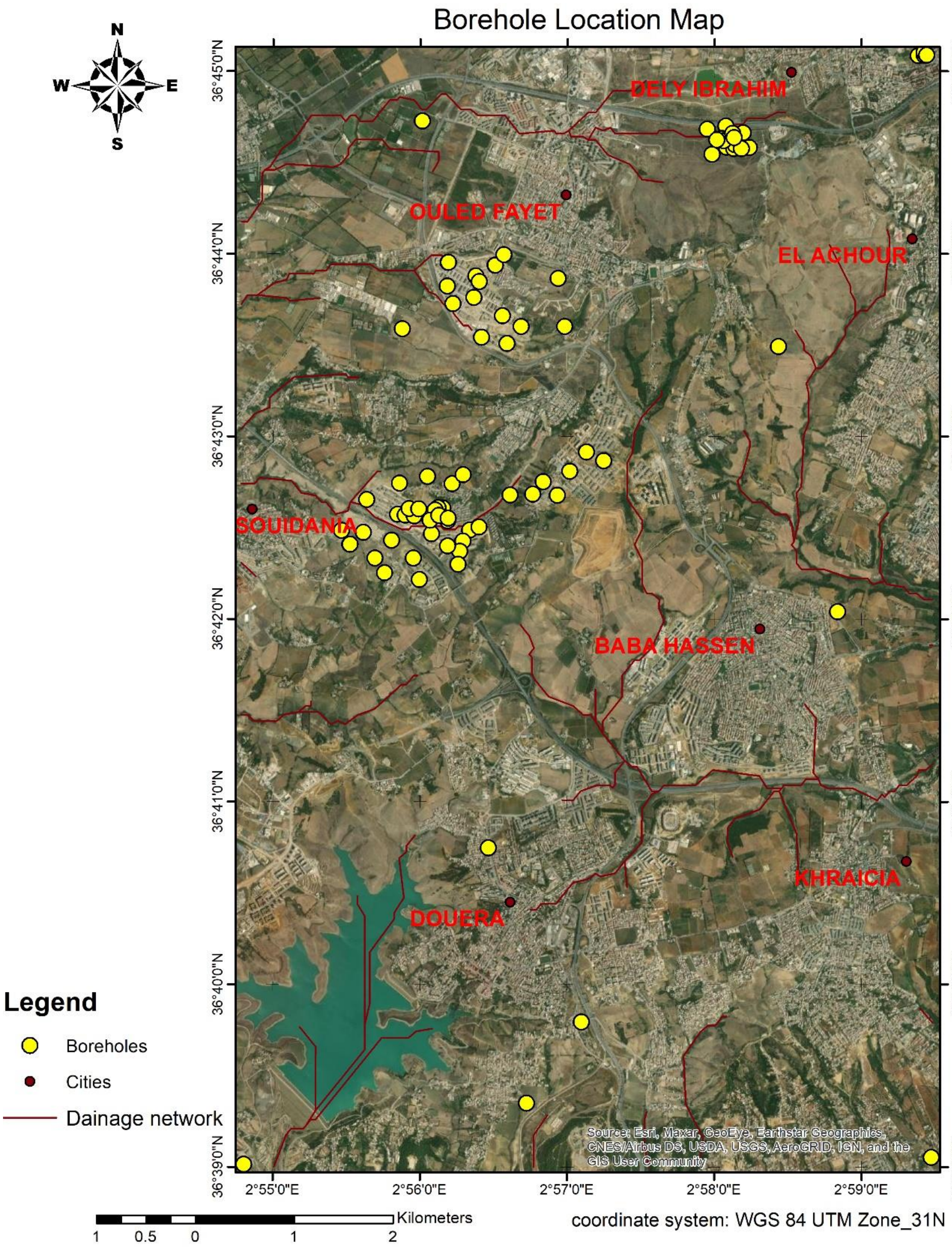


Figure 36: *Borehole Location Map.*

The thematic layers of the selected factors governing landslides, including slope, cohesion, friction angle, water content and distance to drainage network were developed.

The thematic layers that correspond to factors that are produced from the punctual data base were made using the IDW tool in ArcToolbox.

Topographic related factors such as slope degree and drainage network were derived from a Digital Elevation Model (DEM) of the study area taken from EORC/JAXA (Earth Observation Research Center/ Japan Aerospace Exploration Agency). and the total surface of the study area were calculated with ArcMap which is 78.75 km².

All thematic layers were converted to raster format, and each raster was classified into several classes (mostly 5 classes).
The area of the classes of each factor layer were calculated
The percentage of the areas out of the total study area surface were calculated also.
The preparation procedure for each thematic layer is summarized below:

II.1 Slope factor:

In the present study, slope factor data were extracted from the DEM (digital elevation model).

The slope is one of the main parameters in the slope stability analysis. The slope angle directly affects landslide; thus, it is used in preparing landslide susceptibility maps.

In some of the recent studies, such as by (Yao, et al., 2008) and (Nandi & Shakoor, 2009), this parameter has been considered as the most important factors in landslide susceptibility mapping. For preparing landslide susceptibility map, the slope map was divided into five slope categories. ‘

The lower slope angle the better which means that high slope values receive a low class value and vice versa.

The results revealed the following:

Table 6: *Areas of slope map classes.*

Slope classes	Area (km²)	Area (%)
0 – 5%	16.61	21.00%
5 - 10%	20.58	26.01%
10 – 15%	16.27	20.57%
15 – 30%	23.05	29.13%
>30%	2.61	3.29%

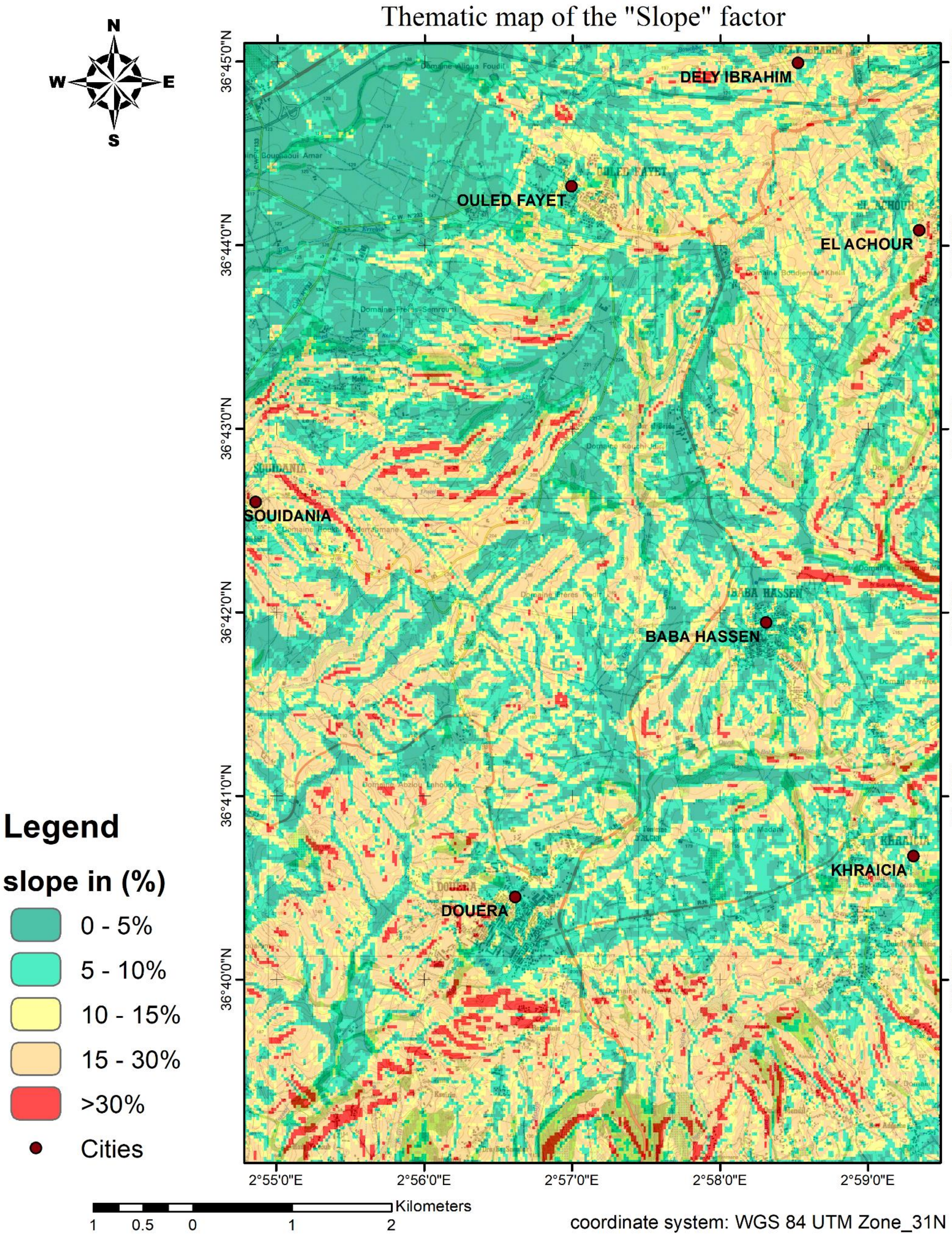


Figure 37: *Thematic map of the slope factor.*

II.2 Soil cohesion:

The cohesion of a soil is the property that allows to oppose the sliding of the grains that compose it and to resist a shear force, that is to say to oppose the sliding of a layer, this allows to limit the exposure to the danger of landslide.

Knowing the cohesion of soils allows to limit the exposure to the risk of landslide, also. the potential of landslides increases by decrease in soil cohesion values. which makes it a major factor in mapping landslide susceptibility.

The integration of our database of the « soil cohesion » parameter in Excel and its export to ArcMap for thematic analysis allowed us to produce the thematic map of the « soil cohesion » factor.

The higher the cohesion, the better. high values for cohesion will be in a class with a high value.

The results revealed the following:

Table 7: *Areas of soil cohesion map classes.*

Soil cohesion angle classes	Area (km^2)	Area (%)
0.21 – 0.38	12.22	15.51
0.38 - 0.47	23.54	29.90
0.47 - 0.57	19.28	24.48
0.57 - 0.68	19.70	25.02
0.68 - 1.03	4.01	5.09

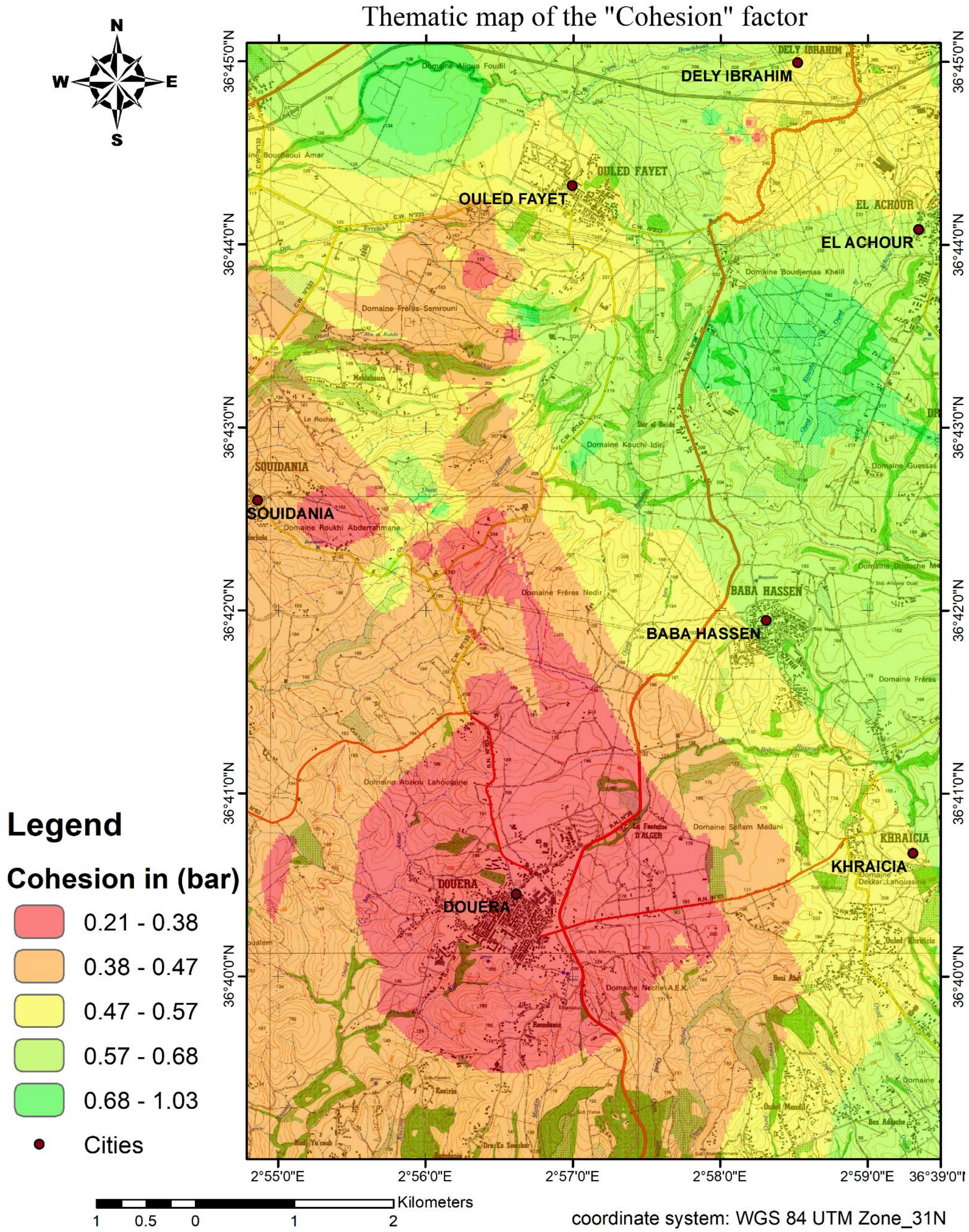


Figure 38: *Thematic map of the soil cohesion factor.*

II.3 Soil friction angle:

Soil friction angle is a shear strength parameter of soils. Its definition is derived from the Mohr-Coulomb failure criterion and it is used to describe the friction shear resistance of soils together with the normal effective stress. It has a very important role in landslides occurrence

In the effective shear stress, the soil friction angle is the angle of inclination with respect to the horizontal axis of the Mohr-Coulomb shear resistance line.

The occurrence of landslides increases by decrease in the values of soil friction angle.

The integration of our database of the « soil friction angle » parameter in Excel and its export to ArcMap for thematic analysis allowed us to produce the thematic map of the « soil friction angle » factor.

The higher the friction angle, the better. high values for friction angle will be in a class with a high value

The results revealed the following:

Table 8: *Areas of soil friction angle map classes.*

Soil friction angle classes	Area (km²)	Area (%)
4 -9.21	11.89	15.10
9.21 - 11.77	23.28	29.56
11.77 - 13.84	33.10	42.03
13.84 - 17.32	7.47	9.49
17.32 - 25.1	3.01	3.82

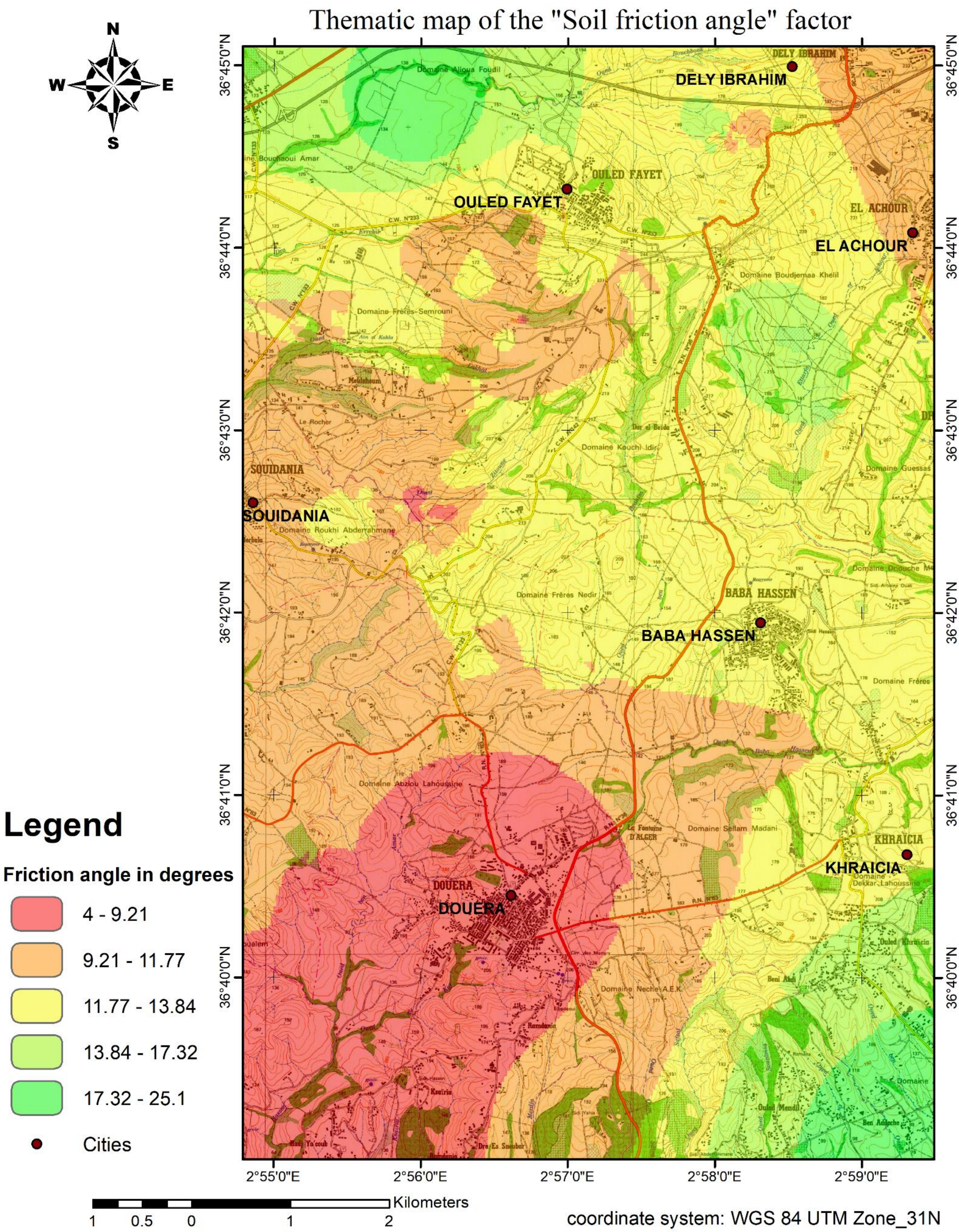


Figure 39: *Thematic map of the soil friction angle factor.*

II.4 Soil water content:

The important role of water in landslides should be emphasized. Its presence at the level of the sliding surface seems to be a key factor in the sliding process. In addition, a soil whose water content exceeds a certain threshold has reduced or no grain cohesion.

The integration of our database of the « soil water content » parameter in Excel and its export to ArcMap for thematic analysis allowed us to produce the thematic map of the « soil water content » factor.

The lower the better which means that high water content values receive a low class value and vice versa.

The results revealed the following:

Table 9: *Areas of soil water content map classes.*

Soil water content classes	Area (km^2)	Area (%)
14 – 18.4	20.82	26.44%
18.4 - 22.7	10.97	13.93%
22.7 - 27.1	12.13	15.40%
27.1 - 31.5	22.93	29.12%
31.5 - 35.8	11.90	15.11%

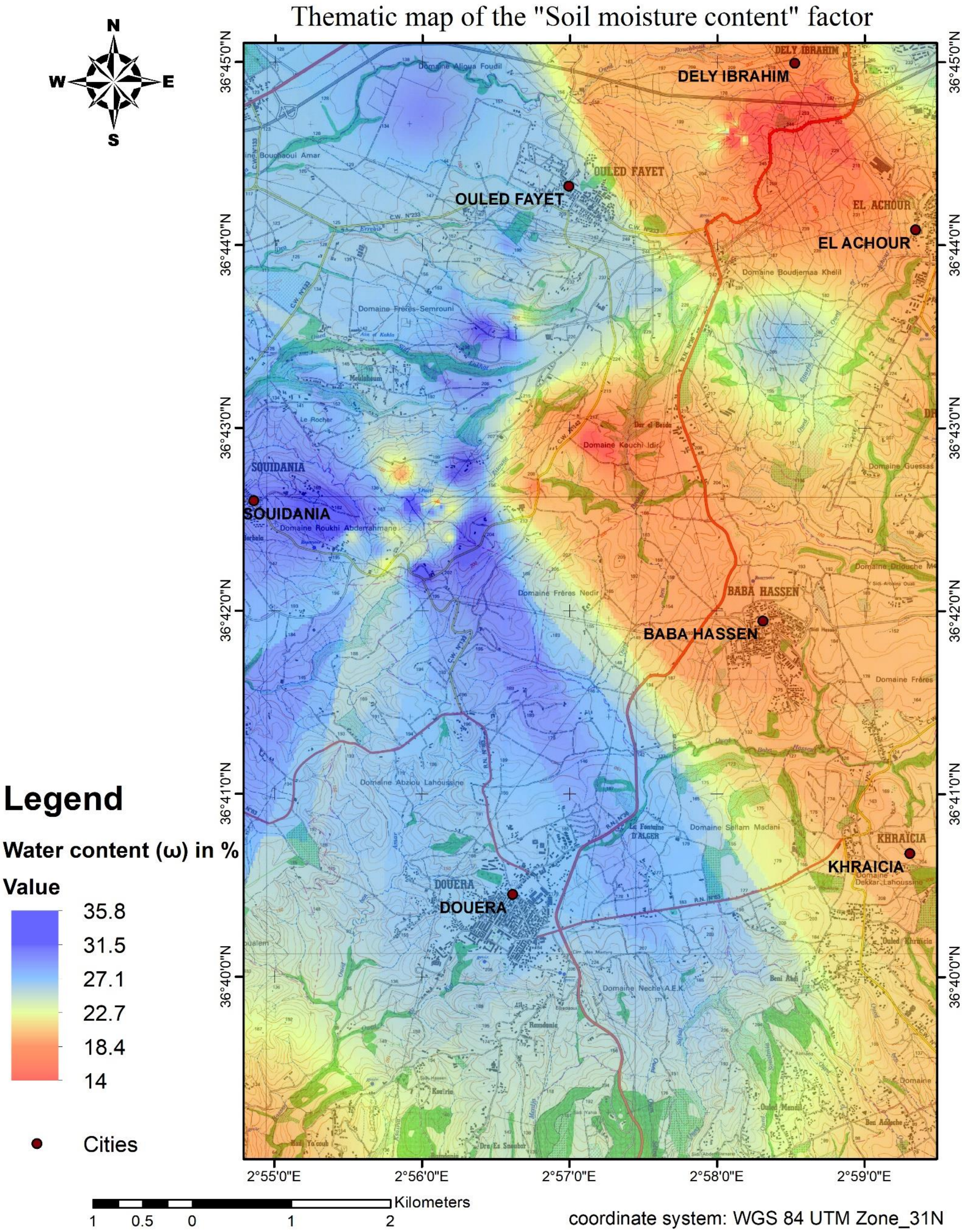


Figure 40: *Thematic map of the soil water content factor.*

II.5 Distance to drainage network:

Rivers play a major role in landslide development (Park, et al., 2013). Generally, potential of landslides increases by decrease in distance to drainage network, because streams may adversely affect stability by eroding the slopes or by saturating the lower part of material, resulting in water level increases (Ercanoglu & Gokceoglu, 2004).

In the present study, the drainage network was produced from DEM by hydrology tools in ArcGIS 10.4.

Five different classes were generated using Euclidean distance method to determine the degree to which the streams could affect the bank slopes (Figure 41).

The farther distance from drainage network the better; thus, the higher the class value.

The results revealed the following:

Table 10: *Areas of distance to drainage network map classes.*

Distance to drainage network classes	Area (km^2)	Area (%)
0 -130	22.39	28.36
130 - 280	22.42	28.40
280 - 420	18.98	24.05
420 - 650	11.64	14.74
650 - 1670	3.50	4.44

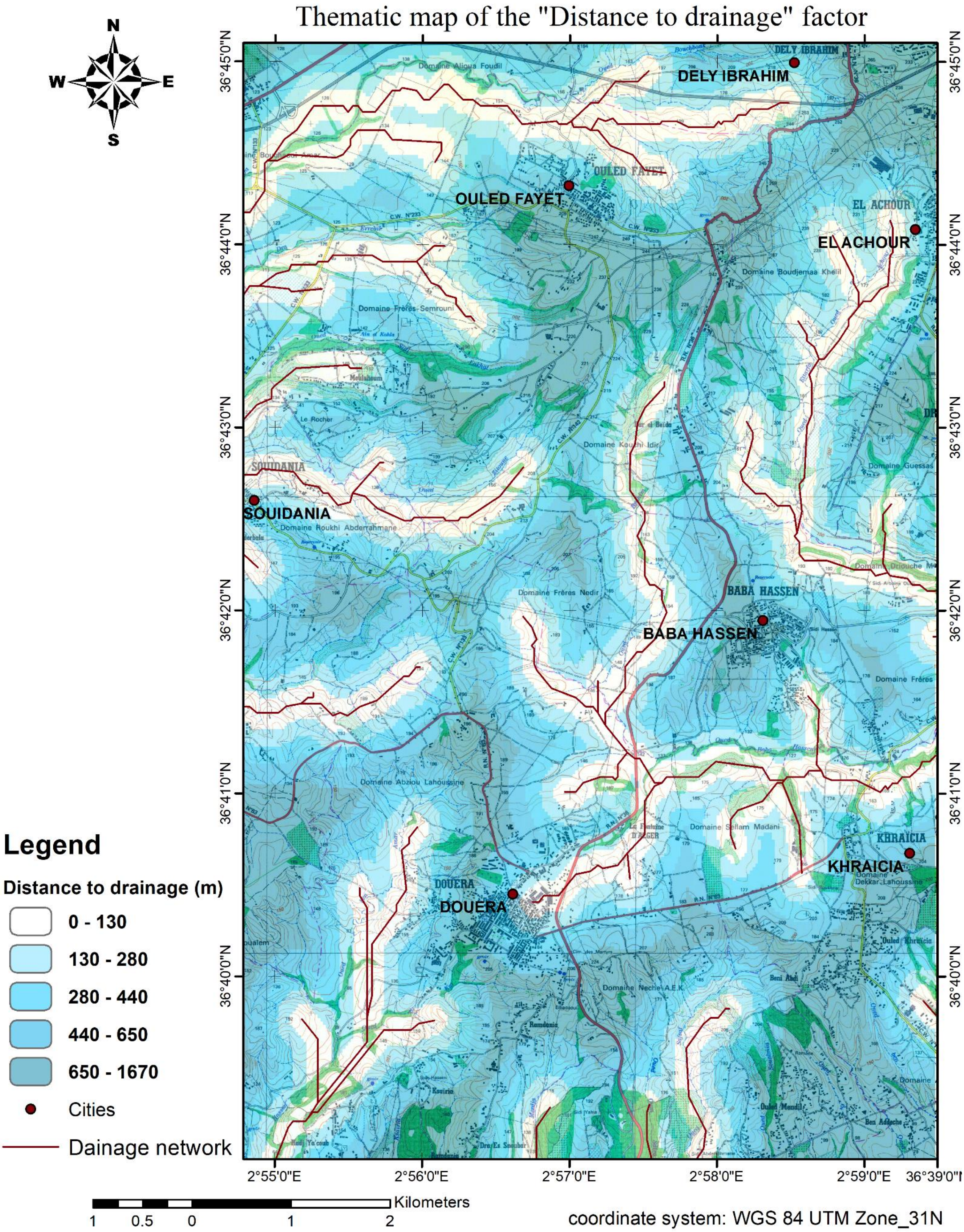


Figure 41: *Thematic map of the distance to drainage network factor.*

III. Susceptibility mapping:

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

In order to establish a pair-wise comparison matrix (Table 11), factors of each level and their weights are shown below:

Table 11: *comparative pairwise judgment matrix.*

Pairwise comparisions	slope	cohesion	friction angle	water content	distance to drainage	Weights
slope	1.00	2.00	3.00	4.00	3.00	0.38
cohesion	0.50	1.00	2.00	3.00	3.00	0.25
friction angle	0.33	0.50	1.00	3.00	0.50	0.13
water content	0.25	0.33	0.33	1.00	0.20	0.06
distance to dringage	0.33	0.33	2.00	5.00	1.00	0.18
Sum	2.42	4.17	8.33	16.00	7.70	

To compute the weights of each factor shown in pairwise comparisons matrix, we need to make the standardized matrix. Were each comparison number is divided by the sum of his respective column, and the weights are the average that correspond to each factor horizontally

Table 12: *Standardized matrix.*

standardized matrix	slope	cohesion	friction angle	water content	distance to drainage	Weights	weights %
slope	0.41	0.48	0.36	0.25	0.39	0.38	37.87
cohesion	0.21	0.24	0.24	0.19	0.39	0.25	25.28
friction angle	0.14	0.12	0.12	0.19	0.06	0.13	12.61
water content	0.10	0.08	0.04	0.06	0.03	0.06	6.24
distance to dringage	0.14	0.08	0.24	0.31	0.13	0.18	18.01

In this hierarchical classification approach, it is necessary to check the coherence of our approach by calculating the consistency or consistency ratio (**CR**). Of course, the values of the pair-wise comparison matrix will normally be well considered and not set arbitrarily. The latter constitutes an acceptance test of the weights of the various criteria (Saaty, 1977). This step aims to detect any inconsistencies in the comparison of the importance of each pair of criteria. The **CR** consistency ratio is approximately a mathematical indicator of the judgment concerning a decision made randomly; **CR** is the ratio between **CI** and a Random Consistency Index **(RI).** The **RI** index, presented in (Table 13) with **n** is number of factors or criteria (5 in our case):

Table 13: *Values of RI according to the number of factors.*

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

The **CR** is calculated using:

$$CR = \frac{CI}{RI}$$

And the **CI** is the consistency index that is expressed as:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

Where **λmax** is the largest or principal Eigen value of the matrix and is calculated from the matrix and **n** is the order of the matrix (in our case **n**=5 so **RI**=1.12). According to (Saaty, 1977), the coherence ratio must be ≤0.1 or an imprecision of less than 10%.

The next stage is to calculate **λmax** so as to lead to the Consistency Index and the Consistency Ratio.

So, in order to calculate the principal eigenvalue, we need to calculate the normalized eigenvector, so we use for that the preference matrix below, to compute the normalized eigenvector of each factor shown in this matrix, each comparison number of each factor (vertically) is divided by its corresponding weight.

We obtain the normalized eigenvector by adding the obtained values (horizontally).

After that we calculate the eigenvalue (λ) by dividing each element of the normalized eigenvector by the corresponding weight of factor.

If any of the values for **λmax** turns out to be less than **n**, or 5 in this case, there has been an error in the calculation, in our case all the values are over 5 so the calculations are correct.

Finally, the principal eigenvalue (**λmax**) is the average between the eigenvalues, which: **λmax** = 5.33

Table 14: *CI and CR worksheet.*

preference matrix	slope	cohesion	friction angle	water content	distance to drainage	normalized eigenvector	λ	λmax
slope	0.38	0.51	0.38	0.25	0.54	2.05	5.42	5.333232693
cohesion	0.19	0.25	0.25	0.19	0.54	1.42	5.62	
friction angle	0.13	0.13	0.13	0.19	0.09	0.66	5.20	
water content	0.09	0.08	0.04	0.06	0.04	0.32	5.12	
distance to drainage	0.13	0.08	0.25	0.31	0.18	0.95	5.30	

After we had the principal eigenvalue (**λmax**), we can calculate the consistency index that is expressed as:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \Longrightarrow \quad CI = \frac{(5.333232693 - 5)}{(5-1)} = 0.083308173$$

Now we have **CI** and **RI** (from the table were RI=1.12), we can calculate the consistency ratio which given by the following equation:

$$CR = \frac{CI}{RI} \Longrightarrow \quad CR = \frac{0.083308173}{1.12} = 0.074382298 \Longrightarrow \text{CR=5.06\%}$$

Because **CR** = 0.05 ≥ 0.1; we are in the safe side.

Note: All the calculations are done with the Excel software.

III.1 ArcMap AHP calculation:

The ArcMap has the possibility of adding an AHP extension analyzer which facilitate the calculation, it lets you define all criteria which you consider relevant for your decision problem.

We need to use reclassified raster data though. Classified rasters should be within the same class value range (the extension does not check for this) and also that high/low class values consistently capture a desired/non desired state. For example. if high values within a raster a considered non-desirable, these high values should be put in a class that has a low value. Other reclassification schemes can of course be used but the user needs to ensure the consistency of the whole process.

So, reclassification of the different layers is needed, following: **Spatial Analyst Tool ⟶ Reclass ⟶ Reclassify.** in the ArcToolbox.

We reclass all the layers in 5 classes were 1 refers to low risk probability all the way to 5 which represent the maximum risk probability.

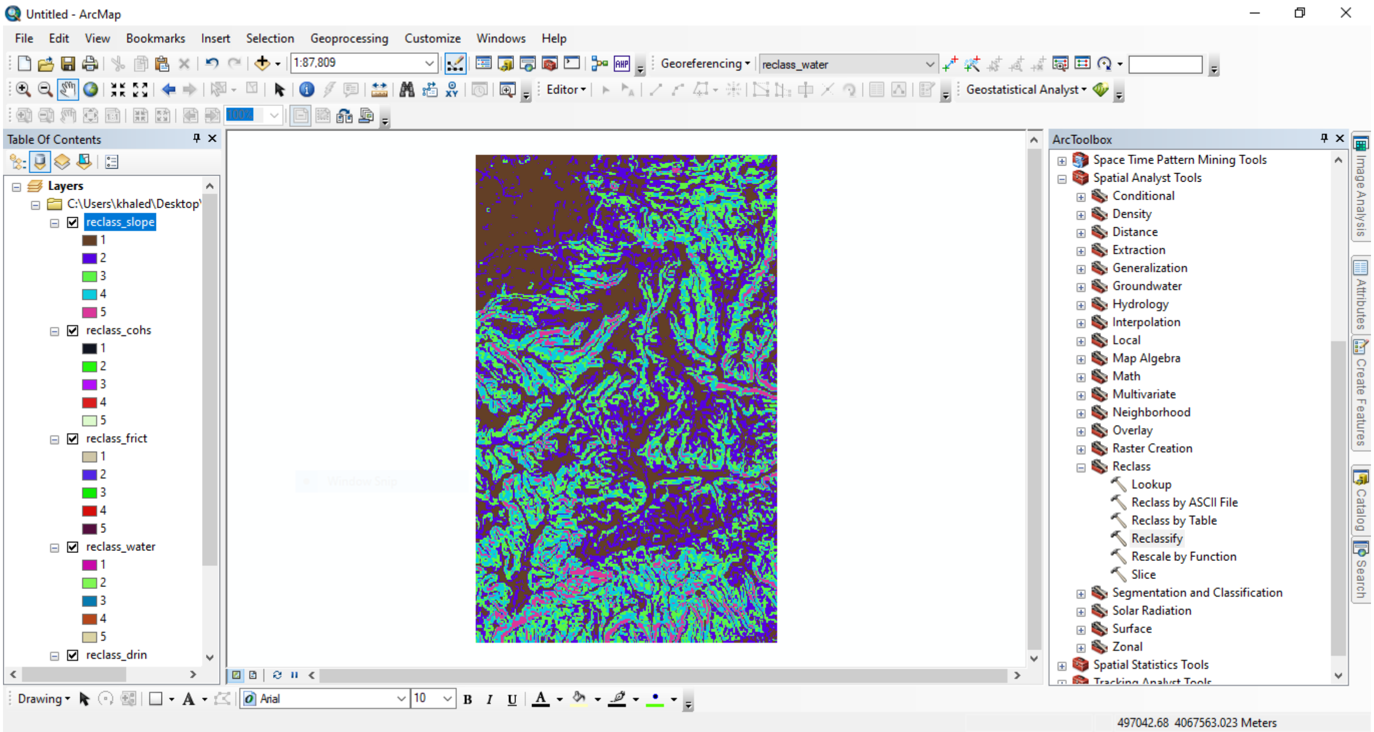


Figure 42: *ArcMap window showing the different layers after reclassification.*

After reclassification of the factors, we move to the AHP tool in ArcMap. It’s a tool developed by “Oswald Marinoni”.

III.2 AHP evaluation:

Step 1: Start the extension by clicking the AHP button.

Step 2: Define the criteria (here 5 reclassified criteria with classes ranging from 1 to 5 are used)

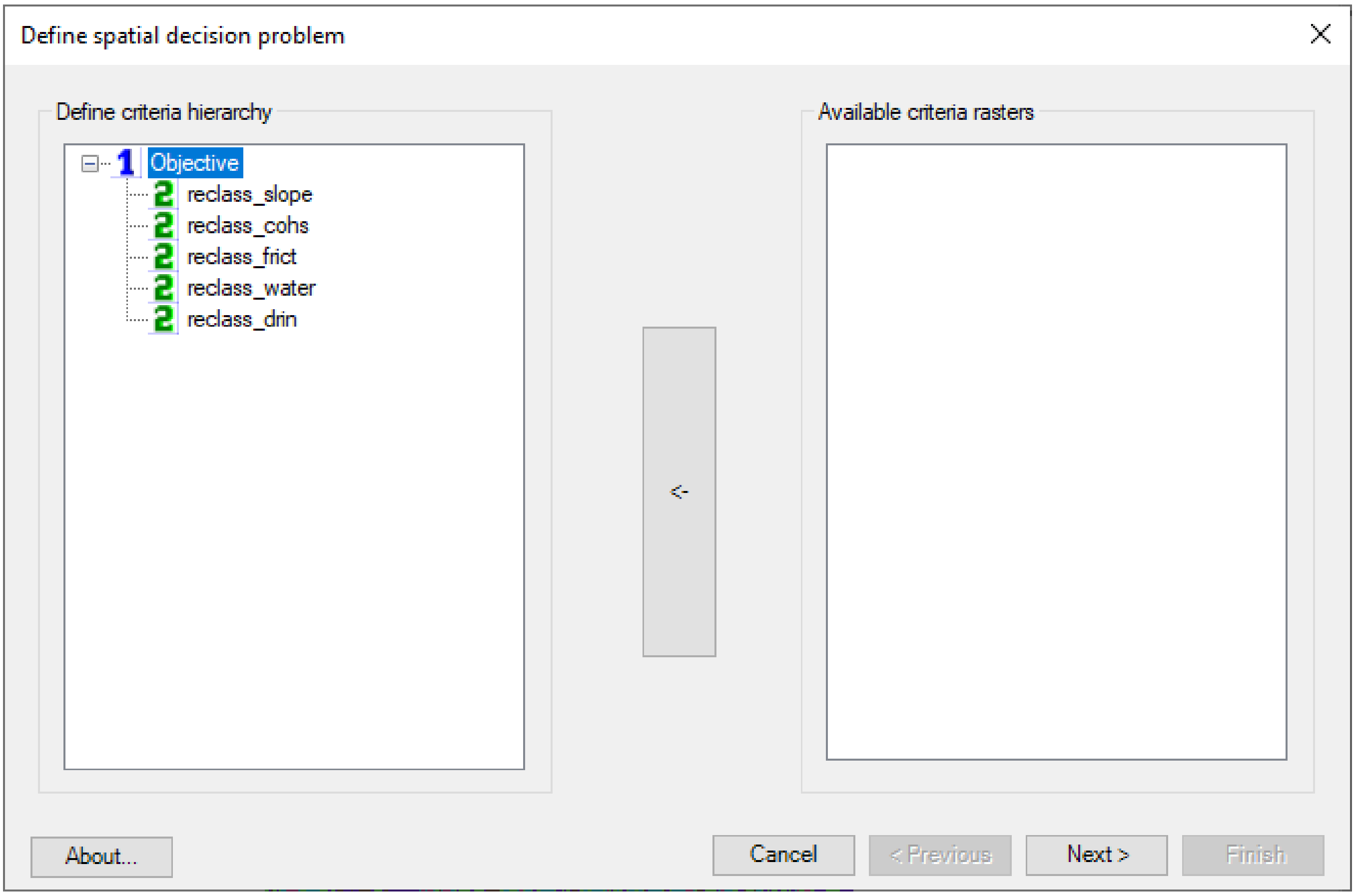


Figure 43: *AHP extension window, defining the criteria hierarchy step.*

Step 3: determine preference values (use the values provided in Table 11). And Push the Compute button. The results are displayed in the text box, finally push the create map button to generate the map.

As shown in the "Set weights" window below, we can see that the results are pretty much the same with the results that we obtained from the Excel calculations.

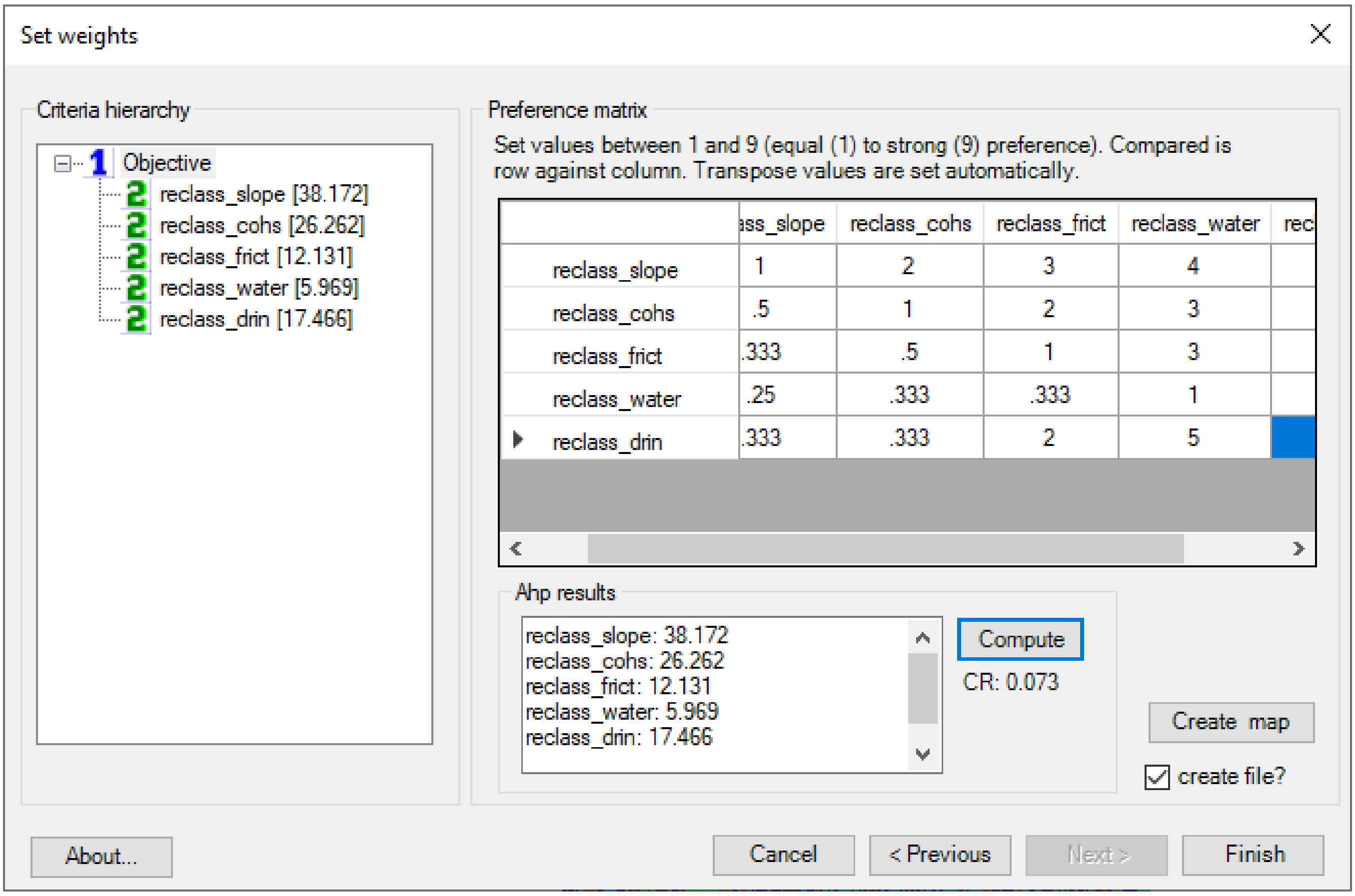


Figure 44: *AHP extension window, defining the criteria corresponding weights step.*

Finally, the "create map" button allows us to generate the thematic landslide susceptibility map.

III.3 Landslide susceptibility map:

All produced layers were then combined using weights of factors determined by the AHP method and generated with the AHP extension to create the landslide susceptibility map.

Finally, the results were classified into five classes (very low, low, moderate, high, and very high) in the landslide susceptibility map.

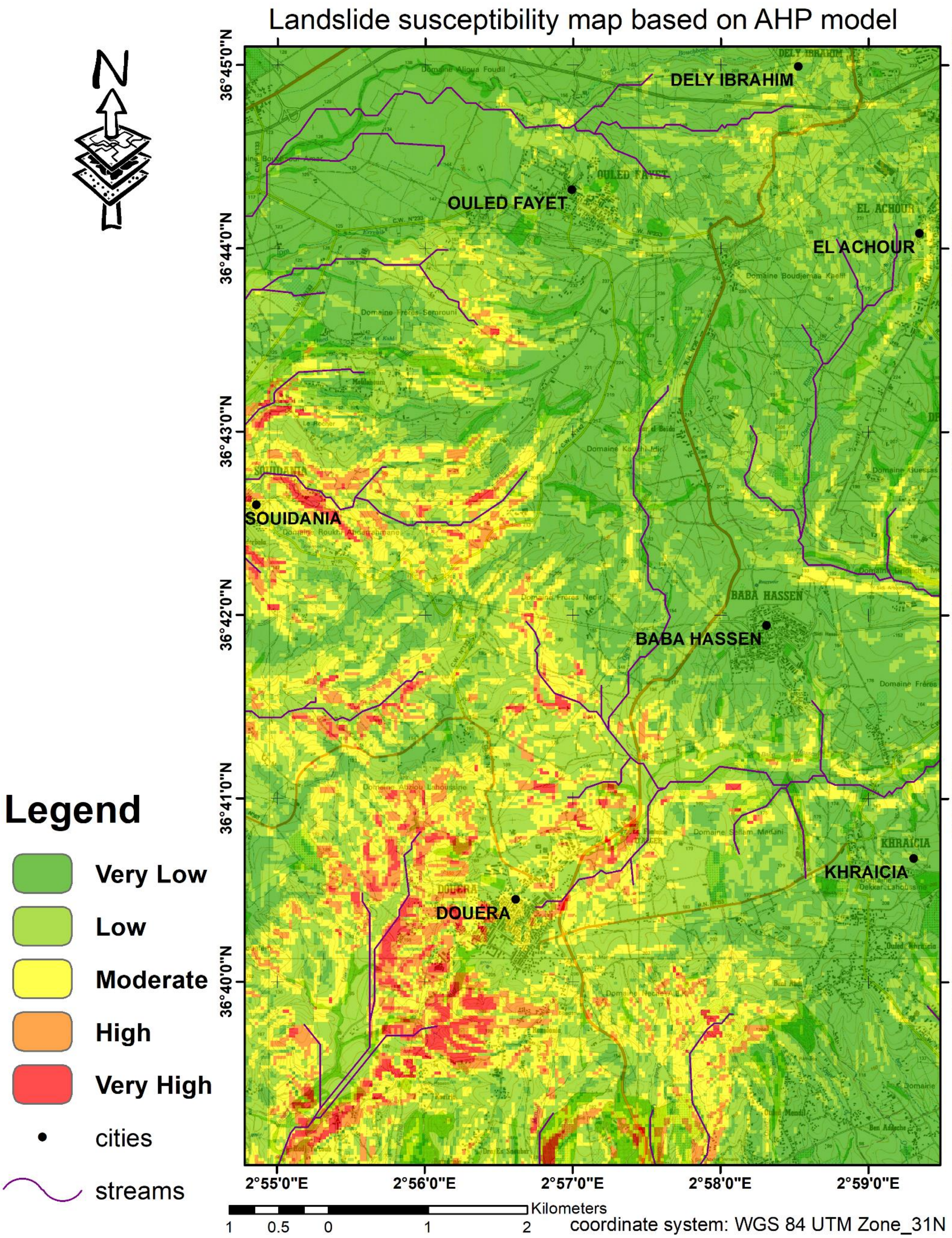


Figure 45: *Landslide susceptibility map based on AHP model.*

IV. Results and discussion:

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

In this study, AHP method was used to prepare landslide susceptibility maps in the Algerian Sahel region (Algiers).

This region is a landslide prone zone because of its own characteristics including the topography, climate conditions, geotechnical and geomorphology structures.

After preparing landslide inventory map, five layers have been considered. Based on this study.

The result of this study shows, that when field conditions are properly determined by good proficiency, the AHP method can give more truly results (Moradi, et al., 2012).

Based on the results of analyses as shown in (Table 15), very low, low and moderate susceptible occurrences represent 47.11%, 32.24%, and 14.27% of the total study area, respectively. The high and very high susceptibility areas represent, respectively, 4.74% and 1.64% of the total study area.

Table 15: *Areas of susceptibility map classes.*

Susceptibility classes	Area (km^2)	Area (%)
Very low	37.10	47.11
Low	25.39	32.24
Moderate	11.24	14.27
High	3.73	4.74
Very high	1.29	1.64
Total	78.75	100.00

The results from the susceptibility map shows that the areas at very high to high risk of landslides effectively correspond to areas with steep slope (usually more than 30%) and characterized by more or less low cohesion & friction angle and high water content (more than 31.5%) and very close to drainage network (less than 130m) are represented by the regions of Souidania and especially around the water dam of Douera.

The medium risk zones correspond to zones whose geotechnical characteristics (a slope, cohesion, water content and a moderate to low friction angle) are little to moderately high, are located in ouled fayet, dely ibrahim, El Achour.

The low to very low risk susceptibility areas are correspond to very good geotechnical and topographical characteristics which gives them the Preference in rating, are represented by the regions of Khraicia and Baba hassen.

General conclusions, recommendations and perspectives

General Conclusions

Geographic Information Systems (GIS) is being exploited widely in many engineering problems, which involves spatial data management. Landslide hazard mapping, one of the important tasks in disaster/hazard mitigation projects is a typical problem involving huge database. A framework for the landslide hazard mapping in GIS is discussed with an illustrative example. The posterior analysis of GIS results gives the engineer a better understanding and visualization of the problem and results.

The landslide is a vital natural hazard, and therefore, the recognition of areas at risk of landslides and the mapping of the susceptibility to landslides are the interest of responsible organizations and researchers. Landslide susceptibility analysis can be done under the circumstance of having few existing data about the factors causing landslides using AHP method, which allows fast and practical analysis of landslides based on the collection of data and manipulation and the analysis of the necessary environmental data for landslide susceptibility.

The Algerian Sahel is prone to landslides due to their geological, geotechnical and geomorphological settings. In this study, the spatial relationship between field landslide occurrences and causative factors, including slope degree, soil cohesion, soil friction angle, soil water content, distance to drainage network were assessed using AHP and GIS techniques. The landslide susceptibility map was classified according to the natural break method into five classes with an area of 47.11%, 32.24%, 14.27%, 4.74%, 1.64% of the total study area, for very low, low, moderate, high and very high classes, respectively.

The superposition of the different maps allowed us to develop a landslide occurrence map. We notice that the areas most susceptible to this hazard are located mainly in the region of Douera, Souidania and little bit in Ouled Fayet, indeed, by comparing the different maps, we see that these regions have very weak soil geotechnical characteristics (low cohesion and friction angle) and very Rugged topography (steep slopes and dense drainage network).

For this, it is recommended to take all precautions with regard to the implementation of any type of projects in these areas in order to ensure the safety and stability of these projects such as methods of strengthening and improving the soil like the surface water management (rainwater, runoff water, etc.), internal water management, the construction of retaining walls, etc.

Nevertheless, the risk remains present in some areas in the occurrence is medium like the southern part of Dely Ibrahim and El Achour, and can be triggered by the effect of certain factors such as rains and earthquakes.

Moreover, human activities namely the road and house construction and the expansion of agricultural lands into forested lands intervene in inducing landslides through altering the slope stability along the river banks.

The landslide susceptibility map of the study area provides more information about future landslides, which makes it viable.

Such map may be helpful for planners and decision makers for land-use planning and slope management in the study area to provide prevention of landslide risks and to take preventive and suitable security measures.

Finally, we believe that the association between the database of the Algiers Sahel and the thematic maps of the characteristics of the latter constitutes an interesting support for orienting development and defining the best sites.

However, our research only focused on a limited region, that of the study area. The impact of the landslide hazard could be quite different in other places within the Algerian Sahel.

The work that we have done could be completed and continued in different aspects. It would be relevant to extend this study to the national level.

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