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The Use of Remote Sensing and GIS to Identify Water Erosion Risks Areas in the Moroccan High Atlas. The Case Study of the N'fis Wadi Watershed

Adama AMAYA[1], Abdellah ALGOUTI[1], Ahmed ALGOUTI[1]

[1]Université Cadi Ayyad, faculté des Sciences, Département de Géologie, Laboratoire GEOBASSMA, Bd Prince My Abdellah, B .P 2390, 40 000, Marrakech, Maroc

Abstract : The N'fis wadi is a part of hydraulic Tensift watershed. It starts in the axial zone of the Marrakech High Atlas. The water erosion in the N'fis watershed promotes dams collectors siltation, which is a major water supply problem in this area. The present work is to develop a water erosion risk map of the N'fis Wadi watershed; in the aim to enable decision makers, implementing a management strategy of the watershed, in order to fight against siltation. In this context a methodological approach is adopted to achieve our objective. This approach is based on the creation of several thematic maps (hypsometric, slope, friability, fracturing, and vegetation cover) with digital processing of the satellite Landsat data, SRTM data, topographic maps and geological map of the study area. The superposition of these maps allowed the identification of the active water erosion areas, across the watershed. This card is validated by field surveys.

Keywords: N'fis watershed, siltation, water risk, remote sensing, GIS

1. Introduction

The water erosion is one of natural engines of dams siltation in the high altitude areas. It is a socio-economic and environmental crucial problem because it leads to a high risk of flooding and the destruction of infractructures (hydroelectric, drinking water treatment station...).

The water erosion is very present in the catchment of the N'fisWadi, located in Marrakech High Atlas. According to the Higher Council for Water and Climate (1991), the Lalla Takerkoust dam built on the N'fis wadi, loses annually by siltation a water volume of 20,106m^3 on average, equivalent to a degradation of 330m^3 / Km^2/an. This phenomenon evolves with the factor diversity involved in the erosion process. Indeed, the region is characterized by a very rugged terrain, a generally rocky and soft lithological structure, an irregular rainfall and often stormy, a dense fracturing, and rarely dense vegetation cover. The struggle against water erosion becomes a necessity, especially since the development of a watershed is essential to the sustainability of the environment and the economy of a country.

In this context, several methods have been developed to assess water erosion. Some of which are qualitative approaches (Le Bissonnais et al., 1998 ; Boukheir et al., 2001 ; Abaoui et al., 2005; Bachaoui et al., 2008; Ake et al., 2012). Others are quantitative approches such as the Universal Soil Loss Equation (Wischmeier and Smith, 1978), as amended (Foster et al., 1996), the Roose's model (1984). The use of one of these approaches, depends on the watershed physical characteristics and the available datas. In the case of the N'fis watershed, quantitative approach is constrained by the applicability conditions of the soil loss equations. These equations require plots (small areas), our study area is large. So, for mapping the water erosion risk of the N'fis watershed, which is the origin of solid materials uprooted and transported by water to dams, we opted for a qualitative approach, based on the combination of parameters (slope, fracturing, altitude, lithological friability, vegetation cover) in a GIS. The aim of this work is to provide a first document operable to guide management priorities in the N'fis watershed; as the implementation of effective soil conservation, must first be preceded by an erosion risk assessment in the space (Moussa et al., 2002; Souchère et al., 2005). This work also helps to evaluate the benefits of using remote sensing and GIS in mapping the water erosion risk.

2.Presentation of the study area

2.1. Geographic and climatic context

The N'fis Watershed is located in the High Atlas of Marrakech in Morocco, at about fifty kilometers in the south of Marrakech city (Figure 1). He pours his load in the Haouz plain. The latter is under a continental climate characterized by a relative aridity, but our study area, due to its mountainous nature, shows a humid temperate climate even in its upstream part. It is characterized by a spatio-temporal rainfall variability (Alifriqui et al., 1995). The average annual rainfall is around 400 mm in the Imin El Hammam climatic station, and the maximum

Adama AMAYA (Correspondence)

amayaadama@gmail.com

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annual rainfall can reach 700 mm in high altitude climatic stations. The temperature at the opposite of precipitation is quite regular. The measurements show an average annual temperature of 18.6 ° C , with an absolute maximum of 46 ° C (July and August) and absolute minimum of -7.5 ° C (December and January) .

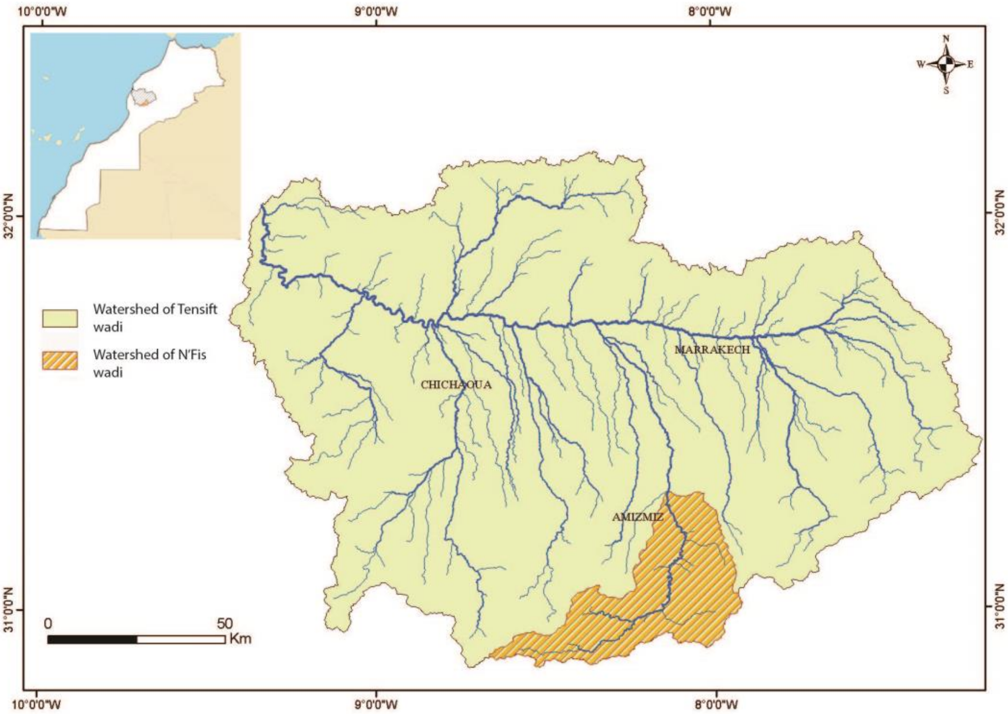

Figure 1 : Study area location

2.2. Geological and geomorphological context
The N'fis watershed is essentially composed of a basement affected by the Hercynian orogeny, and surmounted by a secondary and Tertiary coverage. Its upstream part, which is the axial zone of the Marrakech High Atlas is formed by magmatic terrains (granites, granodiorites, andesites, rhyolites, basalts, etc.), and metamorphic rocks (schist, gneiss, quartzite). Its downstream part which is a part of the northern subatlasique area is the plateau area with especially Mesozoic and Cenozoic land, whose lithology is composed of softer rocks alternating: sandstone, siltstone, and clays. The field surveys combined with the geological map 1/500.000 numerical analysis, show that the soft rock (permeable soils) occupy 20% of the watershed area, semi- soft (semi- permeable soils) have a ratio of 9 % and hard rocks (impermeable soils) occupy 71% of the watershed area. The large impermeable soils distribution is an erosion factor, as these promote runoff.

The watershed geomorphology is marked by the dominance of alluvial fans, fluvial and torrential terraces, whose surfaces are torn by more or less deep ravines (Nahid, 2002). The N'fis wadi carries blocks and pebbles from the basement, from upstream to the outlet following three directions: NW -SE, NS, NE-SW. However, it receives various alluvial tributaries and colluvial materials, from scree and landslides.

3. Materials and methods
The methodology used in this study is qualitative, based on the exploitation of geological, topographical and satellite data as well as surveys and observations on the field.

3.1. Materials used
The datas used are:
• Geological map of Marrakech 1 /500.000 (Choubert 1957), digitized and georeferenced in UTM WGS 84 system.
• Eleven topographic maps (1/ 50.000) covering the entire watershed of the N'fis wadi. These maps were digitized and georeferenced in the same geodesic system as the geological map before being assembled into a single document covering the entire watershed.
• A DTM file (digital terrain model) of the "Shuttle Radar Topography Mission " with a resolution of 90 m.

• Two scenes Landsat 5:
Product : TM L1T , ID: LT52020382011248MPS01 ; Cloud Cover: 0 % Date of acquisition: 2011/9/5 ; Quality: 9.
Product : TM L1T , ID: LT52020392011216MPS00 ; Cloud Cover: 0 % Date of acquisition: 2011/8/4 ; Quality: 9
Data processing was performed with the software ArcGIS 9.3 (map digitization and GIS implementation) , ENVI 4.3 (image processing) . After this treatment, a basic physical data of the study area was established to create layers, and to map areas prone to water erosion risks.

In the field, several GPS (Global Positioning System) points were taken for testing the limit of the lithologic facies and the fault presence, as well as locating landslides or mudslides areas or infrastructure destruction by water hazards.

3.2. The slope map

The digital terrain model (DTM), with the help of appropriate ArcGIS extensions, has permitted to make maps characterizing the hypsometric, slope and drainage of the study area watershed. The slope map is divided into five slope classes: 0 to 10 °, 10-20 °, 20-30 °, 30-40° and > 40 ° (Table 1). The class number was chosen based on our knowledge of the field. The hypsometric map is also subdivided into five altitude classes (Table 2). The quantification of each characteristic and each parameter has been facilitated by the use of calculation tools in ArcMap. The rainfall is a representative factor in the erosion process, we used the altitude to characterize the rainfall erosivity, as rainfall changes with altitude. This alternative is used because we have incomplete rainfall datas in the majority of climatic stations. So the rainfall can't be spatialized in the watershed.

Table 1: Slopes classes and indices assigned

Slope degree (°)	**Index**	**Risk class**
0 - 10	1	Very low
10 - 20	2	Low
20 - 30	3	Moderate
30 - 40	4	High
>40	5	Very high

Table2 : Altitude classes and indices assigned

Altitude (m)	Index	Risk class
640 -1200	1	Very low
1200 - 1800	2	Low
1800 - 2400	3	Moderate
2400 - 3000	4	High
3000 - 4079	5	Very High

3.3. Friability map

The geological map (Marrakech 1/500.000) has been digitized to map lithologic facies, and create a database on the dimensions of the various geological terrains. The erosion consequences observed in each lithologic layer and rocks analysis, pushed us to assign an index corresponding to the vulnerability degree to risk. Thus, four classes of materials are defined (Table 3).

Table 3: Friability classes and index assigned

Facies	**Index**	**Materials friability**
Magmatic rocks, quartzite	1	Resistant rocks
Schists	2	Moderately resistant rocks
Limestone, sandstone, wheathered granite, conglomerate	3	Vulnerable rocks
Clays, shales	4	Very vulnerable rocks

3.4. Vegetation map

Both satellite Landsat TM scenes were assembled under the ENVI software to cover the entire study area. A supervised classification was performed and gave a "Raster" files showing the zonation of vegetation cover and soil denudation. The raster is subsequently exported to ArcMap to be cut as the watershed and then to be converted into "Shapefile" polygons. Thus, the datas and the quantifications can be retrieved and integrated into the database. Vegetation map obtained is divided into five classes according to the density of the cropping system

(Table 4).

Table 4: Vegetation classification

Type	Index	Risk class
Dense foret	1	Very low
Sparse foret	2	Low
Polyculture	3	Moderate
Bare soil	4	High
Bare rocky ground	5	Very high

3.5. Fracture density map

Under the ENVI software, the use of directional filters allowed to create the lineament maps of the study area. Lineament maps are exported to ArcMap to be digitized. Digitization was performed on straight structures omitting roads, bridges, cliffs, ridge lines, slope failures and other geomorphological appearance. The fracturing map established, allowed the extraction of datas using a statistical approach, different fractures or faults orientation and their density. We thus subdivided this map into five fracture density classes (Table 5).

Table 5: Fracture density class of the N'fis Watershed

Lineament density	Index	Risk class
Very low	1	Very low
Low	2	low
Moderate	3	Moderate
High	4	High
Very high	5	Very high

4. Results and discussion

4.1. Hypsometric map

The hypsometric map (Figure 2), has altitudes ranging from 640 m at downstream of the watershed, to 4079 m at its upstream extremity. The areas of the highest altitudes are located in the southern, eastern and western parts of the watershed, however, the lowest ones occupy the northern part. More than 60% of the watershed area has an altitude above 1800 m.

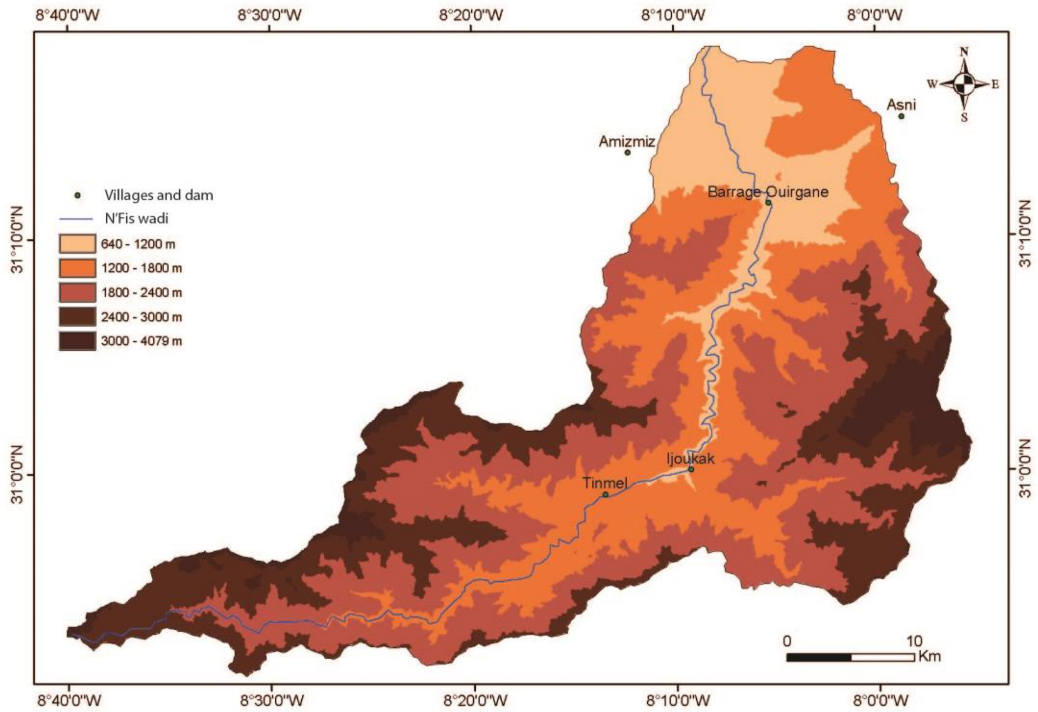

Figure 2: Hypsometric map (in meters) of the N'Fis watershed

4.2. The slope map

The slope map analysis (Figure 3) shows that the watershed is highly steep, except, at its outlet, at the Ijoukak- Tinmel depressions, and at the upstream in the Tichka granite lands, where it is moderately steep. The slope class (20 ° - 30 °) is the most common in the watershed, it occupies an area of approximately 566,34 km^2 or 39,26% of the total slope areas. The classes of low slope represent a percentage of 13,79% and 22,98% for moderate. The classes of high and very high slope, occupy 63,23% of the watershed area. These steep slopes makes the watershed vulnerable to water erosion and its wide distribution in the watershed, grants the study area, an enormous sensitivity to natural hazards.

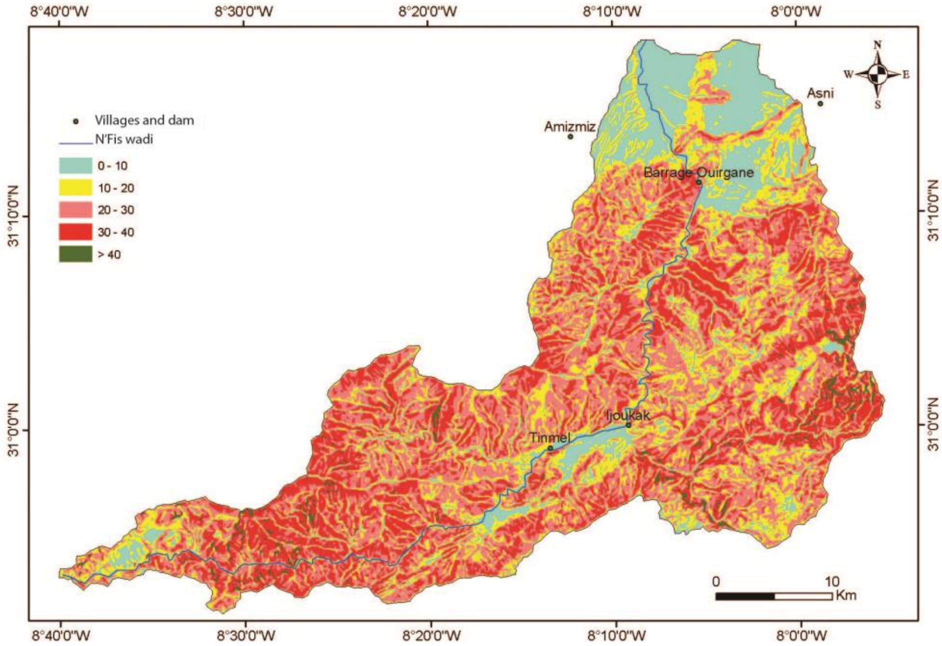

Figure 3 : Slope map (in degrees) of the N'Fis watershed

4.3. Friability map

The analysis of soil friability map of the N'fis watershed (Figure 4) and the statistical distribution of the material friability classes, allows us to deduce that the N'fis watershed generally consists of friable rocks, representing 64,9 % of the catchment area, with a share of extreme friability of 10,71%.

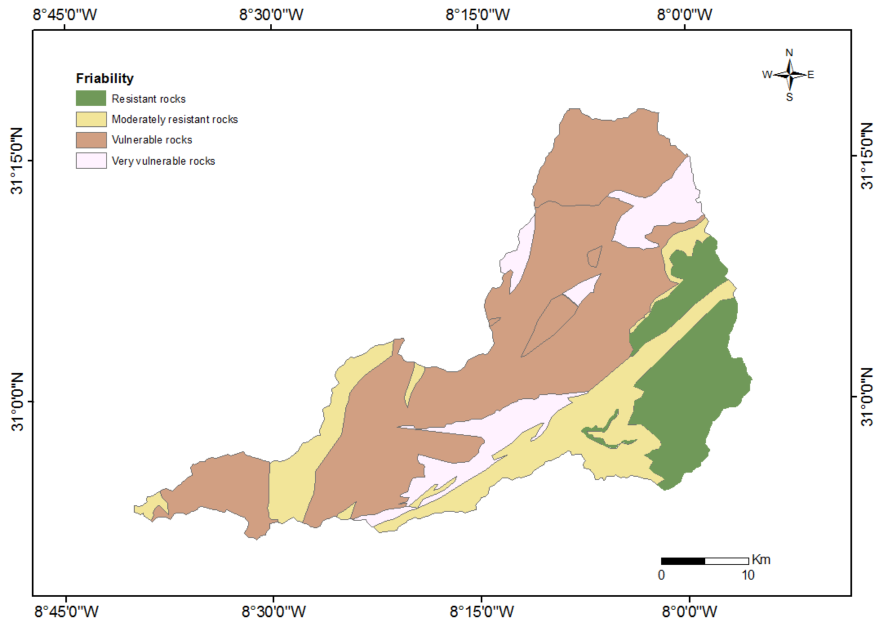

Figure 4 : Friability map of the N'Fis watershed

4.4. The fracturing map

The fracturing map creation followed two procedures: standard methodology based on field surveys and on the study of the geological map of Marrakech 1 /500.000 (Choubert, 1957), and a more recent methodology using remote sensing datas.

Generally, the watershed of the N'fis wadi shows an observable brittle tectonic, in the basement grounds like in the coverage grounds. The major faults are oriented NE- SW and NW -SE to NNW- SSE (Qarbous et al., 2008) (Figure 5).

By using directional filters of ENVI software, hundreds of lineaments were detected, but after field observations and analysis of high-resolution satellite images, we removed all structures other than fractures.

The result expression on a direction rose (Figure 6) shows a similarity of the fracturing directions with those of the geological map, except for the west-east direction, which becomes more pronounced. This observation is explained by the cleavage omnipresence in magmatic intrusions of the Tichka granite at the watershed upstream, and the deformation of the Paleozoic land. The statistical approach and the establishment of the density map (Figure 7) confirms this finding by showing an upstream zone with a very dense fracturing. This zone is more vulnerable to the erosion. In terms of magnitude, the densest areas in fractures, occupy 69.6 % of the total watershed area and correspond to classes from moderate to high risk.

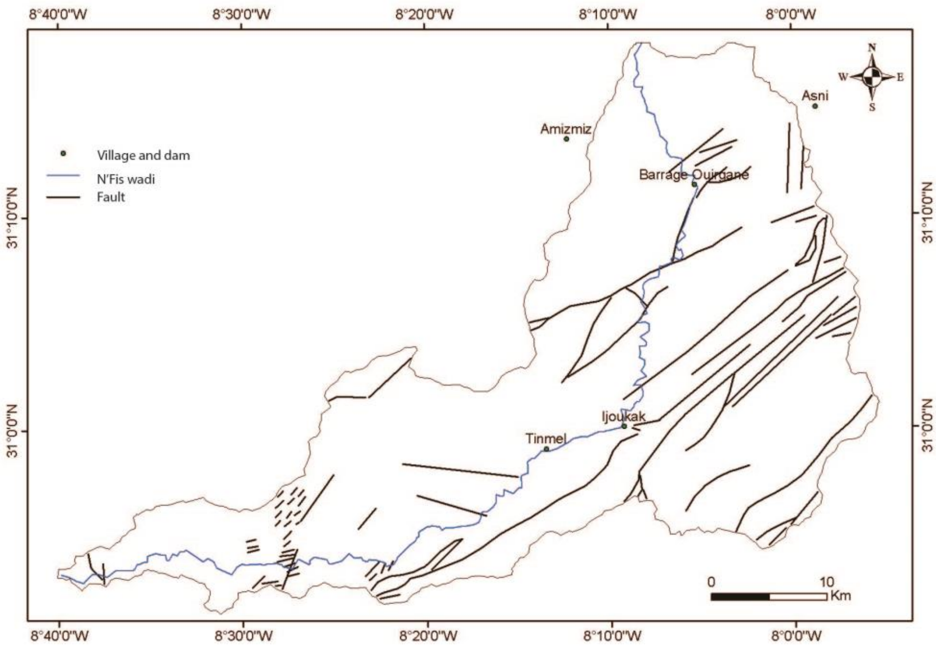

Figure 5: Fracturing map from the geological map 1/500000

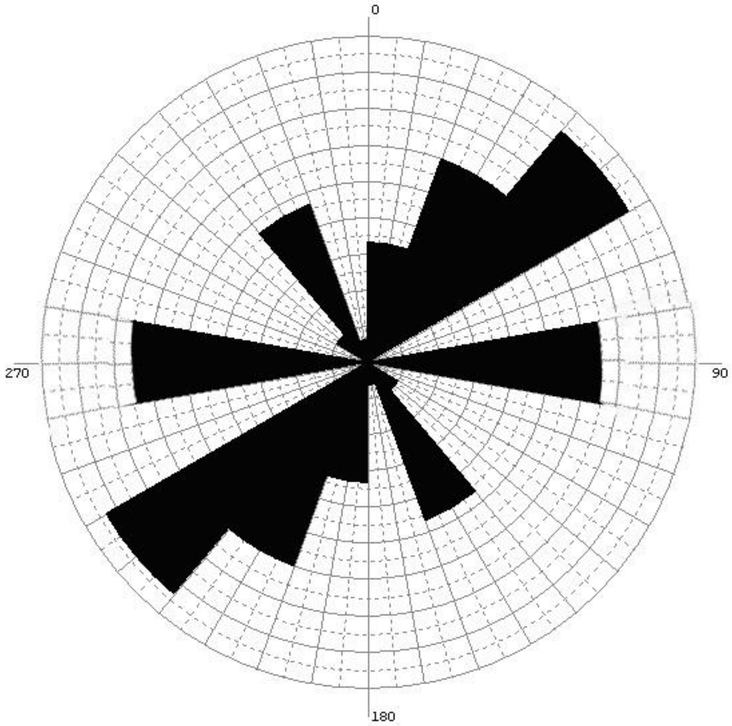

Figure 6 : Rose of the fracturing directions of the N'Fis watershed

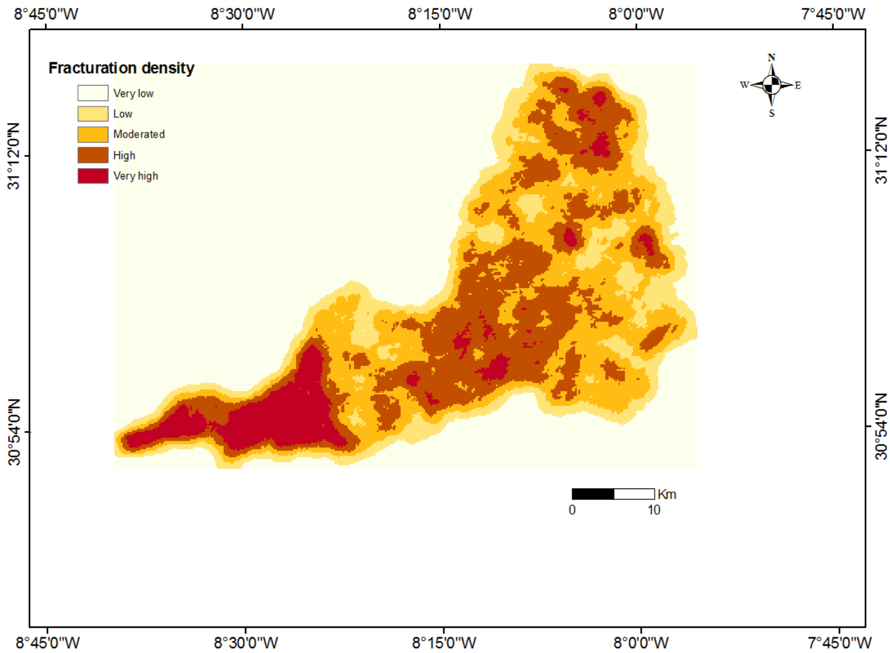

Figure 7: Fracturing density map of the N'Fis watershed

4.5. Land cover map

The water erosion risk can be very important in bare soil and stream flows can be directly influenced by the land cover (Hudson, 1996). Thus, the elaboration of a vegetation cover map is necessary. In our study area, the northern slopes are poorly exposed to the sun, which results in a proliferation of oak and cedar forest. The map extracted from a supervised classification of Landsat TM satellite image (Figure 8) shows, also, bare land (Primary and Precambrian basement), occupying more than 50% of the catchment area. The arboriculture and polyculture fields are rare and follow, especially, large ravines and beds of large channels. This reflects the importance of the area exposed to water erosion in the study area. The highest risk areas are located at the west and the far north of the watershed.

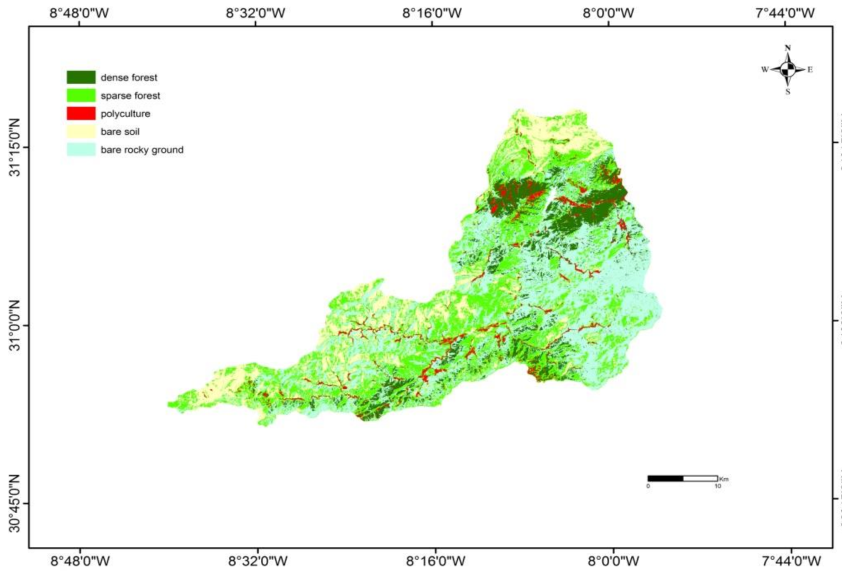

Figure 8 : Vegetal cover map of the N'Fis watershed

4.6. The water risk map

The superposition of the different maps: hypsometric map, slope map, density fracturing map, land cover map and friability map, under ArcGIS, led to the creation of a map that locates areas, potentially vulnerable to the risk of water erosion (Figure 9).

We note that the classes of the highest water risk (scale of 3 to 5) are located at south-east and west of the catchment area, in the fracture density from 3 to 5, slices of altitudes above 1800m, slope classes above 20 °, and on the bare rocky soils. However, there are risk areas at low slopes and with the presence of vegetation cover, such as in Ijoukak, Tinmel and Talat -n- Yacoub depressions. The risk factor in these areas is the lithology; it consists of Triassic sandstones and shales. Indeed, sandstone allows water to pass through the fractures and joints, causing severe erosion. Similarly, the very old flattened lithological layers are very brittle and cause frequent landslides. They are identified as high water erosion risk areas, as well as clay soils, where erosion occurs by large ravines.
Thus, in the N'fis watershed, the level of exposure of an area depends on the conjunction of factors influencing erosion. However lithology appears the main erosion factor.

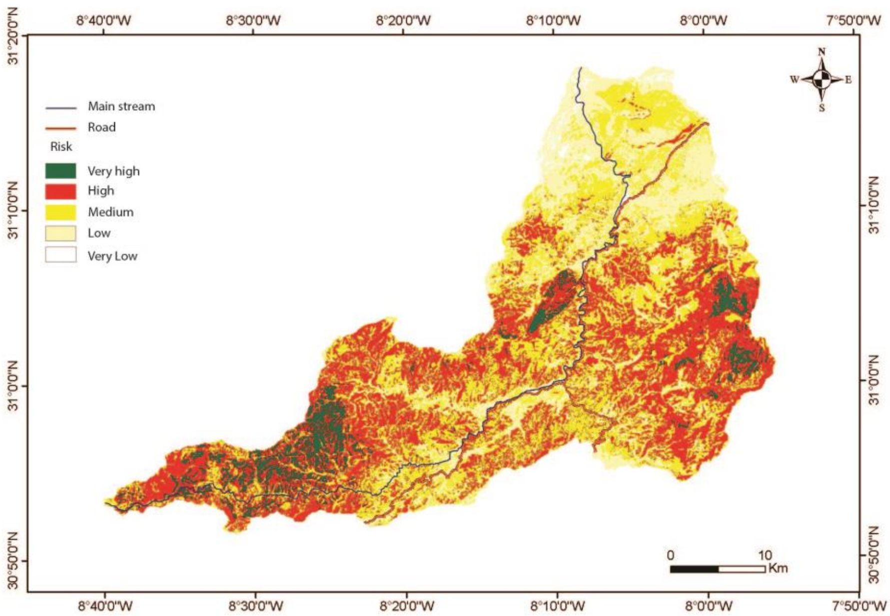

Figure 10 : Water erosion risks map of the N'Fis watershed

5. CONCLUSION

The present study attempted to produce a summary document that shows the major trends in the spatial distribution of vulnerability to water erosion in the N'fis watershed. The latter is the first map of the water erosion risk in the catchment of the N'fis Wadi, where environmental and infrastructure issues are high. The methodology combines the most representative erosion factors in the occurrence of the erosion in the study area, such as topography, vegetation, lithology, fracturing.

The risk map obtained after the crossing of these factors shows that more than three quarters of the catchment area is subject to moderate risk, high and very high risk. This card can be used to target interventions of the priority development, with a view to fight against siltation and all other consequences of water erosion. The mapping method of water erosion used in this work, may be applied to other regions having the same characteristics as N'fis watershed. It is applicable on large watersheds as on small watersheds, and its flexibility makes it easy to update the stale datas.

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