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Prediction of soil water erosion risk within GIS- case study of Beni Amrane Dam catchment (North of Algeria)

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Abstract. Isser River is one of North Algeria's major resources. It is vulnerable to water soil erosion because of favourable conjunctions of different geomorphological, hydro-climatic and lithologic factors. This case study has been carried out on the Beni Amrane dam Catchment, which is located in the bottom of Isser River, in North Algeria. The study involves a mapping of main factors of water erosion: rainfall erosivity, soil erodibility, slope and land use. Essentially a data mapping specification analysis shows, on each factor, how to identify the areas that are prone to water erosion. 04 classes of multifactorial vulnerability to water erosion have been identified: areas with low vulnerability (10 per cent); area with middle vulnerability (49 per cent); areas with high and very high vulnerability (38 per cent and 3 per cent). This could be a first guidance document for a rational use of land in the region and better secure the Beni Amrane dam against reservoir siltation.

1. Introduction

Erosion and sediment transport are major constraints to agricultural development and dams' management. They cover 45% of Tell areas, i.e. 12 million cultivable hectares [1]. The volume of materials that collect each year in the reservoirs of the Algerian dams are estimated at 20 million m^3 on average per year [2], which contributes to reduce by 0.3% per year the water storage capacity estimated at 6.2 billion m^3 [3].

Diversity of hydrological and sedimentological characteristics in different parts of the basin involves different but related processes. At the basin mouth, sediment transport closely depends on the sediment load from upstream and on training conditions. The measurement done at this point is only the outcome of all heterogeneity of the basin. Spatial variability of the catchment basin, therefore, requires a fine discretization. For that purpose, the vision of these phenomena is very different depending on space and time scale at which each one places itself. Many works have settled strong relationships linking sediment transport with explanatory parameters in order to understand the complex mechanisms of sediment transport and quantify the volume of sediment transported. Because of the high cost of conservation and the concurrent production targets such as the increase in the population, the development of the infrastructures and the degradation of the grounds, it is necessary to target the solutions and the resources in the high-risk zones, rather than to equitably distribute them between the landscape [4]. The cartography of erosion is a fundamental tool to know the distribution and the geographical extent of the phenomenon as well as its qualitative characterization [5]. Our primordial goal is based on the knowledge and understanding of the environmental dynamics. Thus, a diagnosis of natural environment situation on geographical framework is necessary, especially within a geographic information system (GIS).

The case study of Beni Amrane dam Catchment is located at the bottom waters of Isser River. It extends between longitudes 3° 20' and 3° 60' East and between latitudes 36° 40' and 36° 10' North (CF figure 1). It covers an area of 847 km^2, around more than 20% of the total surface area of Isser basin to which it belongs. The Beni Amrane dam catchment has an annual run off mean of 414 million m^3/an. Its mouth is at 70 km south east of Algiers.

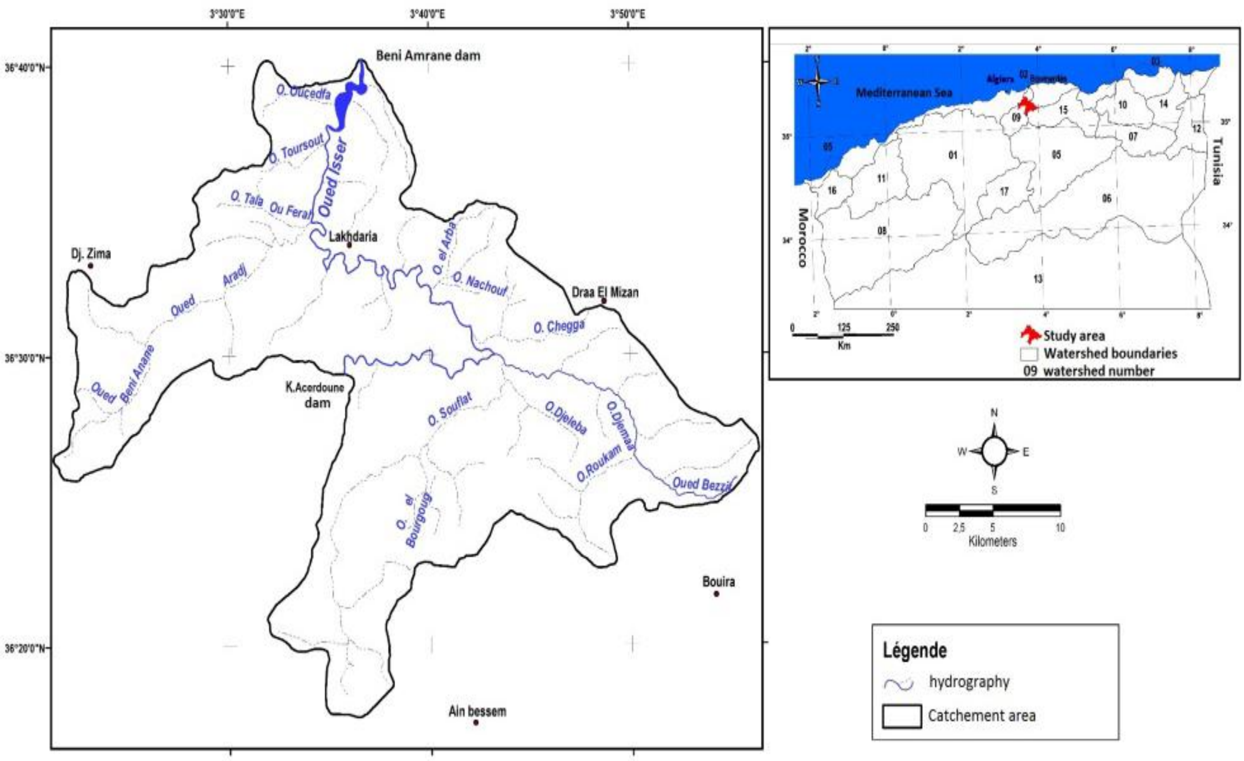

Figure 1. Geographic situation of Beni Amrane dam Catchement area.

2. Materials and methods

Since soil erosion is particularly difficult to measure directly in real time, it is necessary to use models that allow the estimation of the rate or state of this phenomenon. Several erosion models have been developed, some of which have an empirical basis such as the USLE (Universal Soil Loss Equation) [6] and its modified versions, others physically based such as the project of prediction of water erosion, WEPP of Foster and Lane.

The choice of the model depends on the variability of the basin area, punctual data and precipitation [7]. These models require very precise sampling based on punctual measurements and very large scale maps. In the study area, we only have maps at scales less than or equal to 1/500,000, and the lack of data on the region's soil structure and precipitation intensity does not allow us to use a quantitative model of the type USLE. To overcome these drawbacks, we have opted for a method based on a qualitative model of expert system based on a crossing of parameters determining erosion in the form of logical combinations, namely, lithology, rainfall, slope Topography and land use, whose weights have to be balanced [8] based on current knowledge on different types of erosive functioning. Cartographic and descriptive data on the factors influencing the water erosion process will be integrated into a GIS.

The methodology is described according to the flow chart shown in figure 2.

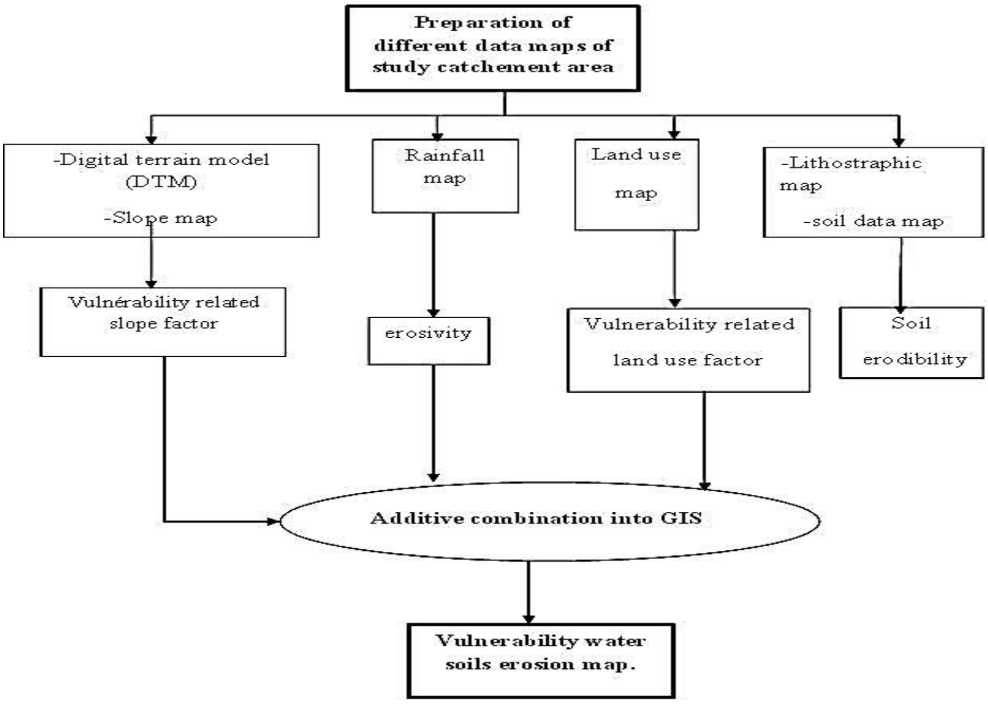

Figure 2. Different processing stages of erosion risk evaluation map.

Data acquisition required a bibliographic approach and electronic data discoveries on the data provided pedologic and geologic service of the National Water Resources Agency [9] and the National Institute of soil, irrigation and drainage [10]. After processing, it was possible to make the main elements and to use the predict approach.

Map data were taken back to ANRH, INSID and the National Meteorology Office (ONM) and were operated. Those data mainly consist of the following:

- A rainfall map of northern Algeria, drawn up on the annual averages of rainfall for the period (1965/1966- 2001/2005), at the scale 1/500000 [9];
- Soil use maps for the following Wilayas: Boumerdes, Bouira, TiziOuzou and Medea at the scale 1/25000: The year 2011 [10];
- Lithostratigraphic map of northern Algeria at the scale 1/200000 [9];
- Hydro-climatological and water quality monitoring map sat the scale 1/500000 [9];
- Shuttle Radar Topography Mission Images With coordinates: N35E003, N35E004, N36E003, N36E004: 23rd September 2014; (source; https://earthexplorer.usgs.gov/).

3. Results

The processing of one-factor vulnerability database was performed with the professional software MapInfo 11.0, and ArcGIS 10.0 (maps digitalization).

3.1. Rainfall map

Rainfall-related erosion parameters are:

The height of precipitation: it has little to do with the amount of erosion, the higher the precipitation height, the greater the volume of water runoff, which promotes water erosion.

Intensity is the main factor in erosion. The greater the intensity, the stronger the threshing effect of the ground.

In the study area only data from the rainfall station of Djebahia (09 04 03) is available, but with a single rainfall station it is impossible to specialize the rainfall intensity.

The classification of annual average rainfall according to the annual average rainfall map of the world is divided into five distinct classes (CF table 1)

Table 1. The world average annual rainfall classification.

World Average annual rainfall (mm)	Classes
< 250	1
250-500	2
500-1000	3
1000-2000	4
>2000	5

This classification was made on a global scale. The average annual rainfall in the study area varies from 350 to 900 m is considered that an average annual rainfall of 1500 mm may favor strong erosion [11]. Referring to these data, discrimination is proposed at the scale of the study area (CF table 2).

Table 2. Average annual rainfall classification of study area.

Average annual rainfall (mm)	Classes
< 500	1
500 – 800	2
> 800	3

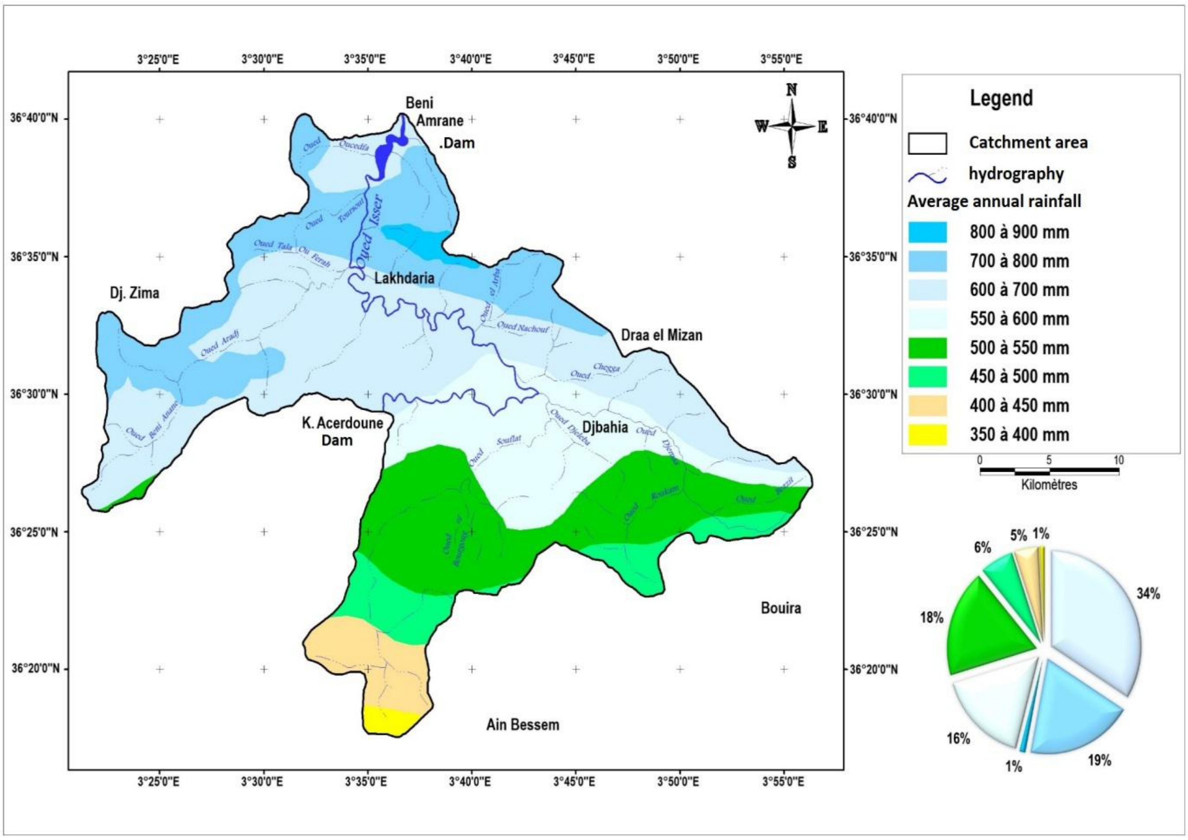

Figure 3. Average annual rainfall map.

From the average annual rainfall map of the Beni Amrane dam basin (CF figure 3), we have classified and then codified the different ranges of average annual rainfall, which resulted in a map of rainfall erosion.

Only low, medium and heavy precipitation is represented on the study site. Low precipitation spreads over an area of 100 km^2, i.e. 12% of the total area of the basin, and moderate precipitation occupies 87%, while heavy precipitation occupies only 1% of the total area of the basin.

3.2. Slope map

The slope map (CF figure 4) is one of the basic elements for the analysis of the physical characteristics that determine the suitability of the various zones. Indeed, the potential and limits of land use depend to a large extent on the slope since this contributes to the determination of erosion possibilities in relation to other factors of the mechanization of crops, Irrigation, grazing opportunities, installation and development of reforestation vegetation.

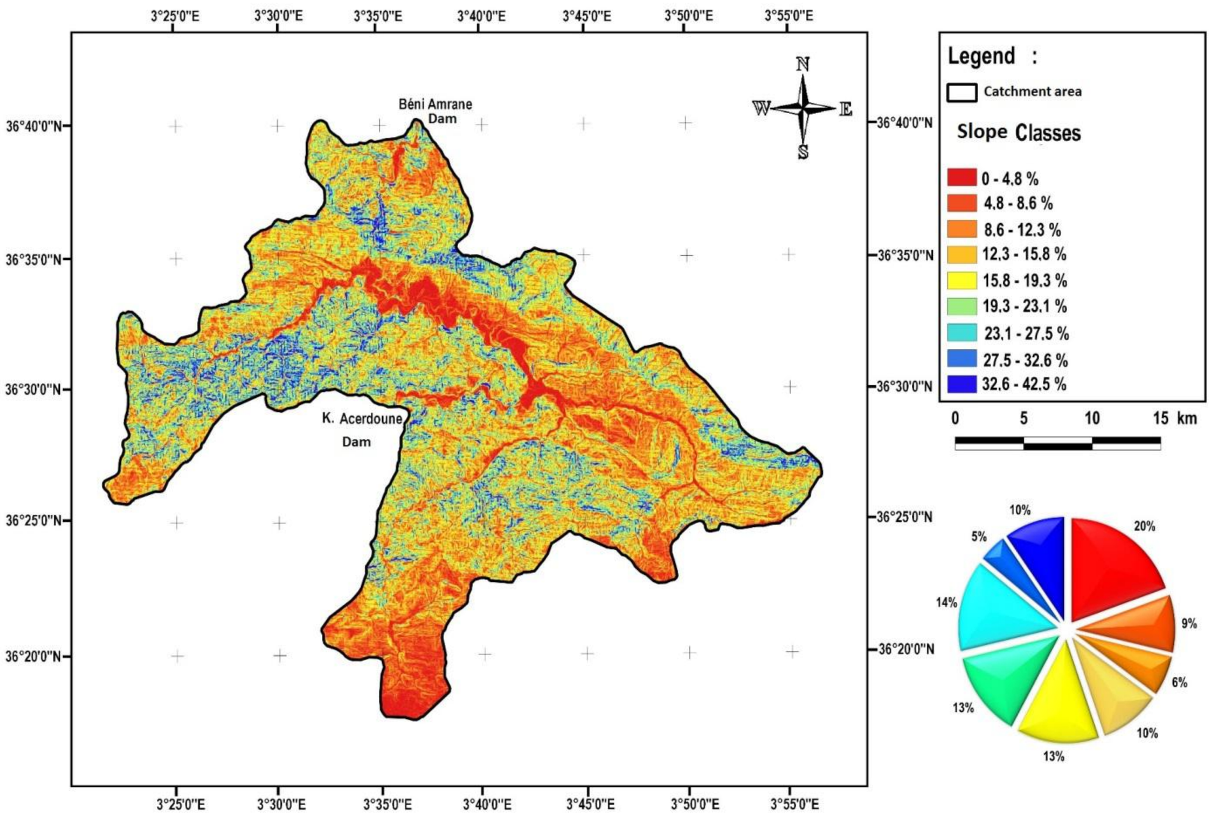

Figure 4. Slope map.

The length of the slope has more uncertain effects [12]. This was not reflected in this study.

The slope map of the study area was reclassified based on the Roose classification (1977) and transformed into a map of vulnerability to soil erosion according to the inclination of the slope.

- 0-5%: weak slope;
- 5-15%: average slope;
- 15 - 25%: steep slope;
- >35%: very steep slope.

For each slope class, an index ranging from 1 to 4 (CF table 3) is assigned, with 1 being assigned to the low slopes (<5°) and 4 to the steep slopes (> 15°).

These four classes cover respectively:

- 13% of the study area for slopes between 0 and 5%;
- 33% for those between 5 and 15%;
- 34% for those between 15 and 35%;
- And 20% for those above 35%.

Table 3. Slopes classes and attributed indices according to Roose, 1977.

Slopes	Code
0 – 5 %	1
5 – 15 %	2
15 – 35 %	3
> 35 %	4

3.3. Land use

From the land use map of the Béni Amrane basin (CF figure 5), we assigned to each class a degree of protection against water erosion.

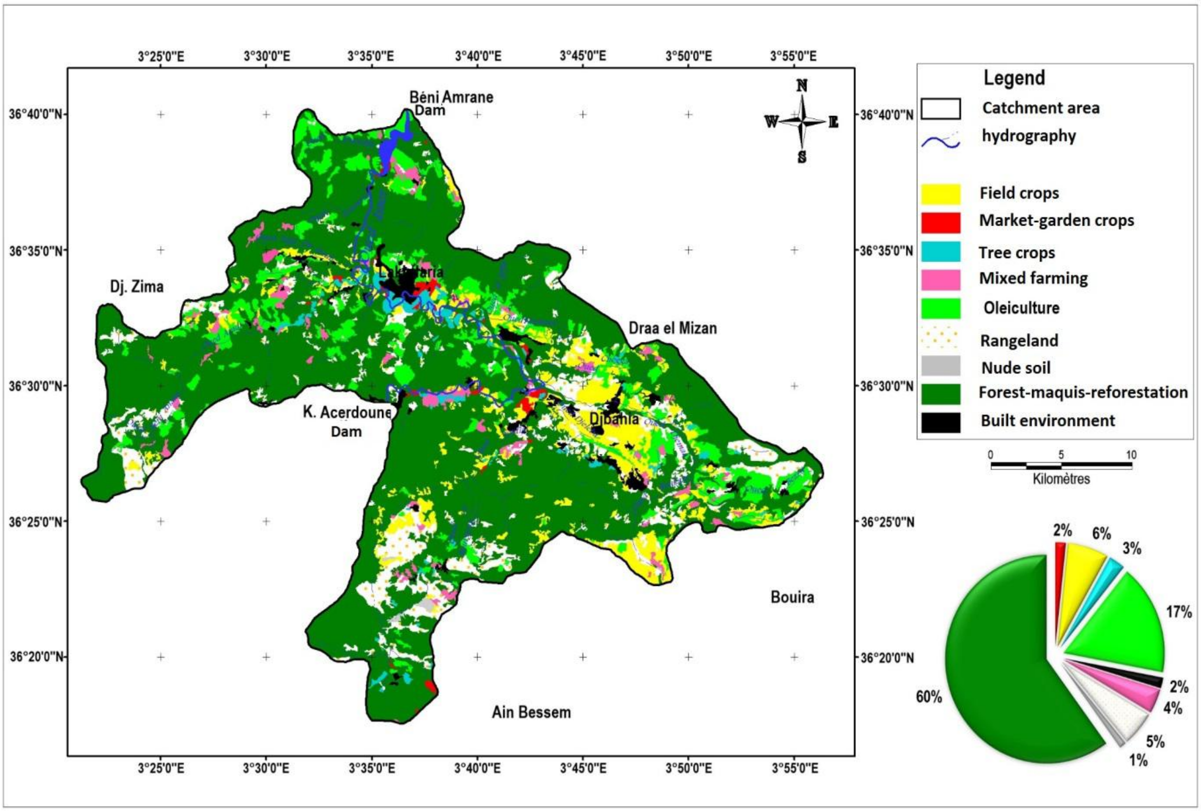

Figure 5. Land use map.

- Degree 1: strongly protective.
- Degree 2: moderately protective.
- Degree 3: slightly protective.

- Degree 4: non-protective.

The classification of Roose (1977) was used to derive an appropriate classification. Roose classifies the vegetable coverings into three groups:

- Permanent vegetation cover.
- Temporary vegetation cover.
- Incomplete vegetation cover

This classification method was detailed by subdividing the incomplete vegetation cover group into two groups: grazing and bare soil.

- Permanent vegetation cover includes:
  - The forest cover
  - Reforestation.
  - Perennial crops.
  - Fruit plantation and fruit trees.
- The temporary vegetation cover includes:
  - Annual crops: Cereals, extensive and semi-intensive agriculture and arable land.
  - Pastures: include very degraded and less degraded pastures

The map established makes it possible to discriminate nine classes of land occupation: 1 / dry field crops; 2 / vegetable crops; 3 / tree crops; 4 / polycultures; 5 / olive growing; 6 / range; 7 / bare soil area; 8 / forest - bush - reforestation; 9 / built space.

The classification is made using a GIS by assigning to each object a value that indicates its degree of sensitivity to erosion. This classification is based on direct observation of land use categories, and has resulted in a land use sensitivity map. Four classes are identified: range lands, bare ground, very dense vegetation, sparse vegetation or medium density.

Each class is assigned a value between 1 and 4, with 1 being assigned to the least vulnerable class and 4 to the most vulnerable class [13]

The dam catchment area is the most affected part by a semi-arid climate regime that determines the vegetal cover. In terms of soil erosion, it is the factor "coverage rate" that occurs more.

The land use map of the dam catchment area (CF figure 5), generated from the land use map prepared by the National Institute of soils, irrigation and drainage (INSID), highlights without a second thought that the vegetal cover mainly consists of trees, shrubs and herbaceous plants, i.e.; 70% of the total area. The rest primarily includes cereal and economic crops, dried vegetable and market gardening in the open fields or under glass.

According to [13] each coverage rate is indexed in table 4 below.

Table 4. Coverage rate classes and assigned indices.

Coverage rate	Index	Assignment
Very dense vegetation	1	Highly protective
Scattered or medium density vegetation	2	Moderately protective
Cultivated land	3	Slightly protective
Bar land	4	Non-protective

According to the map obtained, the distribution of vegetation cover at the level of the catchment area is respectively; 20% of the slightly and non-protective land and 80% are considered protective.

3.4. Soil map

The lithological map of the dam watershed of Beni Amrane reveals a wide variety of surface formations predominantly clay soils derived from marl formations (CF figure 6).

Soil sensitivity classes for each soil type are attributed from their texture, on which the formation and stability of the aggregates depend, and which results in large part from the nature of the origin materials. Some of the soils on massive rocks (granite and limestone) are classified as low and medium erodibility, while soils on friable rocks (sand and molasses) and coarse textured soils, regardless of the origin material, are considered as strongly erodible [14].

Although limestones and sandstones are permeable and hard formations, their association with swelling clays promotes the triggering of runoff from which fine particles are entrained [15].

Taking into account the degree of friability of the substrates., the clay and marly facies have thus been grouped together as brittle, flyshaking as moderately resistant and sandy as very resistant [16].

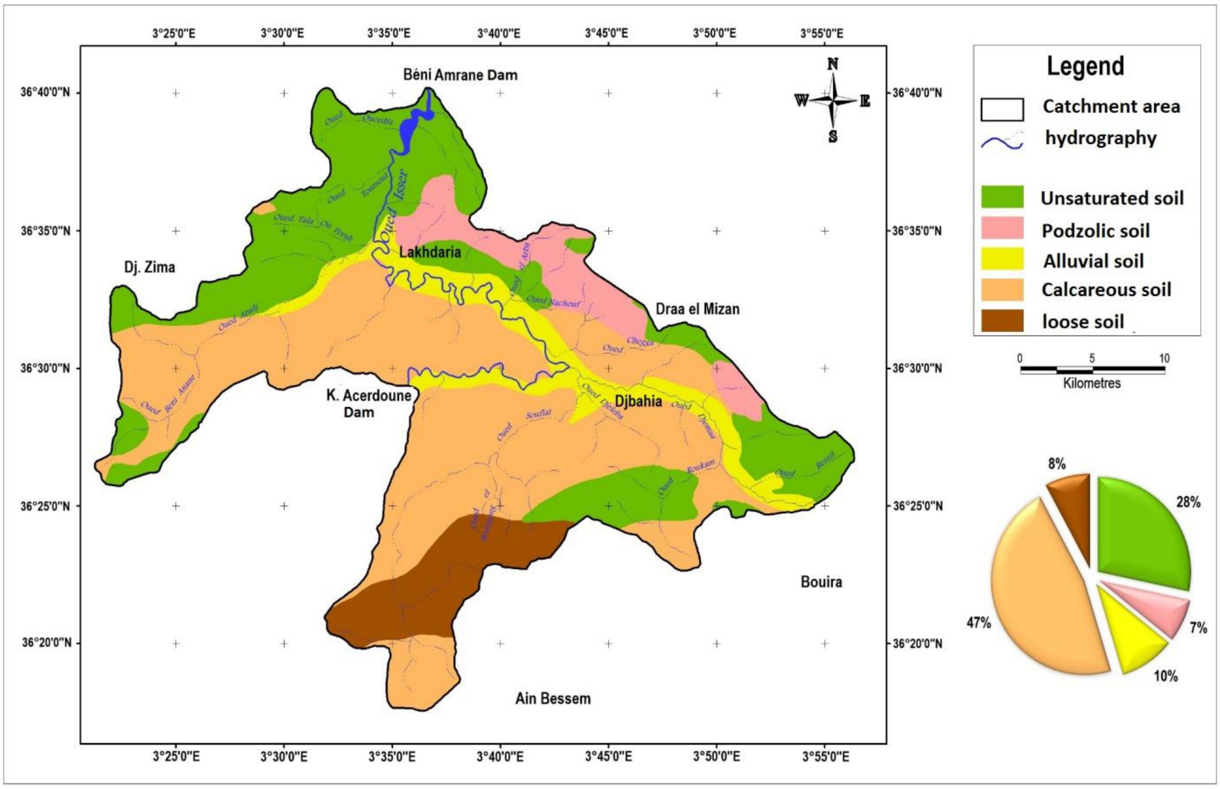

Figure 6. Soil map.

Marly soils, when dry, remain non-erodible, but as soon as they reach certain moisture, their susceptibility to detachability and runoff increases.

The sensitivity classification includes, in ascending order, four classes that have been identified as:

Class 1: Slightly sensitive; Class 2: moderately sensitive; Class 3: highly sensitive; Class 4: highly sensitive.

The lithology map shows that the majority of the basin, more than 75%, consists of weakly or moderately compacted sedimentary rocks or soils and rocks or soils that are not very resistant or strongly altered throughout the basin. We also observe a frequency of 14% of sediments or soft soils, non-cohesive and detritus materials, particularly in the middle of the basin and in areas of low to medium slope. High permeability carbonated rocks and cohesive soils fractured or moderately altered, poorly permeable occupy 11% of the total area of the basin.

The dominance of weakly or moderately compacted sedimentary soils and of soft sediment increases the erosive potential of the watershed.

3.5. Water erosion vulnerability map

The study of the vulnerability of soils to water erosion presupposes, as mentioned above, the logical combination of several factors [17] In a GIS; without forgetting that here we have limited by three external factors, in addition to lithology, at the same time effect and cause.

The problem of weights has been the subject of research by several researchers. The unanimously recognized role of vegetation density and slope against water erosion led us to retain weighting coefficients for each factor.

The crossing of the various thematic maps was carried out by applying weighting coefficients inspired by the general principles used by Le Bissonnais [18]. The highest weighting is attributed to the "vegetation cover" factor, which is considered to be the dominant factor, and the lowest weighting is attributed to precipitation because we do not have rainfall intensities, but only the average annual heights. Factor 2 is attributed to lithology and factor 3 is given to the topography. The general principles used to weight the parameters are as follows [19]:

- Only bare lands and cultivated lands are susceptible to runoff. It has no influence on prairies and dense forests;
- The influence of the slope increases when it is associated with a weak vegetation cover;
- The erodibility factor occurs only in the case of steep slopes;
- The effect of climate increases with susceptibility to erosion, for example in cases of very low susceptibility to erosion (e.g. permanently covered on low slope), the hazard remains very low whatever the rainfall erosion.

We proceed by combining the corresponding attribute tables into the four thematic maps where codes were assigned in order of increasing vulnerability to erosion within each class of factors (tables 2-5). The multifactor vulnerability to erosion of a given sector is evaluated by taking into account the effect of the four parameters by the following formula:

$$I=\sum_{J=1}^{4}\sum_{i=1}^{4}P_i*S_j$$

Where: I is the index of vulnerability to water erosion; Pi is the weighting of parameter i (rainfall, soil, slope, vegetation); Sj is the contribution of the class i for each of the parameters i.

Table 5. Classes of lithofacies and assigned indices.

Lithofacies	**Lithofacies that existant in the study area**	**Code**
Non altered compact rocks, strongly cemented conglomerates, crusts, ferruginous sandstone outcrops (massive limestone, strongly rocky soils, igneous or eruptive rocks, locally encrusted soils).	-	1
Carbonate rocks, fractured or moderately altered cohesive rocks or soils	-Flysch of the Aptian and the Albian -Limestone and marly limestone of Jurassic age	2
Low or moderately compacted sedimentary rocks or soils (slate, shale, marl ...) and rocks or soils that are not very resistant or strongly altered (marl, gypsum, clay slate, etc.)	-Shales and quartzites of the Albian -Clay, marls and sandstones of the Miocene -Paleozoic Micaschists -Marl and Limestone of the Coniacian-Maestrichtien -Marl, sandstones and sandstone limestone of the Upper Eocene	3

	-Marl and limestone of the Cenomanian.	
Sediment or loose soil, non cohesive and detritus material	-Cailloutis, reddish sandy clay of the Miocene -Quaternary Terraces: eluvium marly limestone -Oligocene series of clays at the base and sandstone at the top -Alluvium of the Quaternary	4

Thus, for classes 1,2,3,4, which represent an area with an average annual rainfall of less than 500 mm with fractured cohesive rocks flushing on a slope varying from 15 to 35% on bare ground, the index is 30 (1 * 1 + 2 * 2 + 3 * 3 + 4 * 4). Four classes of vulnerability to erosion have been drawn: low (indices 4 to 13), average (indices 17 to 24), strong (indices 17 to 32) and very high (32 to 40).

The figure below shows the map of sensitivity to water erosion of the Beni Amrane dam catchment with these four classes.

The soil sensitivity map to water erosion (CF figure 7) is carried out by crossing lithology maps, annual average rainfall, slopes and land cover.

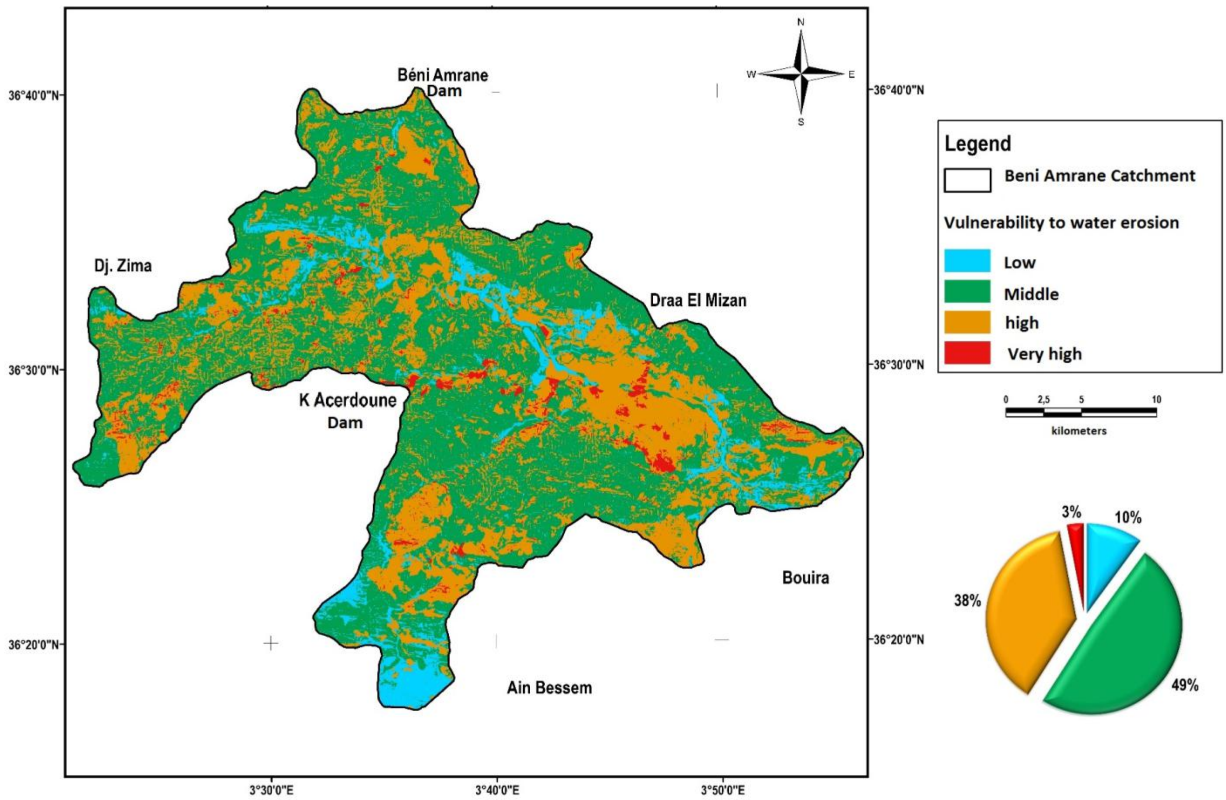

Figure 7. Water erosion vulnerability map.

Four classes appear:

- Class 1: low sensitivity to erosion represents 9% of the total area.

- Class 2: average sensitivity to erosion represents 53% of the total area.
- Class 3: high sensitivity to erosion represents 36% of the total area.
- Class 4: high susceptibility to erosion represents 2% of the total area.

After a general description of the physical environment of our basin, we observed that the part located at the center of the basin and in the West is favorable to the erosive phenomenon. This part is hilly or encountered land steep (> 15°) and a canopy of low density.

There is a dominance of sensitive soils to medium and high water erosion. These affect 89% of the study area, with an almost general distribution in a large sector. A proportion of 36% of the area of the basin is highly sensitive to erosion and 2% of a very high susceptibility. These areas concern land with steep slopes, with crops or matorrals, which possess either herbaceous or degraded vegetation cover, with plowing on sloping land and with slightly resistant surface formation.

The units which are moderately susceptible to erosion occupy 53% of the basin area and correspond to outcrops on low to moderate slopes, and / or are occupied by dense vegetation cover, or soil where cropping practices are appropriate. On the other hand, very low risk soil classes (9% of the basin) are located mainly at the level of tree crops and dense forests, where the well protected soil facilitates runoff and limits the risk of aggressive runoff and erosion; these zones have a slope generally between 0 and 4%. Studies by C.W. Roose (1991) have shown that even on a slope of less than 1%, erosion may occur. This is groundwater erosion, without formation of channels or gullies, with runoff not being able to concentrate.

The mapping of sensitivity to water erosion at the BeniAmrane dam catchment provides information on the extent and current state of soil degradation. They reflect the state of erosion resulting from the predominance of maroon-silty soft formations, steep slopes and aggressive runoff. To refine the results, it will be necessary to update the data, to improve the combined methods implemented and to integrate additional parameters (spatial variability of rainfall intensity, soil infiltrability....).

4. Discussions

Knowing that policy makers are much more interested in the distribution of erosion risk than its absolute value [20], a cognitive qualitative model has been implemented on the watershed of Beni Amrane focusing on simple parameters representing the main factors of water erosion, namely soil inclination, soil occupation, surface soil formations and precipitation.

The classification of sensitivity to water erosion as a function of the inclination of the ground is not refined, as long as it has been made on the basis of a 30 m resolution MNA map, from where the slopes were calculated for each pixel of 30 m by 30 m, which does not always reflect the reality of the terrain. Indeed, it would be more credible to work on 5 m or 10 mb good resolution images even though the MNA map was realized with curves of low equidistance (20 m). Similarly, groundwater erosion whose main cause is the energy of heavy rainfall on bare soils [21] is not considered and occurs in low slope soils, which can generate a high loss of soil.

The sensitivity classification according to the land-use map of the National Institute of Soils, Irrigation and Drainage (INSID) is still reliable, as long as it has been carefully compared with more recent satellite images, where no major changes have been noticed. Nevertheless, consideration should be given to the development of land-use change scenarios [22]. The majority of the surface of our basin is covered by forests and reforestation, that is 60%, where the vegetation cover protects against the phenomenon of rainfall, prolonging the soil permeability and reducing the runoff volume. On the other hand, a large quantity of runoff energy is absorbed by the litter that maintains the mesofauna (influencing the rate of infiltration). However, the state of the vegetation cover directly affects the roughness of the soil. This depends in particular on the number of stems per square meter. A vegetation cover composed of numerous herbaceous plants will have a more effective soil protection action against runoff than trees [20]. Human intervention which accounts for 30% of the surface area accentuates its fragility to groundwater erosion by clearing and cultivating large crops, polycultures and especially crops small and medium-sized slopes.

Although limestones and sandstones are permeable and of hard formations, their association with swelling clays promotes the triggering of runoff from which fine particles are entrained [14]. Marly soils, when dry, remain non-erodible, but as soon as they reach a certain degree of humidity, their susceptibility to detachability and runoff increases. Although sand is inconsistent, it is not certain that sandy areas are always very sensitive to water erosion because water can infiltrate quickly [23].

The spatialization of the erosivity based on the annual mean precipitation map of the period (1965-2005) is not sufficient without taking into account the intensity of the rains during the flood events.

The map that we have realized can be refined by integrating new parameters related to the morphology of the terrain such as the length and direction of the slope and the hydrological behavior such as the variability of rainfall intensity expressed in the dry and humid season.

5. Conclusion

This work is a first contribution in vulnerability to water erosion of Beni Amrane Dam catchment area. This could be a first guidance document for a rational use of land in the region and better secure the dam against reservoir siltation.

The Beni Amrane dam catchment is sensitive to water erosion. The combination of biophysical factors (steep slopes, very erodible soft rock, and very permeable soil) makes the basin a vulnerable zone to water erosion. The results of the study of susceptibility to erosion reveal that 41% of the catchment area is of high to very high erosion susceptibility. The main consequence of this will be the siltation of the Béni Amrane dam, which is an inevitable phenomenon, but which can be reduced through implementation of appropriate technical and biological measures within the basin. We recommend the following means of control: Reforestation, restoration of soils, establishment of benches, creation of small dams (hill reservoirs), planting of crops along the level lines, planting of long-stemmed vegetation in the wadis.

For the silting of dams, several devices have been taken into consideration to combat this phenomenon (methods of hunting, drawing by current density and dredging).

Improvement of pastures: Soils can be protected against erosion only by maintaining the plantations on the slope and shed, at least during the first years, with the aim of ensuring the success of plantations and to achieve a density and even decrease the solid flow. Since breeding is the main resource for the local residents, it is essential to improve the pastures while taking care to avoid overgrazing.

For shoreline protection, the biological fixation method is the most effective, but technical measures (mechanical procedures) are essential in order to reduce the velocity of runoff.

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