Eco. Env. & Cons. 27 (November Suppl. Issue) : 2021; pp. (S339-S350)
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ISSN 0971–765X

Evaluation of water erosion by mapping and application of the PAP/RAC method in the Prerif of Ouazzane

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(Received 10 April, 2021; Accepted 15 June, 2021)

ABSTRACT

This work is interested in mapping the areas vulnerable to water erosion by the method PAP/ RAC (Priority Activity Programs / Regional Activity Center) and Geographic Information Systems (GIS) at the level of the watershed of Oued Joumouaa, located in the Western Prérif. The synthetic map of the predictive phase shows the distribution of erosive states, with 36.21% of the basin area subject to high to extreme erosion. The descriptive phase provides information on the distribution of the different forms of erosion and shows the dominance of sheet erosion which occupies 76.6% of the total area of the basin. The third phase of PAP/ RAC is the superposition of the results of the predictive and descriptive phases gives the consolidated map which is characterized by strong soil alterations in relation with medium deep gullies located in the middle part of the watershed. These forms may be due to the absence of vegetation cover, the steep slope and the aggressiveness of rainfall.

***Key words**: GIS, PAP/RAC, Water erosion, Watershed, Western prerif.*

Introduction

The risk of erosion is one of the greatest environmental problems affecting the whole world. The Mediterranean countries with a semi-arid climate are not immune to this environmental problem, especially Morocco, where more than 40% of the land is threatened by the risk of water erosion and the situation continues to deteriorate (FAO, 1990). The magnitude of the phenomenon is more important in the Rif and Prérif hills which cover only 6% of the Moroccan territory, but which produce more than 60% of sediments (Benzougagh, 2019). According to the High Commission of Water and Forest and the fight against desertification water erosion affects more than 23 million ha. This situation is related to climate change on a global scale. It is favored by several factors, lithological (fragility of land), climatic (high intensity of rainfall), geomorphological (declination, slopes), hydrological (dense and branched network), pedological (clay soils) and anthropic (deforestation, cultivation technique, construction of engineering structures, ...), plant cover, and socio-economic, are all favorable to the acceleration of the process of erosion (Benzougagh, 2019). The damage caused by erosion is numerous: (degradation of infrastructure); (flooding, reduction of soil fertility and productivity), (reduction of water storage capacity in dams and siltation of dams) On the social level, soil degradation accentuates the level of poverty and consequently the immigration of populations to cities. From an economic point of view,

agriculture is affected by the decrease in productivity of cultivated land, and road and water infrastructures (dams) are not immune to this risk: they are mostly destroyed. Faced with this situation, the sustainable management of natural resources is recommended. Several methods are used for a better knowledge of the erosion phenomenon, in particular: morphometric analysis, the Universal Soil Loss Equation (USLE), and its revised version (Revised Universal Soil Loss Equation = RUSLE), PAP/CAR, (1998) ... etc. For this study, we are interested in the PAP/CAR method of which several previous studies carried out on several watersheds show their importance for the mapping of quantitative erosion and the modeling of the factors responsible for the genesis of this risk; among these studies, those of: Aboulabbass *et al.*, 2005; Mesrar *et al.*, 2015; Boukrim *et al.*, 2016.

The objective of the present study is the mapping of areas vulnerable to water erosion based on the guidelines of the PAP/CAR model which focuses on the integration of natural factors influencing water erosion, to namely: erodibility, slope, soil type, lithology and vegetation cover. The achievement of this objective calls for the combination of the guidelines of the PAP/RAC approach and the techniques of spatial remote sensing, Geographic Information Systems (GIS) in the watershed of oued Joumouaa (59Km²). The goal is to develop a thematic map of priority areas of erosion risk to help decision makers choose the preventive measures needed to reduce the impact of erosion risk on the population, their property and the environment.

Characteristics of the study area

The Oued Joumouaa watershed is a sub-basin of the Oued Ouergha, located in the southern part of the Rif. It covers an area of about 59 Km² and a perimeter of 60 Km. It is limited to the north by Zoumi; to the south by oued Ouergha; to the east by oued Drader and to the west by Tafrant ouergha.

It is part of the province of Ouezzane and includes several rural municipalities: Zoumi, Teroual, Ounnana, Zghira, and Lamjaara (Fig. 1).

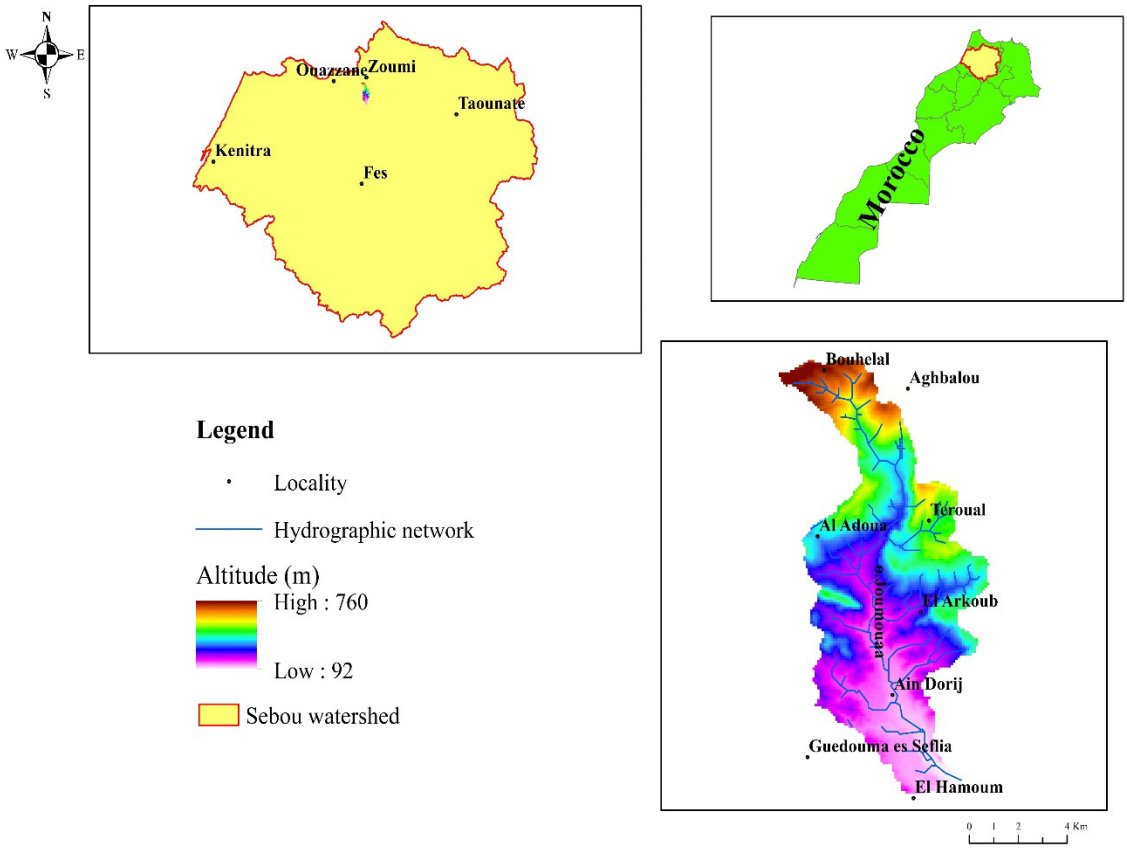

Fig. 1. Situation of the oued Joumouaa watershed.

The study area has an elongated shape from northeast to southwest is characterized by a very significant difference in altitude ranging from 92 m to 760 m and by a relief with a strong hilly component that promotes the genesis of the risk of water erosion.

From a lithological point of view, the oued Joumouaa watershed is characterized by the presence of Zoumi sandstone formations in the north of the watershed. The presence of silts, calcareous marls and saliferous red limestones is not negligible. (Geological map 1/50000 of Teroual).

The dominant climate in the study area is Mediterranean characterized by cool, wet winters and dry, hot summers. It is marked by irregular rainfall in space and time.

Methodological Approach and Materials Used

The PAP/RAC approach (1998) aims immediately to make available a methodological tool and a source of information for the implementation of projects and programs for the management of erosion control and in the long term, to contribute to mitigate and better control the processes of erosion to improve land use, rationalize the exploitation of land resources and improve the living conditions and food security of populations.

The PAP/RAC is a qualitative method of water erosion that allows to prioritize the surface of the watershed into distinct units according to the vulnerability to erosion and to determine the most fragile areas.

It consists of three phases (Fig.2): a predictive phase consisting of a mapping of the factors influencing water erosion such as: lithology, slope, land use and vegetation cover. A descriptive phase based on the mapping of actual erosion, it consists in identifying, describing and evaluating the current erosion processes in the study area, as well as the different degrees of exposure to degradation. And an integration phase completes the results obtained during the predictive phase with the descriptive data of the erosion processes. The purpose of this step is to produce the final thematic map which leads to the identification and evaluation of the erosion risk.

The qualitative model adopted for the mapping of soil sensitivity to water erosion in the Joumouaa basin is based on the exploitation of data related to topography, geology, vegetation cover and field observations.

The Landsat 8 and Google Earth satellite images,

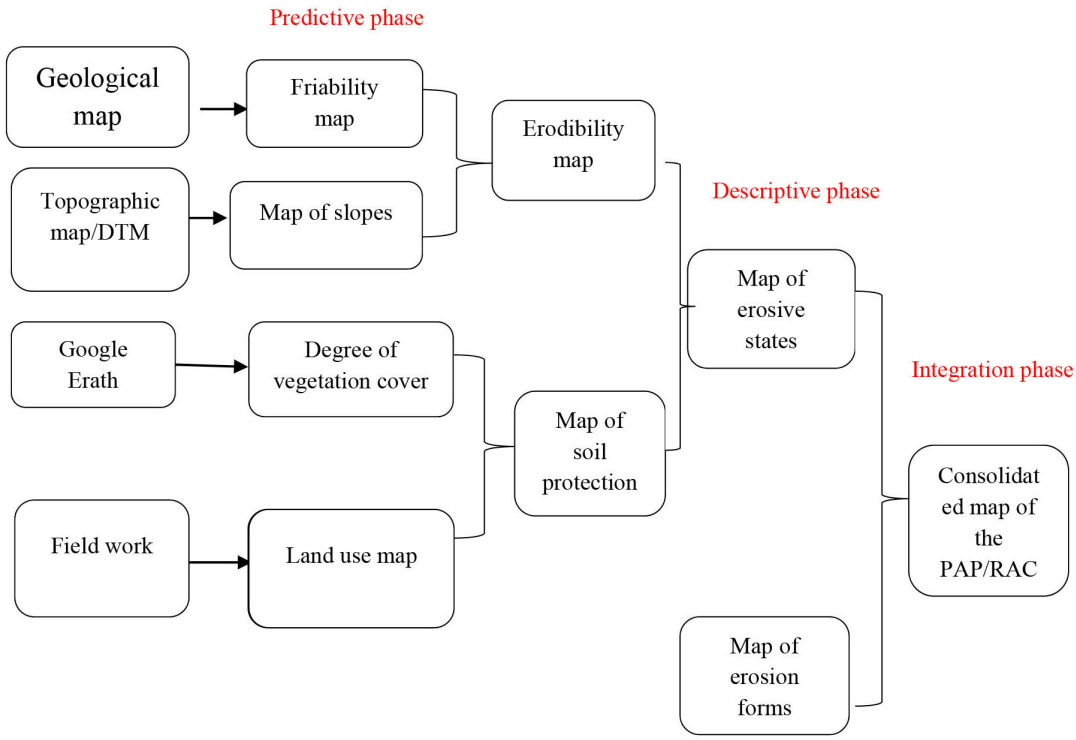

Fig. 2. Methodology adopted for the erosion mapping of the oued Joumouaa watershed.

the digital terrain model (DTM) type ASTER GDEM of 30 m resolution, topographic and geological maps of the study area (Teroual-Oulad aissa at 1:50,000), and field observations, have enabled the delineation of the study area and the realization of various thematic maps, using the features of software dedicated to remote sensing and Geographic Information System (GIS). These data was georeferenced to the Morocco coordinate system.

Results and Discussion

The predictive phase

The predictive phase consists in identifying, evaluating and integrating all the fundamental parameters, such as physiography (slopes), lithology and/or soils, vegetation cover, in order to determine preliminary hypotheses concerning the risk of erosion.

Slope map

Slope is one of the relevant factors for assessing soil susceptibility to erosion (Benzougagh *et al.*, 2017). The steepness of the slope exponentially favors the speed of runoff and consequently the uprooting and movement of soil particles (Ben Rhouma *et al.*, 2018). The development of the slope map was derived from the Digital Terrain Model (DTM) of ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model) images with a resolution of 30 m. This map was divided into five classes according to PAP/CAR guidelines (Table 1).

The interpretation of the map of slopes of the watershed of oued Joumouaa (Fig. 3), shows that the degree of slopes is generally high in the north and low in the downstream part, while the middle part of the basin has high degrees from east to west. The analysis of the slope map database also shows that the class <3% (low) and 3% to 12% (moderate) occupy 8.63% and 33% of the total area of the basin

Table 1. The classes of risk related to the value of slope of the watershed of oued Joumouaa

Slopes classes	Slope values in%	Degree of risk
01	0-3 %	Null to low
02	3-12%	Moderate
03	12-20%	Abrupt
04	20-35%	Very abrupt
05	>35%	Extreme

respectively (5.1 km²) and (19.25 km²). While the class 12% to 20% (abrupt) is predominant, it occupies 36% of the total area of the watershed, or (21.19 km²). Finally, the classes 20% to 35% (very abrupt) and > 35% (extreme) present respectively 18.25% and 4.19% of the study area, that is to say respectively a surface of (10.78 km²) and (2.47 km²). These last two classes present 22.44% of soils above 20%. Indeed, this steep slope favors the genesis of the risk of water erosion in the territory either under the action of precipitation or on the strong flow of surface water.

From figure 3, we can see that the most representative classes are respectively the moderate class with 33% and the abrupt class with 36% of the watershed surface.

Litho-facies map

The litho-facies analysis was performed using a variety of data, including geological, lithological, and pedological information. The PAP / CAR guidelines provide a classification of soil types where each type is associated with a number that describes

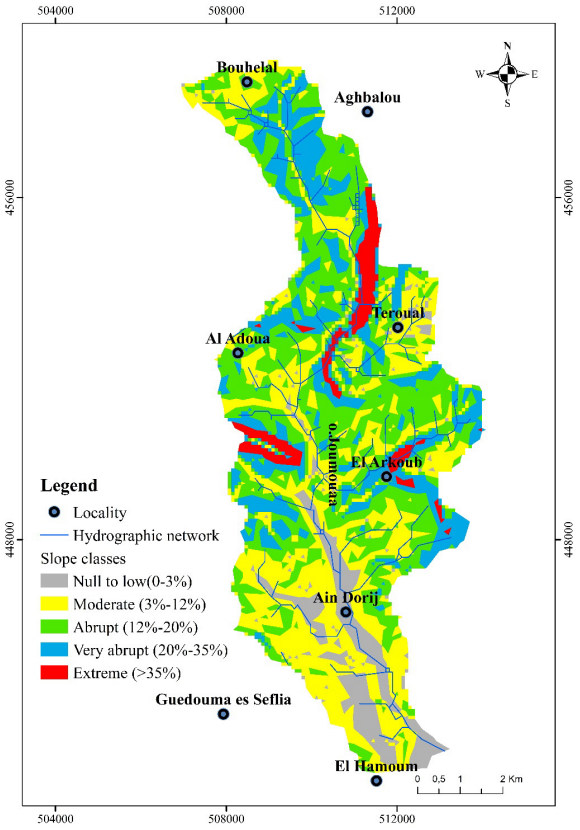

Fig. 3. Map of the slopes of the Oued Joumouaa watershed

the strength, cohesion and constitution of the soil. The litho-facies map constitutes the main substrates of the study area. These are grouped into 5 classes to arrive at the friability map. Table 2 details how the soils were classified according to their types.

The litho-facies map (Fig. 4) shows that the watershed of oued Joumouaa is dominated by the marl component. Thus, we find the sandstone of Zoumi in the North with alternating saliferous clays, in the West it is calcareous marl and in the East pink silt and pebbles.

Friability map

The friability classes are developed from the litho-facies map (Fig. 4) and the degree of soil cohesion (Table 2). The analysis of Figure 4 shows the predominance of class 5 (very high susceptibility to erosion) which represents loose non-cohesive soils and detrital material, includes pink silts, marls with sandy beds and red clays, occupies most of the basin with 53.43% or (31.81 km²) of area. This class is located in the middle and downstream area of the watershed of oued Joumouaa. The class 1 of low sensitivity to erosion corresponding to the sandstone Zoumi, represents 9.78%, or (5.82 km ²) of the total area. The class 2 formed by cohesive rocks fractured or moderately altered (limestone marl) occupies 0.96% or (0.57km ²) of the study area. The class 3 of medium sensitivity to erosion includes rocks or sedimentary soils weakly or moderately compacted (marly limestones, silts and pelites), occupies 33.96% (20.22 km ²) of the study area. Class 4, which is highly sensitive to erosion, is made up of formations that are not very resistant or strongly altered (marl and bariolated rocks), and covers 1.87% (1.11 km²) of the entire basin (Fig. 05).

Erodibility map

Soil erodibility expresses the soil's potential to resist water erosion (Morgan, 2005), based on its compo-

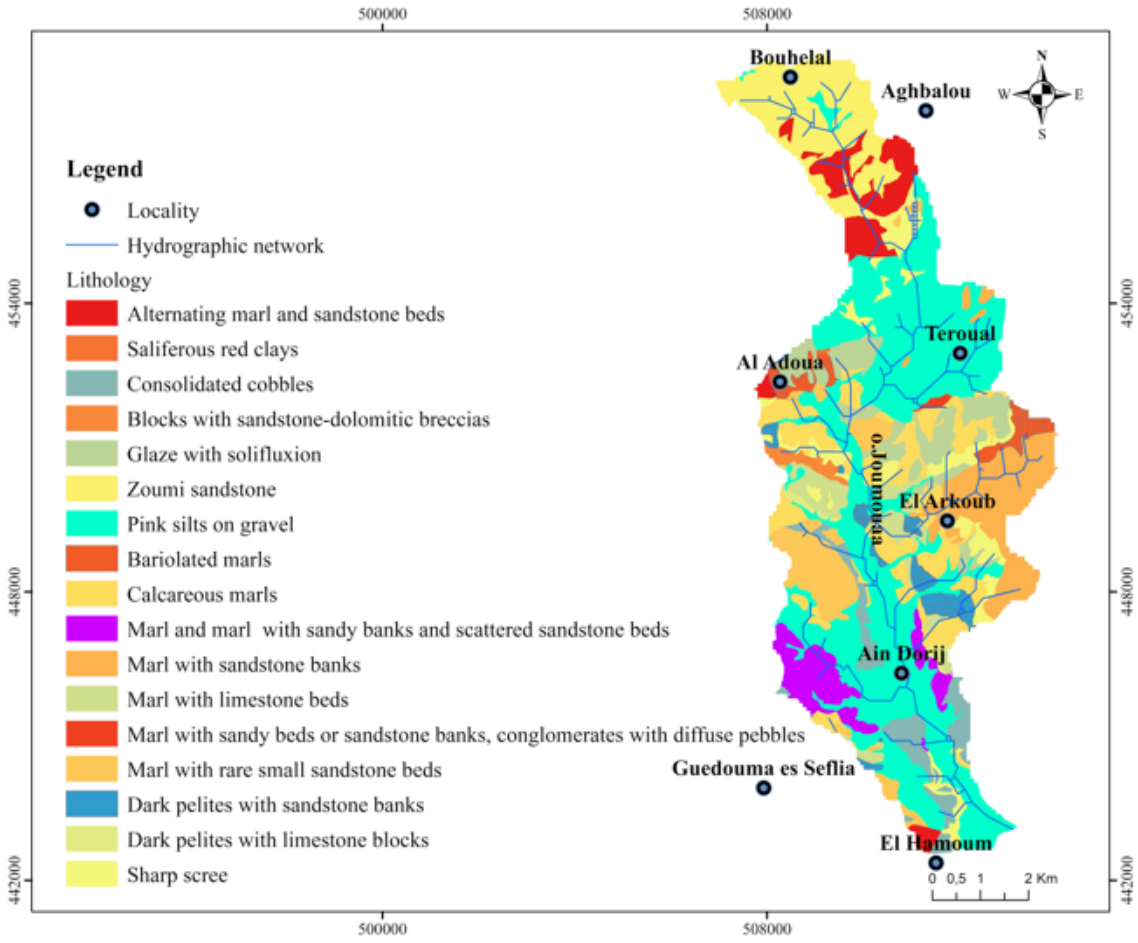

Fig. 4. Litho-facies map of the Oued Joumouaa watershed (Geological map of Teroual-Oulad Aissa 1/50000)

sition, structure and texture (Khallef *et al.*, 2020). Thus, erodibility takes into account the friability of the soil and the steepness of the slope. According to the guidelines of the PAP/CAR model, the erodibility map was obtained from the superposition of the slope map and the friability map (resistance of materials to erosion). Finally, five erodibility classes were distinguished: low, moderate, medium, high and extreme (Fig. 6).

The analysis of the erodibility map (Fig. 6) shows that the extreme erodibility class covers 11.50% of the total watershed area. This class is located in the middle part of the basin. It occurs when the slope is high and the soil is loose and more altered.

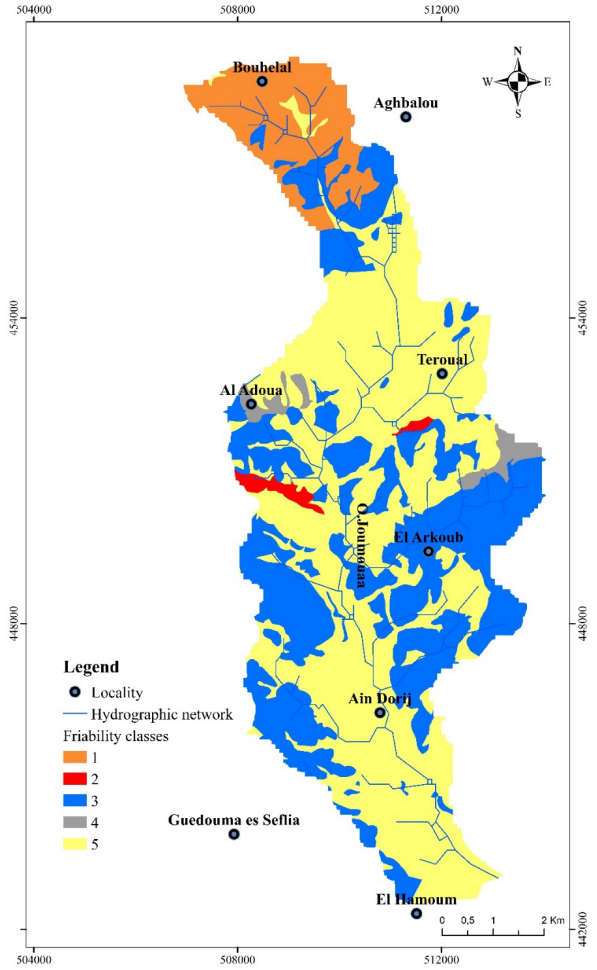

Fig. 5. Map of friability of the watershed of oued Joumoua.

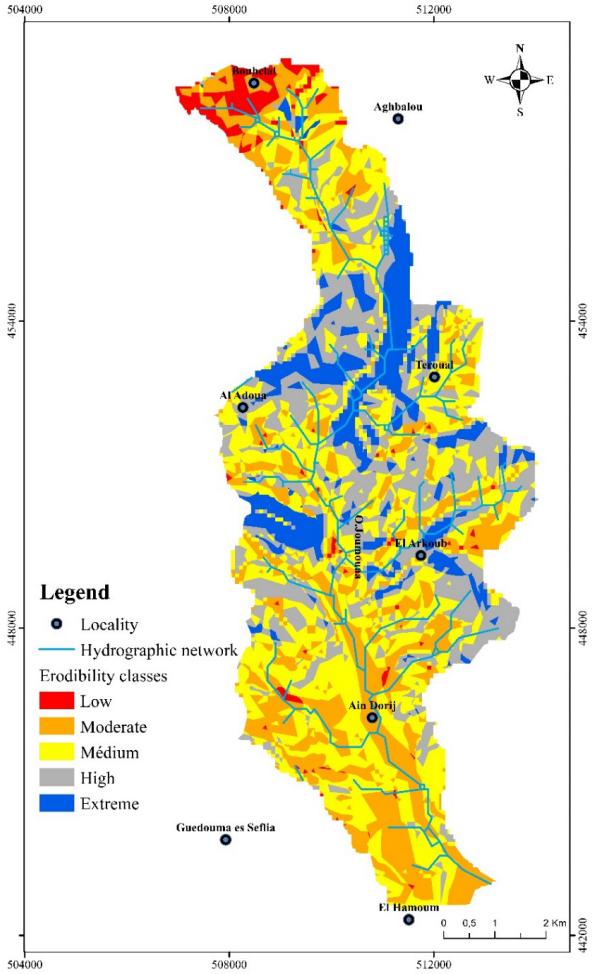

Fig. 6. Erodibility map of the Oued Joumouaa watershed.

Table 2. Classification of litho-facies according to PAP / CAR guidelines.

Class of litho-facies	Degree of soil cohesion
1	Unweathered compacted soils, strongly cemented conglomerates, crusts, outcrops of ferruginous sandstones (massive limestones, strongly rocky soil, igneous or eruptive rocks, locally encrusted soils).
2	Fractured or moderately weathered cohesive rocks or soils
3	Low to moderately compacted sedimentary rocks or soils (slate, shale, marl, etc.).
4	Rocks and/or soils that are not very resistant or that have been strongly/deeply altered (marl, gypsum, clayey slate, etc.).
5	Loose, non-cohesive sediments or soils and detrital material.

The moderate to medium erodibility class represents almost 60.84% of the total area of the watershed. However, the land of strong to extreme erodibility occupies an area of 36.21%. Low erodibility soils cover only 2.92% of the basin area.

The erodibility classes show that the study area is generally dominated by medium erodibility along the basin which can be explained by the presence of fractured or moderately weathered cohesive sedimentary soils. The irregular topography of the Joumouaa watershed favors soil instability and consequently the loss of organic matter and nutrients as well as the deterioration of the soil structure.

Vegetation cover map

The vegetation cover plays an important role in soil stabilization because it allows the conservation of soil and water regardless of the slope, climate and soil (Khallef *et al.*, 2020). The cover density map (Fig. 7) was made based on the NDVI (Normalized Difference Vegetation Index) and by translating each NDVI interval by a class of density of vegetation cover by regenerating it on a GIS software. The result is a mapping of the watershed of the o. Joumouaa watershed in polygons according to the density of cover. This index was calculated from the Landsat 8 satellite image taken on 29/06/2018.It shows four classes of NDVI value. Indeed, the highest values that tend towards (0.43-0.52) correspond to the areas of arboriculture or the vegetation is very dense. The high values (0.33-0.43) represent dense vegetation, the medium density vegetation is represented by values between (0.14-0.23) and the low values (0.04-0.14) correspond to cultivated land.

The application of PAP/CAR model guidelines classifies the vegetation cover levels into four classes (Table 3).

Table 3. Classification of vegetation cover level according to PAP/CAR.

Classes	Degree of vegetation cover	% de degré de couverture végétale
01	< 25 %	58.35 %
02	[25 % – 50 %]	
03	[50 % – 75 %]	30.35 %
04	> 75 %	11.31 %

The distribution of classes within the watershed of the O. Joumouaa shows that the low densities (<25% and [25%-50%]) are presented in the whole basin and cover an area of 34.5 km² or (58.35%) of the total area of the basin. The density class 50%-75% (dense vegetation) covers 30.35% of the basin with an area of about (18 km²), while the class of very dense vegetation (greater than 75%) occupies only 11.31% and covers an area of about (6.68 km²). We can conclude that the majority of the watershed of the o. Joumouaa is covered by low to medium density vegetation. While the very low-density vegetation represents 21.5% or (12.7 Km²) of the total area of the watershed (Fig.7).

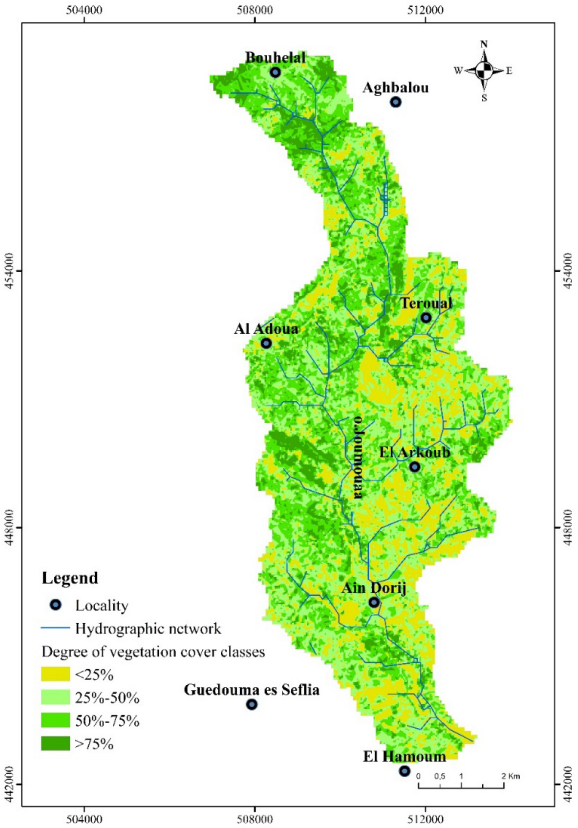

Fig. 7. Map of the degree of vegetation cover in the Oued Joumouaa watershed
(From Landsat 8 of 29/06/2018).

Land use map

The land use map was obtained from the Landsat 8 satellite image taken on 06/29/2018. The classification of land use classified into attributes based on the nature of the polygons is based on the guidelines of the PAP/CAR. At the end of this study, the land use of the watershed of the O. Joumouaa was divided into four classes: Intensive cultivation, Arboriculture, Dense reforestation and urbanized

area (Fig 8).

The analysis of the land use map of the O. Joumouaa basin shows a dominance of the land use in the area. Joumouaa basin shows a dominance of the arboriculture class (row crop) which covers 41.3% of the basin or (24.45 km²) of the total surface. The upstream part is occupied by arboriculture, particularly olive trees (in rows). The dry cultivation (herbaceous) is essentially located all along the basin and covers 19.88% or (11.94 km²) of the territory. The agricultural land (dense reforestation) is spread over an area of 20.59% or (12.16 km²) followed by an urbanized area that extends over an area of 10.70 km² or (18.12%) of the study area. The downstream part is dominated by reforestation and cultivation on a strongly eroded land. From this distribution of the watershed, we can say that the upstream and middle part of the watershed is protected against water erosion. In order to verify this conclusion, we superposed the map of the density of cover and that of the occupation of the soils to obtain the map of protection of the soils.

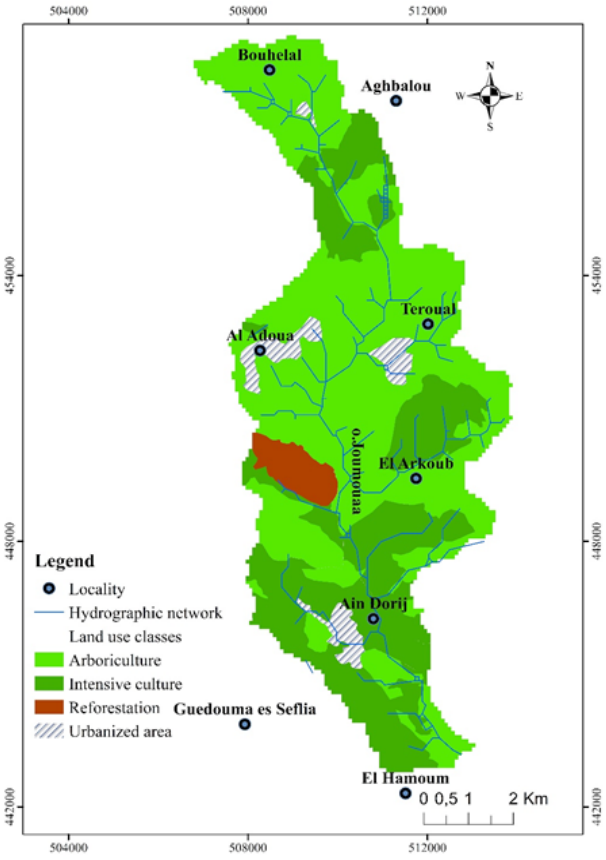

Fig. 8. Land use map of the Oued Joumouaa watershed (from Landsat 8 of 29/06/2018)

Soil protection map

Soil is protected by vegetation cover. The latter can combat runoff and ablation by reducing the energy of aggressive substances (such as the energy of raindrops and runoff), but this effect can vary depending on the plant formation. The degree of soil protection is a function of the type of land use and the density of vegetation cover in the watershed (Khallef *et al.*, 2020). The realization of the soil protection map was based on the superposition of the land use map and the vegetation cover map (Fig. 9). The objective of this map is to detect areas with low and high protection.

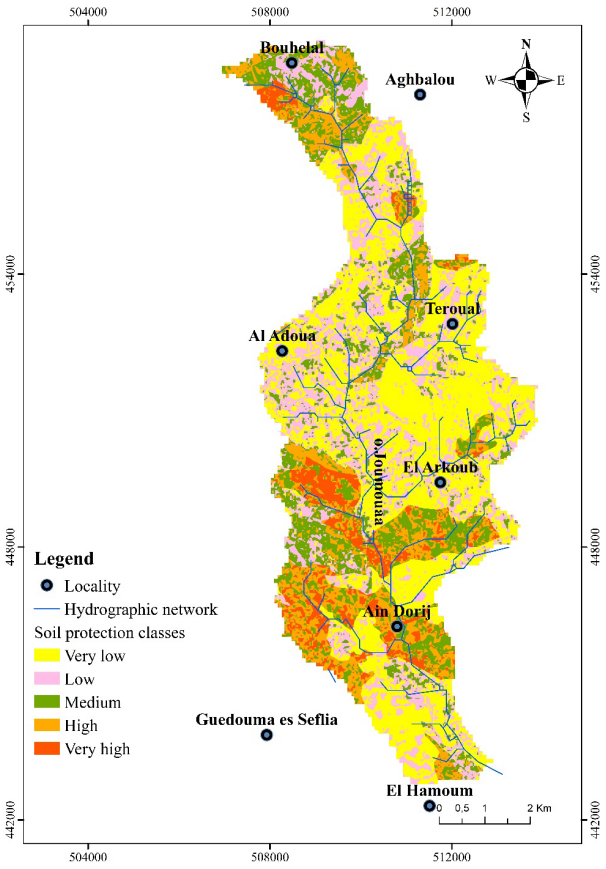

Fig. 9. Soil protection map in the Oued Joumouaa watershed.

According to the guidelines of the PAP/RAC model five levels of protection were defined (Table 4). However, in order to better simulate the soil erosion process in the O. Joumouaa, an additional class of soil protection level was added: class (0) refers to the protection level in highly impervious areas due to urbanization processes resulting from socio-eco-

Table 4. Soil protection classes and levels according to PAP/CAR

Classes	Levels of soil protection
01	Very high
02	High
03	Médium
04	Low
05	Very low

nomic development (Kone, 2017).

According to the analysis of soil protection map we can say that the distribution of very low protection classes (5.82%) or (3.2km²) is located in the middle part especially in the East. Due to the fact that it is a decrease in vegetation cover. The class of low protection is the most dominant, it represents 24% or (13.22km²) of the surface of the watershed, it is distributed along the entire basin. This is explained by the very degraded vegetation cover and also by overgrazing. On the other hand, the medium class of soil protection is spread over an area of about 9.64 Km², or (17.5%) of the surface of the basin of the O. Joumouaa, these lands are located in the upstream and downstream part of the basin. The high and very high class of soil protection represents respectively 13.47% and 5.82%, the latter class is similar to the class of very low protection, it is located in the downstream part of the basin. This is due to the presence of forests that protect the soil. We note that the watershed of the O. Joumouaa is badly protected.

The distribution of soil protection classes from low to medium protection areas are found along the basin. The area shows low to medium protection with percentages ranging from 24% to 17.5%. The areas of very low and very high protection are less represented and occupy only 11.64% of the total area of the basin.

These data show that the basin has a poor protection which allows to say that this area has a more uneven topography which favors water erosion and land movements.

Descriptive phase

This phase gives a real picture of the different forms of erosion existing in the study area as well as their degree of exposure to degradation. It is based on Google Earth satellite images. A GIS software was used to establish a spatial distribution of the real erosion forms.

Map of erosive state

The erosive state map was made by overlaying the vegetation cover map and the soil protection map (Fig.10). According to the matrix of erosive states of soils of the PAP/CAR model (Table 5), five classes of degrees of erosive states were defined (Table 6).

Table 5. The degree matrix of soil erosive states according to the PAP/CAR model.

Degrees of soil protection	Degrees of erodibility				
	1	2	3	4	5
1	1	1	1	2	2
2	1	1	2	3	4
3	1	2	3	4	4
4	2	3	3	5	5
5	2	3	4	5	5

Table 6. The different classes of erosive states according to the PAP/CAR model.

Classes	Degrees of erosive states
1	Very low
2	Low
3	Medium
4	High
5	Very high

The analysis of the map of erosive states (Fig. 10) shows that the most eroded areas are mainly located in the middle part and in some places in the downstream part of the watershed. The distribution of areas on the map of erosive conditions shows that the classes with high and very high erosion risk occupy the majority of the basin 47.88% or an area of (26.45 km2) mainly in its middle part. These areas are characterized by high to medium slopes, low vegetation cover (less than 25%) and high to extreme erodibility. The classes of very low to low erosive degrees are concentrated in the upstream part and in the southwest of the basin, they occupy small areas (21.7%). This distribution is due to the presence of dense vegetation cover on the one hand and the low friability of the formations on the other. The notable class presents 30.4% of the studied area. It is scattered and located along the basin. This can be explained by the relatively soft sedimentary outcrops which leads to their erosion.

The distribution of the degrees of the erosive states shows that the classes with notable, high and very high erosion risk occupy the majority of the

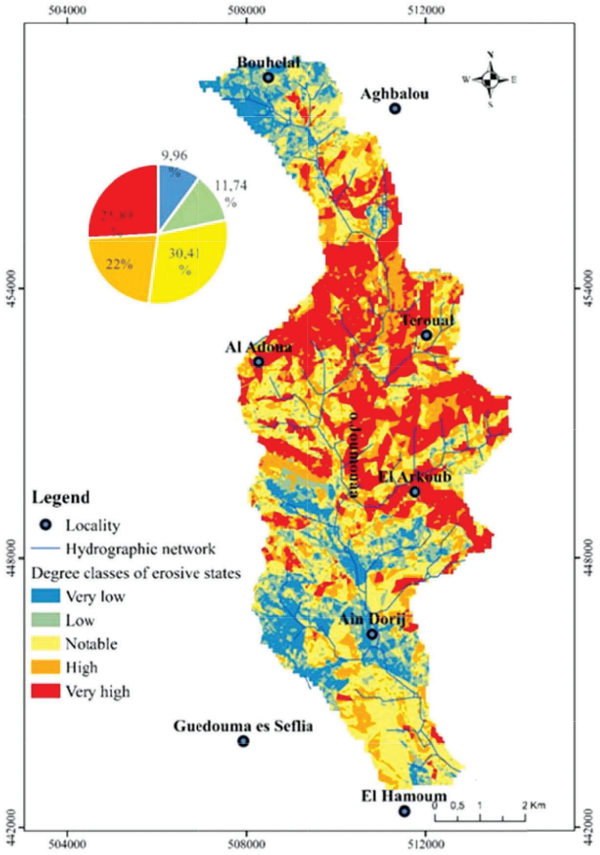

Fig. 10. Map of the erosive state of the Oued Joumouaa watershed.

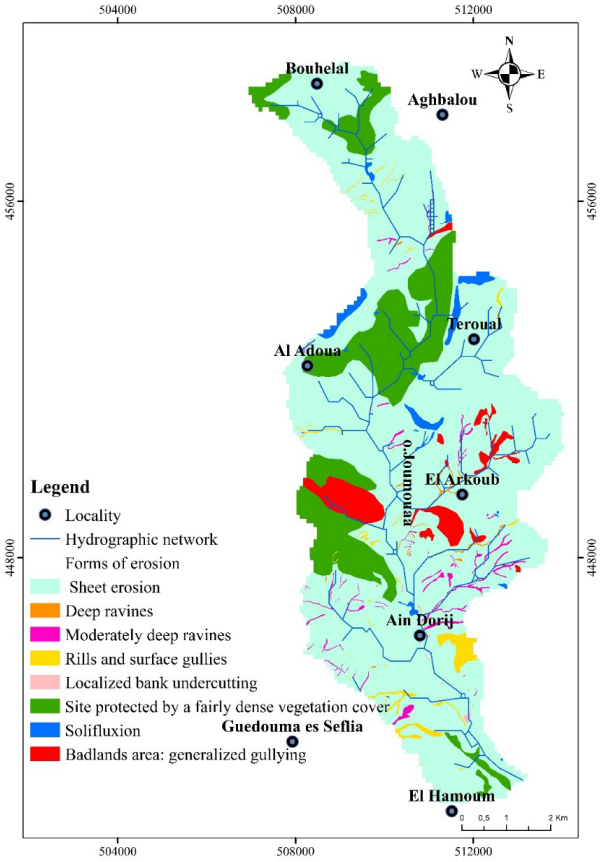

Fig. 11. Map of erosion forms in the Oued Joumouaa watershed.

territory 78,3% that is to say a surface of (43,26 km²) and the classes of very low to low erosion occupy only 21,7% of the total surface of the basin (that is to say 11,99 km²).

Map of erosion forms

The map of erosion forms (Fig. 11) shows the different forms of erosion: sheet erosion, gully erosion and gully erosion. Most often we find associations of different types of erosion on the same area.

The analysis of this map also shows that scouring and diffuse runoff or sheet erosion occupy an area of 46.51 km² or (76.61%) of the total area of the study area. The sites protected by the dense vegetation cover reaches the second place with an area of 9.5 km² or (15.64%) of the watershed. The presence of these two forms of erosion can be explained by the vulnerability of the terrain, the action of watercourses and by anthropic action. These same forms of erosion have been identified in the watershed of oued Aoudour in the central Rif (Boukrim *et al.*, 2016). Other forms such as medium deep gullies, Bad-lands, generalized gullying, gullies and superficial gullies on the slopes, solifluction, deep gullies, localized bank undercutting are very little represented in the watershed of the O. Joumouaa watershed and occupy an area of 4.67 km ie (7.71%) of the total area of the watershed (Fig.11).

Integration phase

This step is the result of the two previous phases, it allows to complete the results obtained in the predictive phase with the second descriptive phase. This product provides us with a very precise cartographic assessment that gives a real picture of the state of soil degradation and the different aspects of erosion.

The consolidated map (Fig.12) obtained in this approach is a qualitative map that is made from the superposition of the map of erosion forms (Fig.11) and the map of erosive states (Fig.10). The map shows that the forms of sheet erosion, diffuse runoff

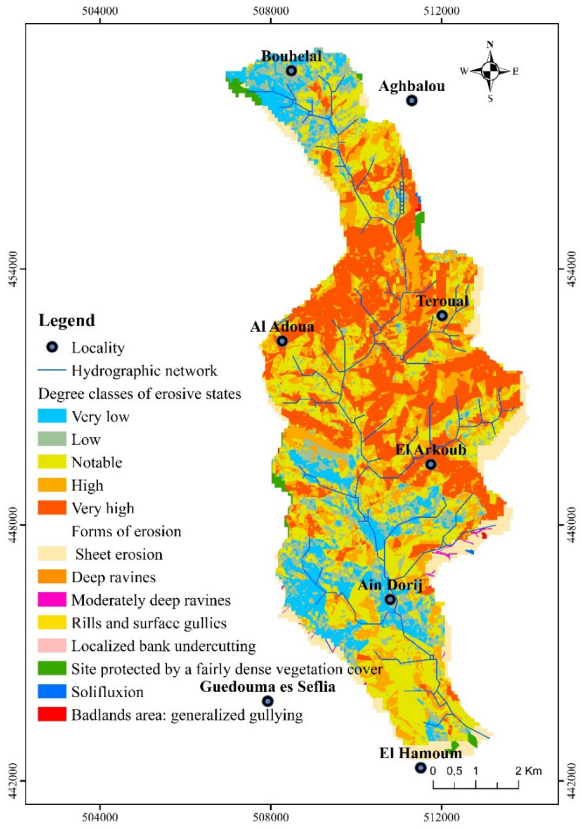

Fig. 12. Consolidated map of water erosion risk in the O. Joumouaa watershed.

occupying the majority of the basin and coincide with the areas undergoing a low to very low degree of water erosion in the study area. It can be seen that the middle part is characterized by different forms of water erosion such as Badlands, medium deep gullies, solifluction, which coincide with areas that suffer a high to very high degree of water erosion. This is explained by the fragility of the marl and marl-clay soils and by the absence of vegetation cover.

Conclusion

This study has shown the interest and contribution of the Geographic Information System and remote sensing to the mapping of water erosion based on a multi-source database.

The basin of oued Joumouaa is characterized by a Mediterranean climate with two well contrasted seasons, one hot and dry and the other cool and wet. The average annual precipitation is everywhere irregular and favors erosion in the whole watershed.

The PAP/CAR method has been used to assess and map water erosion based on natural factors. The importance of this method is verified in the realization of a general report of the risk of water erosion in the

The importance of this method is verified in the realization of a general report of the risk of water erosion in the watershed of the oued Joumouaa from three phases:

- First The descriptive phase (lithology, slope, vegetation cover and land use) which is characterized by the presence of various forms of erosion (laminar and linear with the predominance of sheet erosion ...);
- The predictive phase gave indications on the current state of soil degradation based on the degrees of severity of the different factors controlling water erosion (60% moderate erodibility, 36% strong to extreme erodibility and only 3% weak erodibility);
- The integration or superposition phase of the two previous ones (predictive and descriptive) shows that sheet forms are found in areas where the degree of erosion is very high. The areas protected by a stable vegetation cover correspond to the areas where the degree of erosion is low.

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