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Mapping of soil erosion using the PAP / RAC directive in the Seklafa catchment, Djebel Amour region (Saharan Atlas - Algeria)

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ABSTRACT/RESUME

Abstract: *The Seklafa catchment, with an area of 787 km², which is part of the Jebel Amour region (Algeria), is characterized by a spatio-temporal irregularity of the rains, a gap fairly high thermal, a deteriorated marly lithology and weak and unsuitable vegetation cover, which makes it subject to severe erosion in all its forms. It was therefore the subject of an assessment of erosive states and of the various causal factors of the soil risk erosion by the adaptation of crossed matrices on the basis of the PAP / RAC directives. The three constituent approaches (predictive, descriptive and interactive) are analyzed and mapped by GIS and remote sensing. The predictive approach shows that 28.1% of interest region area has high and very high erodibility. The PCA shows a linear and positive correlation with their causal factors such as; the erodibility (r = 0.799), the slope (r = 0.663), the protection of soil (r = 0.487) and the rocks hardness (r = 0.414). This may mean that these variables better explain erosive states. The descriptive approach showed that, sheet erosion and gully erosion are the most apparent processes in the study area, covering 45.2% and 19.7% respectively. The interactive phase highlighted the overall trends in the surface evolution of the watershed. In view of these results, the use of PAP / RAC in a GIS environment has many advantages, notably those linked to the large number of results.*

I. Introduction

Soil erosion, a severe concern worldwide [1], is considered as one of the most serious land degradation problems in Mediterranean regions [2]. It also affects the quality of surface water and/or groundwater [1], reducing the capacity of the dams [3] and decreasing the soil fertility for agricultural activities [4]. Accordingly, the land area damaged by soil erosion is estimated at 1100 million hectares of land worldwide [5] resulting in the transportation of 2.0 to 2.5x10^{10} Mg of soil to the oceans each year [6]. In Algeria, the annual volume of sediment deposited in the 74 dams is estimated at 65 million m^3 [7]. Although soil erosion is characterized as a natural phenomenon; human activities such as agriculture can accelerate it further in Algeria [8]. Thus, 14 million hectares of land in the country are threatened by water erosion [9]. Therefore, Algeria is a country that witnesses an enormous deficit of water (i.e. below the theoretical scarcity threshold set by the World Bank, which is around 1000 m^3 per inhabitant/year) [10]. According to [11], Algeria is qualified in the category of the poorest African countries in terms of water potential. In 1962, the theoretical availability of water/capita/year was 1500 $m^{3;}$ it was only 720 m^3 in 1990, 680 m^3 in 1995, 630 m^3 in 1998, 430 m^3 in 2020. To meet Algeria's urgent water needs, the States has implemented a strategy consisting of creating 94 hydraulic dams for the mobilization of

surface water resources distributed throughout the national territory. The sector expected to build around 139 dams by 2030 [12].
One of these dams is that of Seklafa with a filling capacity of 55 million m^3. As soon as it is put into service, it will be able to supply 12 municipalities with drinking water and irrigate more than 2000 hectares of agricultural land [12]. However, its catchment area, which is part of the Jebel Amour region, is characterized by a spatio-temporal irregularity of the rains, a fairly high thermal difference, a steep slope, a deteriorated marl lithology and a weak and unsuitable vegetation cover, which makes it subject to severe erosion in all its forms. Multi-time remote sensing data and a GIS were used to assess and map the erosive hazard.
Erosion risk mapping is therefore a key tool for watershed management and development and hence for farmland protection against erosion and prevention of dam siltation [8]. In this setting, several physical-based models such as SWAT, WEPP, AGNPS, ANSWER, SHETRAN [13], USLE [14] and revised versions e.g. RUSLE [15] have been developed to estimate soil loss at watershed-scale [16]. These empirical methods are certainly effective but require a significant amount of data, which is sometimes lacking, making their use inconclusive (e.g. bathymetric measurements, gauging stations, etc.). Therefore, finding a simple but relevant qualitative approach is essential in order to identify the areas potentially exposed to erosion problems, which fall under risk forecasting [17].
This study is an attempt to determine the erosive hazard at the watershed-scale of the Seklafa by the FAO method: PAP / RAC (Priority Action Plan / Regional Activity Center).

II. Materials and methods

The PAP/RAC directive was widely used in North African regions ([18]; [19]). However, the climatic particularity of the Saharan Atlas floor represents a share of the originality of this paper. This directive includes two methodological approaches to map the erosive hazard; the predictive approach and that descriptive [18]. It makes it possible to hierarchically treat the surface of a catchment area in units differentiated according to the vulnerability to water erosion and to qualitatively determine the potentially most fragile areas. It is based on a thematic mapping of erosion factors such as, slope, the hardness of the rocks, land use, vegetation density and forms of erosion.

II.1 Description of the study area

The catchment of Seklafa, in central Algerian region, is located in northern latitudes from 33°46'35" to 34°8'15" and eastern longitudes from 1°56'51" to 2°22'26", with altitude ranging from 1001 to 1559 m above mean sea level (fig.1) and an average altitude reaching to 1309 m. It covers an area of 787 km^2. According to [20], the high proportion of land area committed to matorral and pasture in this region represents 73% of the catchment area. The rest are bare soil and rock out crops. A geological study carried out by [21] revealed that the first ejective style anticline with Jurassic materiel oriented N45° to N50° faulted along their axis; second thickness variations and progressive discordance in association to these faults. Those anticlines are the result of successive faults movements, syn-deposit extensive then compressive. The lithological formation consists essentially of dolomites, dolomitic limestone (i.e. represents 81% of the catchment area) [20] and lower and middle Lias limestone which rest on impermeable Triassic terrains, composed of red clays with intercalations of altered doleritic basalts.
Wadi M'zi forms by far, the most important river with its principal affluents: Wadi Zlagh in the northern sector and Wadi El_Ghicha and its secondary stream such as Wadi Loutiowit and Rekik in the southern sector. The analysis of the hydrographic network of the study area shows a fairly dense character, which shows the importance of the activity of the erosive phenomenon.
The climate of the basin is Mediterranean arid, balanced by the occasional presence of a mountain climate. According to analysis of climate data downloaded from https://power.larc.nasa.gov/data-access-viewer/ (uploaded on 2020); the study area is characterized by mild winter temperatures, rarely falling below zero degrees (in January), and summer temperatures reaching 40 °C (in July). Rainfall is naturally rare (296 mm / year); which occurs mainly during the autumn and spring seasons, and comes in the form of short, heavy bursts rainfall.

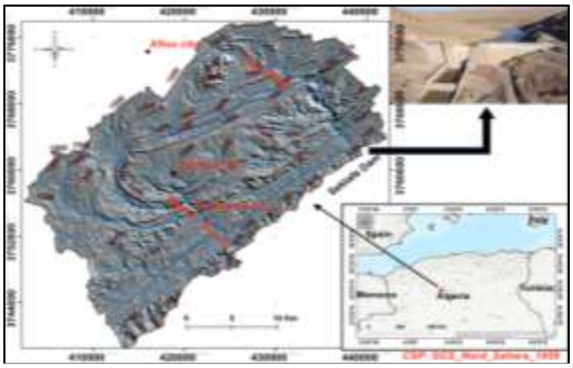

Figure 1. *Study area*

II.2 Data collection and PAP/RAC approaches

To map the erosive risk in the Seklfa watershed using the PAP / RAC method, the integration remote sensing technology (RS), geographic

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information system (GIS) tools, with the principal component analysis (PCA) technique are performed. To do this, several types of data were used:

(i) The images of Shuttle Radar Topography Mission of resolution 30 m from website: https://earthexplorer.usgs.gov/and that from website: https://search.asf.alaska.edu/#/are used.

(ii) A Landsat_8 OLI/TIRS (Operational Land To color) multispectral scene (thermal infrared sensor) (LC08_L1TP_196036_20191019_20191029_01_T1) was acquired. These satellite images are uploaded on 2020 as geotif format, from the following website: https://earthexplorer.usgs.gov/.

(iii) Field observations are effected between September 2018 and April 2020.

(iv) A sheet of the geologic map (J-K 9-10 of Algeria-Laghouat) has been digitized.

(v) Inter-annual precipitation and average temperatures were calculated using daily rainfall data from nine rainfall stations located in and near the Seklafa watershed. Daily weather data for the years 1997 to 2020 was downloaded from NASA's prediction of worldwide energy resources repository (https://power.larc.nasa.gov/data-access-viewer/).

II.2.1 Predictive approach

The predictive approach controls erosion from the thematic mapping of the factors such as: slope, rock hardness, land use and vegetation density. Crossing thematic maps with the data base two by two by the « Overlay » module in the GIS environment made it possible to assess the predictive phase. The overlying of the input data base of soil erodibility map and soil protection map consists in relating them according to the predictive approach matrix (Tab.1).

Table 1. *The PAP / RAC method: the predictive approach matrix [18]*

A: Matrix generating of soil erodibility					
Slop class	Lithofacies class				
	1	2	3	4	5
1	1	1	1	1	2
2	1	1	2	3	3
3	2	2	3	4	4
4	3	3	4	5	5
5	4	4	5	5	5

B: Matrix generating of soil protection				
Land use	Rock hardness			
	1	2	3	4
1	5	5	4	4
2	5	5	4	3
3	3	2	1	1
4	4	3	2	1
5	5	4	3	2
6	5	4	3	2

C: Matrix generating of erosive states					
Degree of protection	Degree of soil 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	4	4
5	2	3	4	5	5

Table 2. *Classification of the input parameters (PAP/RAC of Seklafa catchment)*

Slope	**Tilt**	**Degree**
1	Very Weak	0 - 3
2	Weak	3 – 12
3	Moderate	12 – 20
4	Strong	20 – 35
5	Extreme	> 35
Lithology (according to [22]	**Resistance**	**Rock type**
1	Very strong	Sandy Kimmeridgian, Portlandian Berriasian Limestone bar, oxfordian
2	Strong	Kimmeridgian calcareous-sandstone Sandstone, Basal Kimmeridgian, Kimmeridgian calcareous-sandstone Limestone.
3	Moderate	Kimmeridgian marl-limestone, Kimmeridgian calcareous-sandstone Marls, Valanginian Barremian.
4	Weak	Kimmeridgian terminal in portlandian. Gypsum marls, Tertiare

		continental.
5	Very weak	Recent Quaternary (Soltanian) on 'karstified' dragees, Ancient Quaternary Moulouy Glacis with high terrace.
Land use	**Protection**	**Cover type**
1	Very weak	Pasture and bare soil
3	Moderate	Intensive cultivation near housing
5	Very strong	Clear matorral
Vegetation density	**Protection**	**% density**
1	Weak	Scattered vegetation (< 25%)
2	Moderate	Medium density vegetation (25%-50%)
3	Strong	Dense vegetation (50%-75%)
4	Extreme	Very dense vegetation (>75%)

The result of this step makes it possible to prioritize the study area according to the degree of protection (land use map associated to the vegetation degree map) and the vulnerability of the soil (slope map associated to that of lithofacies) against erosive hazard and to have erosive states map.

The input parameters are classified according to their degree of risk (Tab. 2). The slope's tilt is divided into 5 classes from very weak (0–3) to extreme (> 35) value. This classification takes into account the fact that steep slopes favor a strong runoff. As for the mechanical resistance of rocks, limestones and calcareous sandstones are the most resistant than those of the quaternary formation.

On the one hand, the degree of protection of the soil depends on the type of occupation in question (Pasture, bare soil, intensive cultivation or clear matorral) classified according to the degree of protection and on the other hand on the density. On the other hand, the density of coverage divided into at least four classes dense (25%) to dense (75%). This classification is based on the values of the normalized vegetation index of the study area according to the formula offered by [23]. According to [24], the vegetation density (%) = − 4337 – 3733 x NDVI +161,968 x $NDVI^2$.

II.2.2 Descriptive approach

This approach gives a real image of the different forms of erosion existing in the study area as well as their degree of exposure to degradation. The mapping system used corresponding to the PAP / RAC is a numerical method based on descriptive data of the sites selected on the basis of topography, land use, lithology and drainage density. This data is processed using spatial tools such as thematic maps obtained from satellite images of Google Earth Pro, field observations, the high resolution digital elevation model (DEM) obtained from the website: https: //search.asf.alaska.edu / # /.

II.2.3 The integration phase

The integration approach is the final result of the two previous approaches. According to several studies such as; [24] ; [18], the descriptive approach results from the superposition of the erosive state map and that of the erosion forms obtained by direct descriptive mapping of the erosion forms in the field or by satellite images (fig.2).

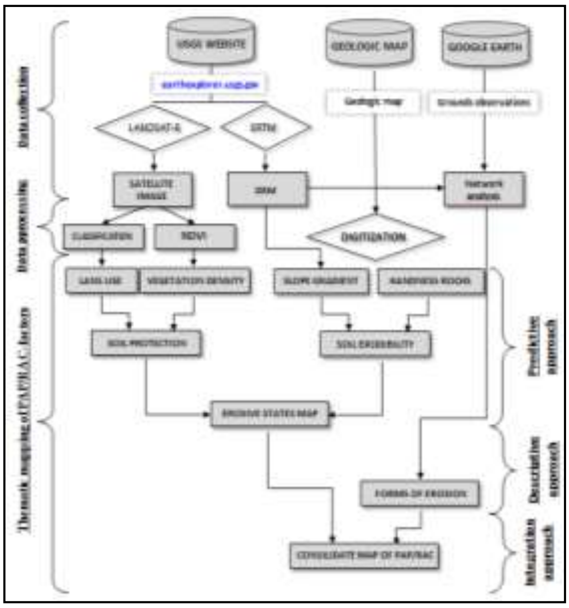

Figure 2. *The methodology followed in this research*

II.3 Statistical analysis (PCA)

To disentangle the complexity and interdependence of factors in the analysis of the risk of erosion, to better understand the impact of each factor and to assess its contribution to soil losses, a multivariate statistical study through PCA (principal component analysis) was used. This analysis of the physiographic and bio-geographical parameters of the watershed was carried out on a data matrix composed of 7 variables (slope, rock hardness, erodibility, vegetation density, soil use, soil protection and PAP / CAR) for 325 observations (i.e. 325 combinations of 7 variables studied). XLSTAT 2014 statistical software was used for data processing.

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III. Results and discussion

After the arrangement of the parameters brought into play in classes according to the PAP / RAC directive the results show that:

III. 1 Predictive approach

III.1.1 Soil erodibility

The properties of bedrock are key parameters for determining the geomorphology of relief's forms [25]. This aspect is generally due to differences in pedogenesis, weathering and ablation depending on the exposure [16]. Additional, other studies have shown a relationship between the lithology of the bedrock and the mechanisms of erosion [26]; [27].

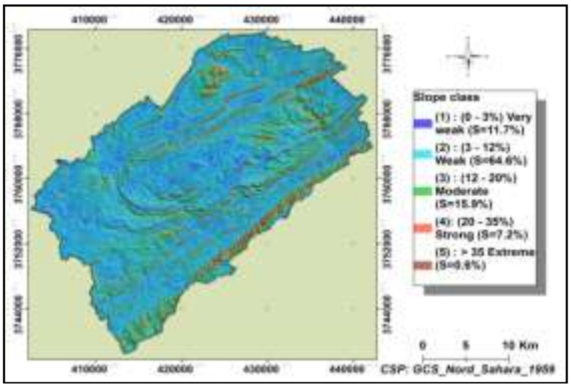

Figure 3. *Slope classes*

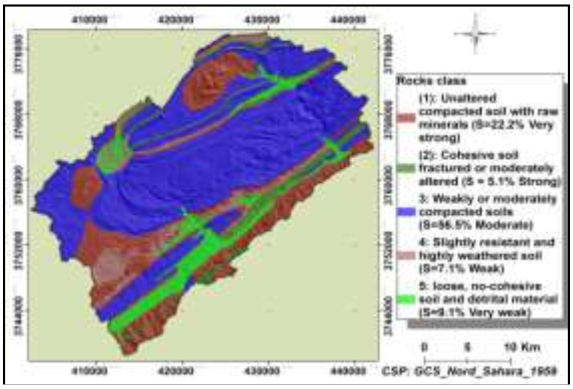

Figure 4. *Rocks classes*

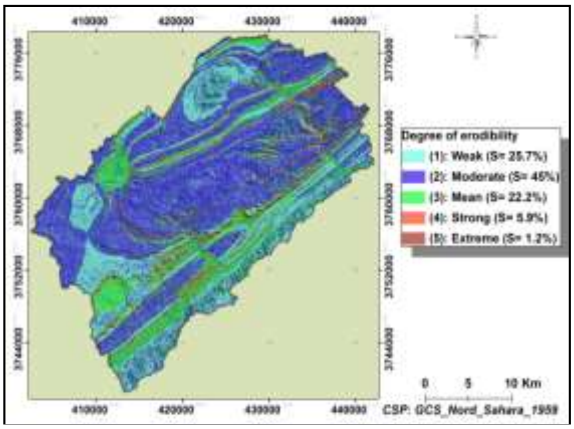

Figure 5. *Degree of erodibility*

According to figure 3, the results indicated that approximately 76.3% of the study area had a slope between 0 and 12%. This slice of slopes coincides with low soil loss values. The 7.7% of the terrain had a high slope characterized by very high erosion risk values. The latter is located in the southern sector and on the rocky rebounds going from southwest to northeast in the central part of catchment area.

The figure 4 shows that the major part of the catchment (56.5%) is characterized by a lithological formation based on Kimmeridgian and Barremian valanginian sandstone. This lithological formation is marked by moderate resistance. The erosive states map shows that the risk of erosion on this formation is weak to notable range (fig.5).

Analysis of the erodibility map (fig. 5) shows that the classes of degree of erodibility from weak to moderate soil occupies 70.7% of the catchment area while the strong to extreme erodibility classes occupies only 7.1% of the surface of basin. The dominance of lands with weak to moderate erodibility is due to the combination of lands with weak slopes (78.3% of the watershed area) and strong resistance of the rocks, which reduce the inertia force of the rains and their accelerations as well as the surface runoff force in general.

III.1.2 Soil protection

One of the most critical factors in reducing soil erosion is the density of vegetation [28]. Indeed, it decreases soil erosion by: protecting the soil against the action of raindrops [29], increasing the degree of water infiltration in the soil [30], reducing the amount of runoff generated [31], maintaining the roughness of the soil surface and improving the physico-chemical and biological properties of the soil [32].

The results mentioned in figure 6 shows that the weak density class occupies 49.3%, so that moderate occupies 47.1%, while the density classes; strong and extreme occupy only 3.6% of the catchment area. In addition, this distribution of vegetation density classes agrees with that of soil protection. We can say that our area study has a weak density of vegetation cover. The themes identified on the land use map (fig.7) are clear matorral, agricultural land (intensive cultivation), pasture and bare land. Analysis of this map shows that this last land use is predominant in terms of area occupying 59.7% of the watershed; intensive crops represent only 0.2%, while clear matorral occupies 40.1% of the study area.

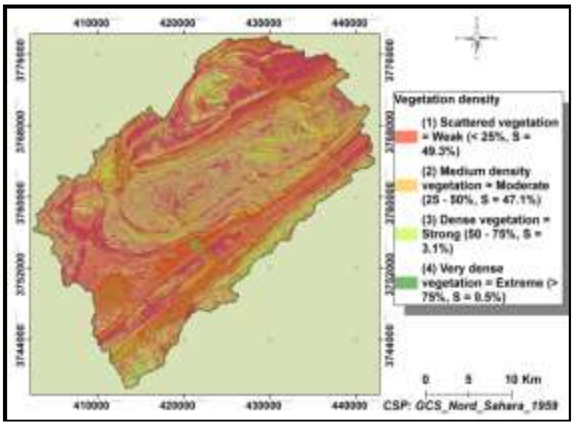

Figure 6. *Vegetation density classes*

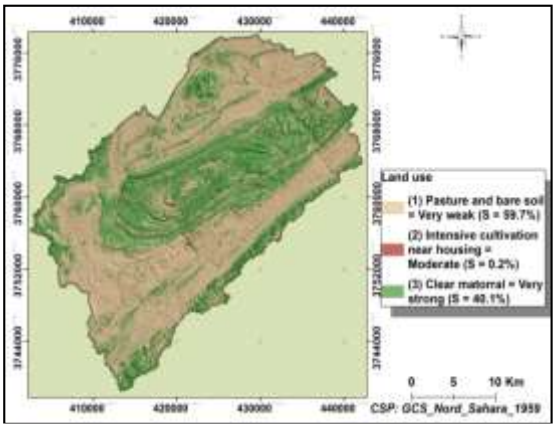

Figure 7. *Land use classes*

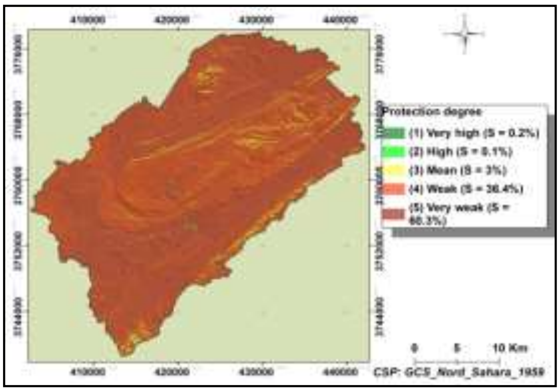

Figure 8. *Protection degree*

The soil protection map (fig.8) made it possible to have five classes of degree soil protection: very high, high, mean, weak and very weak. Analysis of the soil protection map shows that a very weak soil protection class occupies most of the area of the basin (60.3%). This shows that most of the soil is poorly protected against erosion, which can be explained by the amount of pasture associated with bare soil (59.7%) added to clear matorral (40.1%). The classes whose soil protection is considered high to very high only cover 0.3% of the catchment area.

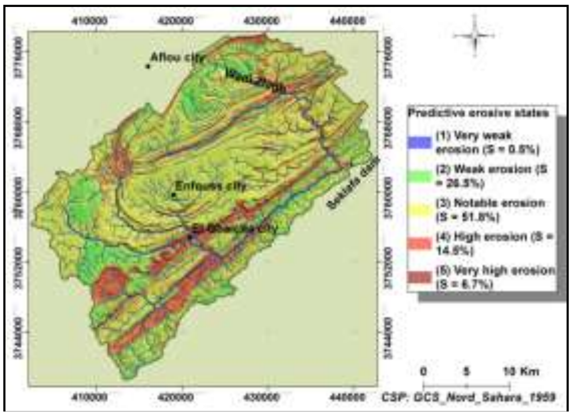

Figure 9. *Predictive erosive states map*

The erosive states map is presented in five classes reflecting different degrees of erosion. These are very weak erosion, weak and notable erosion, high and very high erosion (fig. 9). Analysis of the data on this map shows that the class of very weak and weak erosive risk occupies 27% of the interest region area. Most of the basin (51.8%) is subject to notable erosion, while high-risk to very high-risk areas represent 21.2% of the catchment. These areas at high erosive risk dominate in the south sector corresponding to the friable rock formations of calcareous sandstone and that of the old quaternary Moulouy glacis with high terraces as well as on the steep slopes of the north-west sector and on the marly rebounds successful from south-west to north-east in the central sector of the catchment area.

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III.2 PCA

Table 3. *Matrice de corrélation (Pearson (n))*

Variables	Slope	Rocks	Erodibility	Vegetation density	Land use	Protection	PAP/RAC
Slope	**1**	0.014	**0.822**	0.032	0.038	-0.046	**0.663**
Rocks		**1**	**0.517**	0.028	-0.001	-0.007	**0.414**
Erodibility			**1**	0.052	0.026	-0.058	**0.799**
Vegetation density				**1**	**0.195**	**-0.756**	**-0.341**
Land use					**1**	**-0.184**	-0.022
Protection						**1**	**0.487**
PAP/RAC							**1**

Values in bold are different from 0 at significance level alpha = 0.05

Table 3 shows the correlations between erosive states and causal factors. The variables with statistically significant coefficients with respect to erosive states showing a linear, positive bond are respectively, the erodibility (r = 0.799), the slope (r = 0.663), the protection soil (r = 0.487) and the rocks hardness (r = 0.414). This may indicate that these variables can better explain erosive states.

III.3 The descriptive approach

The descriptive approach to different erosion processes (fig. 10) shows that the catchment includes all forms of erosion covering the study area according to different extension rates. These forms of erosion are generally abundant throughout the basin, however, based on the abundance-dominance approach, we are able to attribute to each geographical area the / or forms of erosion that is occurring.

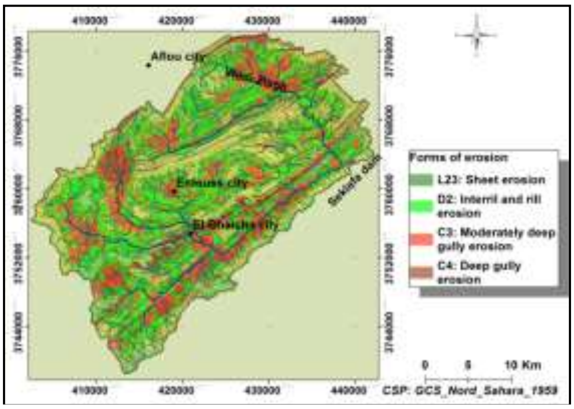

Figure 10. *Descriptive approach map*

The gully erosion and sheet erosion are the most apparent processes of the study area, covering 19.7% and 45.2% respectively. The predominance of these two forms of erosion, especially near the hydrographic network, is explained by the vulnerability of the soils (marl-limestone sandstones) and by anthropogenic activities on relatively moderate slopes.
The combination of two thematic maps resulting from the predictive phase and the descriptive one according to the PAP / RAC method provided a consolidated map that reflects the reality of the current of soil degradation and the future trend of erosion (fig. 11). This last cartographic step leads to a product which identifies and assesses both potential (predictive) and erosive states in their different forms of intensity and trend of evolution.

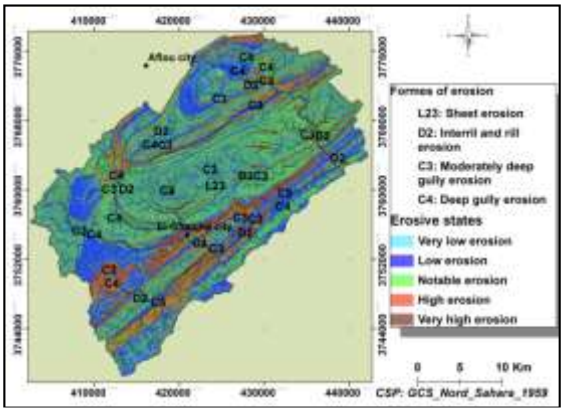

Figure 11. *Consolidated erosion map PAP/RAC*

Figure 11 deduces that the areas at risk of low and moderate soil erosion correspond to gully erosion and sheet erosion. While the erosion forms of

moderately deep and deep gully erosion coincide with areas of high to very high erosion risk.
The spatial configuration of the areas classified as at risk of soil erosion indicates that the areas at high risk of erosion are located in the southern part along the El-Ghicha wadi as well as in the northern part along the wadi Zlagh where erosion of the ravine predominates. However, the areas with very low erosion and low risk are located in the middle of the watershed. In this latter zone, the low risk of soil erosion, as we have indicated, is due to the combination of two factors such as the low degree of slope and the strong resistance of the rocks that attenuate the force of the kinetic energy of raindrops and therefore decrease the surface runoff force in general.
As in other regions of Algeria, the soils of the wadi Seklafa catchment are affected by several interdependent factors influencing the phenomenon of erosion. Thus, the lithological nature is made up of rocks sensitive to erosion (marly limestones represent 72.7% of the total area of the study area). The high classes of slopes (23.1% of the catchment area > 12%) increase the phenomenon of erosion. The soil erodibility highlights the presence of moderate to medium erodibility in the study of the entire area with 67.3%. The plant cover is very low due to the climatic conditions and anthropogenic activities, which are very striking in the central parts of the basin where the vegetation is supported by a very reduced and sparse density formation that reduces the protection of the soils in these areas.
The evaluation results of the interactive phase allowed that an area close to 65% of the study catchment will require intervention measures to counter soil erosion. However, in order to optimize the allocation of resources intended for the short-term and long term reduction of siltation of the Seklafa dam, we suggest that only priority areas receive special attention in terms of anti-erosion measures, including those classified in the last three erosion risk categories (notable to very high erosion, where the bold numbers are presented by star) (table 4).

Table 4. *Evaluation the interactive approach*

Erosive range	**Integration approach**					**∑in%**
	Predictive approach (area in %)	**Descriptive approach (area in %)**				
		Sheet erosion	**Inter-ril and rill erosion**	**Moderate deep gully erosion**	**Deep gully erosion**	
Very weak erosion	0.5	0.1	0.1	0.1	0.0	0.3
Weak erosion	26.5	5.7	5.7	4.0	1.1	16.5
Notable erosion	**51.8***	**12.3***	**11.9***	**7.6***	**1.7***	**33.5***
High erosion	**14.5***	**2.9***	**3.4***	**3.2***	**1.0***	**10.5***
Very high erosion	**6.7***	**1.7***	**1.5***	**0.9***	**0.1***	**4.2***
∑in%	100	22.7	22.6	15.8	3.9	65
∑*in%	**73***	**16.9***	**16.8***	**11.7***	**2.8***	**48.2***

N: Priority classes in terms of management*

Indeed, the Moderate deep gully erosion and deep gully erosion (C3 and C4) respectively affect 11.7% and 2.8% of the catchment area (i.e. 114.1 Km²), are the main erosion processes, will require the most action. These interventions are mainly aimed at countering the gully erosion (Photo. 1). The strategy for protecting these lands consists of installing torrential correction thresholds, constructing drains and outlets on the slopes in order to avoid landslides with marly substrates. The Matorral association, pastures with degraded soils and steppes are the second type of land use in terms of degree of priority where sheet erosion and inter-ril erosion affects respectively 16.9% and 16.8% of basin area requiring anti-erosive interventions.
Due to the current situation, the planting of *Atriplex canescens* and the rehabilitation of degraded land based on *Juniperus phœnicea* (endemic species) are recommended over an area of approximately 265.2 km². This is to ratify the pastoral heritage on the one hand and to attenuate the progression of the incision of inter-ril erosion on the other hand. In addition, to reduce the effect of erosive runoff in our study region, these areas also require the reforestation by the *Pinus halepensis* (Photo. 2).

(Author, 2020)

Photo 1. *Gully landslide*

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(Author, 2020)
Photo 2. *Plant association (P.halepensis)*

Returning to the literature, we note that this method is of great importance in the descriptive knowledge of the phenomenon of water erosion at the basin-scale. In addition, it identifies the most important forms of water erosion. Among the studies that have dealt with this phenomenon in areas of the Mediterranean basin similar to its region, we mention, for example, [33]; [18]; [19]. These studies have shown how important and effective this method is in the qualitative analysis of the phenomenon of water erosion and its contribution to the search for solutions to prepare the watershed according to the forms of soil erosion at the basin-scale.

IV. Conclusion

The study of water erosion by the PAP / RAC method made it possible to conclude that:
The predictive phase provided information on the erosive states of soil degradation based on the degree of influence of the various factors that control water erosion. It shows that 71.9% of interest region area has weak to notable erodibility and only 28.1% has high and very high erodibility. The descriptive approach showed that, sheet erosion and gully erosion are the most apparent forms in the study area, covering 45.2% and 19.7% respectively. The interactive phase highlighted the overall trends in the surface evolution of the watershed. Thus, some much degraded states coincide with spectacular forms of erosion and other more stable states with minor forms of erosion or downright stable areas.
This approach has shown its importance as an effective tool for carrying out, in a simple and rapid way, a general qualitative diagnosis of the erosive states risk at the Seklafa basin-scale. It allowed to set up a multi-source database on the study area and to show the input of geographic information system and remote sensing to the erosion hazard mapping. Although the validity of soil losses is questionable, this method helps actors to (i) plan erosion interventions (ii) simulate evolution scenarios for the study area based on the evolution of land use and the recommended anti-erosion techniques.

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