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Memoire

With a view to obtaining a Master's degree

Sector: *Biological Sciences*
Option: *plant ecology and environment*

THEME

Evaluation of the erosion risk by means of the PAP/CAR model case the region of catchment SEKLAFA laghouat algeria

Supervised by :kharchi Fatiha

Sustained before a jury composed of:

Mr.Chaibi Rachid	**president**	**univ-laghouat**
Mm.Bentaher Fatiha	**Examiner**	**univ-laghouat**
Benchettouh Ahmed	**Supervisor**	**univ-laghouat**

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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 an 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.

Dedicate

I devoted my work to my dear father, you have always encouraged me to continue my higher education and I worked hard to achieve it.

To my dear mother, you sacrificed yourself for my happiness, my studies and my future...

To my dear sisters

To all those who sacrificed their time for science.

And for everyone who uses knowledge for the good and prosperity of humanity.

Thanks and gratitude

I thank God Almighty for giving me the courage, will and patience to complete this work.

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Introduction

1. 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). To do this, this work revolves around three chapters:

Chapter I: Bibliographic overview on water erosion;

Chapter II: Material and methods;

Chapter III: Results and discussion.

Chapter I

Bibliographic overview on water erosion

1.1 Introduction

North Africa, where a semi-arid Mediterranean climate prevails, is particularly affected by water erosion (Bouguerra and Bouanani, 2016). Recent studies on vulnerability to climate change indicate a trend towards an increase in the multiple environmental factors that accelerate water erosion. This is due to long dry periods followed by erosive torrential storms falling on steep slopes with fragile soils. Inappropriate cultivation practices, deforestation, overgrazing and inappropriate human activities are all causes that accentuate soil erosion in this region, which has been described as one of the most water-erosion-prone (García-Ruiz et al., 2013).

The term erosion encompasses all forms of wear and tear on the surface layer of the earth's crust. These are usually distinguished according to the nature of the agent involved: water erosion, wind erosion, glacial erosion, river erosion, marine erosion. The erosion process is generally characterized by three phases: a detachment or ablation phase followed by a transport phase and a deposition or sedimentation phase (Soutteret al., 2007).

Our study focuses on water erosion processes that manifest themselves in different forms, such as diffuse erosion "sheeterosion", channel erosion "inter-rillerosion", linear erosion "rillerosion", ravine erosion "gullyerosion", landslide "landslide" and bank erosion "bankerosion".These forms are the most widespread in the Mediterranean regions (José et al., 2012).

1.2 The factors of water erosion

1.2.1 Climate

The Mediterranean climate is renowned for its erosive showers. Some summer or autumn
storms are indeed dreadful as they cause considerable local damage (Roose, 1994).However, on the scale of large watersheds, it is not localized summer or fall thunderstorms that bring the most sediment into the large reservoirs, but long, generalized, low-intensity showers falling between November and March, a period during which the soils are bare and saturated (BouKhiret al.,2001).It is now widely accepted what water erosion depends on the intensity, height and energy of rainfall (Rooseet all.,2012)BouKheiret al. (2001) found that the erosion tolerance thresholds in a humid temperate climate vary between 2.5 t/ha/year for a shallow soil and 12.5 t/ha/year for a deep soil with a balanced texture and medium permeability. However, this tolerance must be lower in Mediterranean countries because:

- Pedogenesis is much slower in climates with pronounced summer aridity and a very long dry season.
- Soils are mostly shallow and weathering rates are relatively low.
- Arable land is small and declining each year.

1.2.2 Lithology

According to Rooseet al. (2012), Mediterranean soils are no more fragile than tropical soils, but they tend to degrade rapidly as soon as they are denuded and deprived of a regular supply of litter. However, the regosols, ferralitic red soils, calcareous brown soils, black rendzines and grey vertisols that make up the majority of Mediterranean slopes are fairly resistant to sheet erosion.In fact, the erodibility of ferralitic soils decreases from 0.2 to 0.01 t.ha/Mj.mm between clay alteration rocks (basalt) and sandy alteration rocks (fine sandstone). Clay-sand alteration rocks (granite) or silty alteration rocks (shale) occupy an intermediate position. Stony lithosols, very common in Mediterranean mountains, are very resistant (K = 0.01 to 0.05 t.ha/Mj.mm), but not very fertile.

Calcium Vertisols are the most resistant to sheet erosion (K = 0.001 to 0.01t. ha/Mj.mm), but are sensitive to landslides and gullies.Les sols bruns calcaires sont d'autant plus résistants qu'ils ont une charge importante en cailloux (calcaire) et une forte teneur en argiles saturées en calcium (K = 0,01 à 0,10 t. ha/Mj.mm). On the other hand, the leached Mediterranean ferralitic red soils are generally quite fragile (K = 0.20 t.ha/Mj.mm)and then they're low in organic matter. Sodium Vertisols on arid plains are very sensitive to rainfall (K > 0.40 t. ha/Mj.mm).The presence of salts or gypsum within the marls weakens the soils while iron, limestone and pebbles strengthen them, but this resistance is relative and temporary (Rooseet al., 2012).

This fragility of the Mediterranean land is aggravated by deforestation, poor agricultural practices on steep slopes with low levels of organic matter (generally < 2%) together with very high summer temperatures.

These conditions accelerate the primary mineralization of soil organic matter and make the soils fragile, weakly structured and prone to trampling by livestock and the formation of crusts. As a result, these soils are generally very sensitive to erosion (García-Ruiz et al., 2013).

1.2.3 Topography

Rainfall erosion and soil lithology play a large role, while the effects of topography also play a crucial and complex role in water erosion. It is accepted that the steeper the slope, the greater the amount of water runoff, the more dramatic the erosive force will be (Bouguerra and Bouanani, 2016).

In arid and semi-arid areas, the slope gradient is positively correlated with the roughness of the soil surface, which acts to reduce runoff and soil loss (Abrahams and Parsons, 1991; Cooke et al., 1993;

Simanton and Toy, 1994). On the other hand, Rooseet al (2012) observed that the topographical position of the slopes is sometimes more important than the slope itself. The exposure of the slopes of the Mediterranean mountains is important because the south-facing slopes are generally bare and suffer from very high erosion.Moreover, on concave slopes, land losses are lower (D'Souza and Morgan, 1976) than on convex slopes. However, there are multiple interactions between the influence of slope, soil roughness, and topographic position of slopes, landform, vegetation cover and soil lithology, making it a very complex parameter.

1.2.4 Vegetation cover

The vegetation cover is - after rainfall erosivity, soil erodibility and topography - the fourth factor influencing erosive processes. In the PAP/RAC model, the effect of vegetation cover is incorporated into the cover management factor (El-Garouaniet al., 2009; Bouguerra and Bouanani, 2016).It is defined as the ratio of soil loss on cultivated land to soil loss on the same fallow land (Wischmeier and Smith, 1978).On straw soil, the energy of rainfall and runoff is dissipated even on steep slopes by friction with the residues on the one hand. Thus, soil losses remain very modest (Jordánet al., 2010; Sadeghiet al., 2015a).thereby reducing runoff rates and soil losses in different environments, such as agricultural areas (Keesstraet al., 2016; Mwangoet al., 2016; Prosdocimi et al, 2016a,b), grasslands (Fernández et al., 2012, 2014; Fernández and Vega, 2014; Sadeghiet al., 2015a) and forested sites (Robichaud et al., 2013a,b; Pratset al., 2014).On the other hand, the energy and flow velocity of surface water are reduced, increasing the roughness of the soil (Jordánet al., 2010),trapping sediments and nutrients in the runoff stream (Cerdà, 1998; Gholamiet al., 2013).Inaddition, mulching effectively improves water infiltration capacity (Jordánet al., 2010; Wang et al., 2016) and increases the water retention rate in the soil (Cook et al., 2006; Mulumba and Lal, 2008).

Rooseet al. (2012) deduced that the cover of the main crops in North Africa reduces erosion by 20 to 60% compared to a bare plot depending on the density of the crops and the cultivation techniques used. The vegetation cover index decreases up to 0.01 under perennial crops with cover plants and up to 0.001 under forest and straw crops.

Several studies, including that of Herbreteau (2003), show that the determining factor in the erosion of vineyards is plant cover. Le Bissonais (2008) confirms Herbreteau's (2003) observations by stating that vegetation cover is considered the main factor in the erosion hazard.

In Morocco, Laouina (1992) observed that when the soil is covered with dense matorral, short grass, cistus or rock, erosion does not exceed 0.2 to 2 t/ha/year, but as soon as the soil is ploughed, erosion in a rainy year can amount to more than 20 t/ha/year on slopes of 20%. Still in Morocco,The results obtained in the OumEr-Rbia catchment area by Yjjouet al. (2014) show that 64% of the area of the basin has a very low level of vegetation cover. Thus, losses are of the order of 50 to 400 t/ha/year (Yjjou, 2009; Yjjouet al., 2012a), which testifies to the strong erosion exceeding the tolerance thresholds which is of the order of 7 t/ha/year (Yjjouet al., 2014).

In Belgium, in the Walloon region, Goor (2005) showed that the erosive risk is higher on soils

with poorly covering weedy crops or degraded pastoral plants; the risk is lower on more covering non-weedy crops and even lower on dense meadows and forests.In the same study area, Baron (2008) confirmed that permanently covered soils on gentle slopes present a very low risk regardless of the erosivity of the rains.

A well-developed plant cover protects the soil from the action of the rains in a variety of ways:

- The interception of the raindrops allows the dissipation of kinetic energy, which to a large extent reduces the splash effect.
- Plants slow down runoff by the roughness they give to the land.
- Its root system keeps the soil in place and promotes infiltration.
- The addition of organic matter as a result of microbial activity in the root zone improves soil structure and cohesion and therefore reduces the risk of erosion.

Vegetation cover is therefore the most important parameter at our disposal to reduce the risk oferosion.

1.3 Soil and water conservation techniques (SWCT)

Agricultural techniques carried out in a few Sahelian countries (Mali, Nigeria and Sudan) by the local rural population show that the influence of these techniques is not negligible on long glacis with slopes of less than 3%.Ploughing and especially contour ridging improve soil water retention and crop yields (Roose, 2012).Charreau and Nicou (1971) and Lai (1981), showed that tillage of sandy soils allows better rooting and, temporarily, better infiltration and destroys the aggregation of ferralitic soil. However, Boliet al. (1992) and Diallo (1992) observed a significant reduction in erosion (including suspended load) and runoff on ferralitic sandy to clayey-sandy soils.This reduction can be observed on direct seeded soils with intensive cotton/corn rotation.In Europe, anti-erosion works reduce the risk of soil erosion to less than 3%. Vegetative hedges have the greatest impact (57% of the total erosion risk reduction) followed by dry stone barriers (38%) (Panagoset al., 2015). In Algeria, the most productive mountainous areas in the north of the country are subject to severe degradation through erosion.This is due not only to the aridity of the region, but also, and to an increasing extent, to factors related to human activities (Rooseet al., 2008).Overgrazing, poor agricultural practices, deforestation, fires and rangeland clearing have increased over the last century, particularly as a result of population growth. Indeed, 4.1 million inhabitants and 2.5 million hectares were cultivated in 1890 (Boukarzaza, 1993) as against 40.4 million inhabitants and 3 million hectares currently cultivated (MADR, 2016).In the regions of the Algerian Tell and faced with the disastrous situation of soil degradation (reduction of agricultural land fertility and rapid silting of hydraulic works), ANBT (2006) wishes to identify and specify the measures to be implemented to effectively combat the silting of reservoirs, preserve their useful capacity and ensure future wateravailability.

1.4 Forms of water erosion

The phenomenon of water erosion develops when the infiltration of rainwater into the soil stops, either as a result of soil saturation or as a result of the hortenion phenomenon. Thus, these rains run down the slopes carrying away soil particles. Once the runoff is triggered, erosion can take several forms, which combine in time and space (Bouguerra and Bouanani, 2016). Depending on the combination and spatial location of the detachment mechanisms, there are generally three main classes of erosion forms: sheet and gully, gully and slope (Roose, 1994).

1.4.1 Sheet erosion

The sheet or diffuse form is the initial stage of soil degradation by water erosion. Initially, soil particles are displaced over short distances by the splash effect (Photo 1).After a few rains, fine soil is washed away while pebbles too heavy to be washed away accumulate on the soil surface (Roose,1994).

Planche 1.1 The splash effect followed by the displacement of soil particles by runoff(Le Bissonnais*et*

1.4.2 Linear erosion

Linear erosion occurs when surface runoff becomes concentrated and, by increasing water velocity, acquires increased erosive power, resulting in deeper and deeper linear incisions in the soil (Foster, 2004). These are called claws when the small channels are a few centimetres deep and gullies (Photo. 2) when the channels are deeper than 10 cm .Indeed, on a watershed or a plot of land, gully erosion follows sheet erosion by concentration of runoff in the hollows (the incision: table 1). At this stage, the gullies do not converge but form parallel streams. When the gullies form a well-branched network and reach a metric depth, this is referred to as gully erosion (Photo. 3).


Planche2.Gully erosion planche3. Gully erosion

Gullies are the most evolved form of linear erosion, and are distributed over the entire terrain. Sometimes, when the substrate is hard, gullies widen by undermining the banks that are the main source of transported sediments (Ludwinget al. 1996).

Table 1.1 Linear erosion incision shapes

Forms	**Trace**	Length	Width	Profoundness
Label	Sinuous	<1 m	< 10 cm	5-6 cm
Rill	Straight	hundreds of metre	10-20cm	5-10 cm
Laughs	Sinuous	dozenmeters	5-70cm	10-30 cm
Gully	Smoothly	hundreds of metres	50cm to 1 m	30-50 cm
smallgully	Smoothly	hundreds of metres	50cm to 1 m	50-200 cm

1.4.3 Mass erosion

While sheet erosion attacks the soil surface and gullies at slope drainage lines, mass erosion displaces a volume of soil within the soil cover in forms such as mass movement, mudflows, and landslides. It is a form that takes place on steeply sloping terrain. These processes of mass movement are generally called "solifluction".The latter is a movement due to gravity as well as runoff and is part of a set of processes aimed at removing loose formations from the superficial part of slopes and can occur either slowly or rapidly affecting a more or less extensive part of the slope (Hadir, 2010).

1.5 Consequences of water erosion

Soil erosion is a serious and widespread environmental problem around the world. Every year, 75 trillion tons of lands are removed, resulting in the loss of 20 million hectares of agricultural land (Pandeyet al., 2009c).At the same time, the useful volume of water in dams has been remarkably reduced in recent years. As a consequence, in addition to the loss of fertile land and the reduction of the storage capacity of hydraulic works, other environmental problems also arise, namely, the risk to food security, the increased risk of flooding in floodplains, the reduction of water quality and the loss of biodiversity (Onyandoet al, 2005; Sthiannopkao et al. 2007; Zhou et al. 2008; Bewket and Teferi 2009; Wang et al. 2009). In Europe, RIVM (2000) stated that water erosion is one of the most important land degradation processes. It has also been reported that Southern countries are most exposed to erosive risk, with rates of, 58%, 66%, 66% and 85% in France, Italy, Spain and Greece respectively (Imamoglu and Dengiz, 2016).

In Turkey, soil water erosion is the biggest land degradation problem. According to the Ministry of Agriculture, Forestry and Villages, some 58.7% of land is exposed to severe or very severe erosion, including 59% of agricultural land, 54% of forest land and 64% of rangelands (Imamoglu and Dengiz, 2016).

Also in Turkey, especially in the semi-arid and arid Mediterranean regions, erosion is one of the main threats to soil fertility and water resources. It reduces the useful water capacity of dams through the inflow and deposition of soil particles. In addition, sedimentation has dramatic environmental impacts on water quality and aquatic habitat (Akay and Session, 2005; Akayet al., 2008). According to Yukselet et al. (2008), more than 345 million tonnes of sediment are deposited annually to lakes, dams and the sea. In sub-Saharan Africa, soil erosion is generally considered the most severe threat to land productivity, creating negative impacts on agricultural production, infrastructure and water quality (Obalumet al., 2012). Lal (1995) estimated that erosion in these countries leads to a reduction in yields of 2-4% and that if the current trend continues; the yield reduction by 2020 could be 16.5%. The Mediterranean area has the reputation of being subject to very high erosive risks (José et al., 2012).

This phenomenon is also characteristic of the Maghreb countries whose water and soil potentialities are seriously threatened (Khanchoulet al., 2012). In Morocco, specific soil erosion ranges from 0.5 t/ha/year in the Middle Atlas to 50 t/ha in the Rif. This translates into the erosion of 15 million hectares of agricultural land and a progressive and worrying decrease in soil fertility and consequently in soil productivity (Khali Issa et al., 2016).With these losses, not only is soil fertility damaged, but also the useful water volume of the dams is reduced. The Moroccan High Commission for Water and Forests (2008) estimates the annual silting up of dam reservoirs at around 75 million m3, i.e., as we have noted, an annual reduction of 0.5% in their storage capacity, which causes a deterioration in the quality of the drinking water mobilized and a significant loss of water making it possible to irrigate 10,000 ha/year. In Algeria, 45% of fertile land has been damaged by erosion (Gay et al., 2016).The average annual specific erosion varies between 136 t/Km² and 7,200 t/Km² (Achite and Ouillon., 2007). Approximately 6 million hectares are currently exposed to active erosion (Morsliet al., 2012).In addition to the loss of fertility of agricultural land, the phenomenon of silting has affected all the dams where more than 45 million m3 of sediment is deposited each year at the bottom of these reservoirs (Meddiet al., 2016).

Thus, Algeria is today among the poorest countries in terms of water potential, i.e. below the theoretical scarcity threshold set by the World Bank, which is of the order of 1,000 m3 per inhabitant per year (Touati, 2010). Indeed, in 1962, the theoretical annual water availability was 1,500 m^3/capita, which placed the country in a comfortable situation. It was only 720 m3 in 1990, 630 m^3 in 1998 and 500 m3 today (Morgan and Alexis, 2013).to be compared with the 3600 m^3 per inhabitant in France and more than 3 200 m3 in Italy (Truchot, 2006), the 950 m^3 per inhabitant in Morocco (Allain El Mansouri, 2001), the 925 m3 per inhabitant in Egypt (Ayeb, 2004) and the 490 m3 per inhabitant in Tunisia (Cote, 2005). At this rate, it will be only 300 m3 by 2050 (Touati, 2010).

1.6 Methods of assessment and quantification of water erosion Water erosion assessment method

1.6.1 Quantitative methods

The study of erosion processes has, over the last three decades, made use of a range of techniques to quantify soil losses: experimental plots, measurements by benchmarks, rain simulator, gauging stations, technique for tracing sources of sediments using radionuclide elements, thematic mapping and bathymetric measurements. Depending on the objectives sought, the complexity of erosive processes

(Mohamadi and Kavian, 2015) and the sometimes unpredictable consequences of this phenomenon, various approaches and techniques have been adopted to quantify the loose materials torn away by erosion. According to Sadiki (2004), Measurements of different types and at different stages of the erosion process have been carried out:

- At the time of the impact of the raindrops.
- During sediment flow.
- After river sedimentation at dams and reservoirs.

According to Sabir (1986), approaches to the quantification of erosion can be grouped into three different levels: (i) study at the watershed level; (ii) study of the transit of transported solids across a section of the watercourse; (iii) study of siltation (accumulation of sediments) of reservoirs, dams and bunds downstream of a watershed. However, quantifying and mapping water erosion at the watershed level using spatial tools is becoming a major issue (Park et al., 2011; Xu et al., 2012; Panagos et al., 2015; Zhao et al., 2015; Borrelli et al., 2016; Zhang et al., 2017).

1.6.1.1 Experimental plots

It is the most widely used and reliable method, however, it is relatively expensive and delicate.It consists of a plot of land of variable size (a few square metres to a few hundred square metres), limited on all sides by metal walls to avoid interference with the rest of the slopes and to collect only the water from the plot of interest. It is equipped downstream with a catch basin to collect sediment-laden runoff (Photo 4). Solid and liquid flow measurements are taken regularly with a higher frequency during major rainfall events, which are analyzed for density and particle size.

Planche 4.1 Arrangement of an experimental plot (Mohamadi and Kavian, 2015)

This technique enabled Wischmeier and Smith (1965) to arrive at the universal soil loss equation (Sadiki, 2004).This required a large number of plots operating over several years, but the results have encouraged developers to use this equation around the world (Mohamadi and Kavian, 2015; Sadeghi et al., 2016; Kinnell, 2016; Bertol et al., 2016; Anache et al., 2017). This method thus demonstrates the possibility of studying erosion on a large scale.

1.6.1.2 Measurements by benchmarks

This technique is valid for quantifying both sheet and linear erosion. Its principle is very simple, it consists in following the topographic evolution of the soil surface of a plot of given dimensions and previously delimited in order to avoid the influence of the neighbourhood .From this topographic evolution and by a double integration, over width and length, we can determine the volume of sediments carried away by erosion. Either a mesh of stakes or graduated poles (20 cm side length) driven and stabilized in the ground on plots of 1 or 2 m2 can be used, or the heights between the ground surface and a horizontal metal ruler can be measured .Measurements are made by graduated bars that slide through equidistant holes in the ruler and whose flat bases rest on the ground surface (Olivry, 1984).

1.6.1.3 Sediment Source Tracing Techniques

Water erosion measurements in experimental plots on the slopes of the basin are a time consuming and costly approach that only takes into account sheet and gully erosion .Moreover, these measures must be continued for several years in order to take into account interannual climate fluctuations .The number of plots required can also become very large, if one wishes to estimate erosion risk under a variety of soil and agronomic conditions. In addition, in some countries of the world, snow erosion resulting from snowmelt has to be taken into consideration, even if it is difficult to measure. In this context, the use of permanent markers incorporated into the soil is adopted as an essential complement to conventional methods (McHenry, 1968).

Various isotopic elements in the soil have been suggested as tracers of the erosive process. The technique of sediment source tracing was first introduced in the United States in the 1980s (Ritchie and McHenry, 1990) and has been used around the world (He and Walling, 1996; Benmansour et al., 2006a; Li et al., 2010; Walling et al., 2011; Yang et al., 2011; Wilkinson et al, 2015) in particular in the Mediterranean regions, namely Morocco (Damnati et al., 2004; Sadiki, 2004; Zouagui et al., 2012; Benmansour et al., 2013), Tunisia (Benslimane et al., 2013), Algeria (Toumi, 2013), Romania (Robu and Giovani, 2009) and Slovenia (Zupanc and Mabit, 2010).

The radionuclide elements in the soil are the result of nuclear fallout from upper-air atmospheric testing in the 1950s and 1960s (Benmansour et al., 2013). These elements have proven to be effective in estimating sediment sources within the watershed and inferring the dominant processes. The radioactive elements that are the subject of this study are Beryllium (7Be) (Mabit et al., 2008; Huisman et al., 2013;

Taylor et al, 2014), Radium-226 (226Ra), Radium-228 (228Ra), Thorium-234 (234Th), Thorium-228 (228Th), Potassium-40 (40K), Total Organic Carbon, Total Nitrogen, Total Phosphorus (Benslimane, 2013), Cesium-137 (137Cs) and Lead-210 (210Pbexc) (Benmansour et al., 2013). It appears that the radioactive elements in the soil in particular, Caesium-137 (137Cs) and Lead-210 (210Pbexc), may constitute an excellent alternative technique compared to other traditional "erosion/sedimentation" water erosion measurement techniques at the watershed level (Zupanc and Mabit, 2010).

The principle of this technique is very simple; it consists in comparing the radioactive element content in the soil compared to its content in uneroded control sites. Since the area studied is larger, it is considered preferable to consider several sites representing the initial fallout in order to incorporate the spatial variability of the fallout. This approach consists of selecting undisturbed reference sites (stable site: neither eroded nor flooded).The reference site should be flat, with no agricultural activity in the year of the nuclear fallout (1960) and preferably should be covered by grassland (Toumi, 2013). From these reference sites, and using a soil burial instrument, soil samples are taken at depth intervals of 2 centimetres in order to establish a depth profile of the quantitative vertical distribution of the various radioactive elements studied. Subsequently, mathematical conversion models are used to convert the point radionuclide activities to rates of erosion and/or deposition (Walling et al., 2002).

I.6.1.4 Gauging stations: turbidimetry (solid flows)

Water erosion occurs when soil particles are loosened by the kinetic energy of raindrops and transported by shallow surface flows and accumulates as sediment downstream.The solid flow is the quantity (in kilograms) of sediment (particles, clays, silts, sands, gravels,) transported by a watercourse to a given section during a unit of time (second). In semi-arid areas, if linear erosion is not active, sheet erosion is the main source of sediment (Benkadja et al., 2013). Achite and Meddi (2004) found that estimating the sedimentation rate of dams and their lifespan requires a good knowledge of solid inputs. Different empirical models have been developed around the world to calculate the amounts of sediment. Pandey et al. (2016) exhibited all models used around the world. Examplesinclude: SWAT (Soil Water AssessmentTool) (Rostamian et al., 2008; Setegn et al., 2009; Wang et al., 2010; Oeurng et al., 2011; Cai et al., 2012; Zhang et al., 2014; Zabaleta et al., 2014), WEPP (Water Erosion Prediction Project) (Raclot and Albergel, 2006; Pandey et al., 2008; Pandey et al., 2008; Pandey et al., 2008; Pandey et al., 2008), WEPP (Water Erosion Prediction Project) (Raclot and Albergel, 2006; Pandey et al., 2008; Pandey et al., 2008; Pandey et al., 2008), WEPP (Water Erosion Prediction Project) (Pandey et al., 2008; Pandey et al., 2008; Pandey et al, 2009c), AGNPS (Agricultural Non-point Source Model) (Haregeweyn and Yohannes, 2003; Mohammed et al., 2004;

Chowdary et al., 2004; Jianchang et al., 2008; Cho et al, 2008), ANSWERS (ArealNonpoint Source Watershed EnvironmentResponse Simulation) (Moehansyah et al., 2004; Ahmadi et al., 2006; Singh and Frevert, 2006) and SHETRAN (EuropianTRANsportHydrological System) (Figueiredo and Bathurst, 2007).

Their application according to the space (point or global) of the scale (parcel or watershed), time (content or for a specific event) and the estimation of diffuse or concentrated erosion, as well as their possibility of integration with GIS gives better results. A number of algorithms or empirical equations have been used to estimate soil losses either on slopes or at stream level (Pandey et al., 2016).

Some investigators focus on the direct relationships between liquid flow (m3/s) and solid flows (Kg/s) (Qs = aQb), using suspended sediment concentration data from monitored sites in rivers (Asselman, 2000; Abdellaoui et al, 2002; Achite and Ouillon, 2007; Bencheikha et al. 2008; Benkadja, 2008; Ouechtati and Baldassare, 2011; Khanchoul et al. 2012). Other researchers have used different approaches to estimate sediment quantity at the basin scale. Shoa et al (2013) used the Sediment Distribution Ratio (SDR) model in a GIS environment to estimate sediment quantity in large basins based on distribution processes and rainfall characteristics.Rawat et al (2013) used the Sediment Yield Index (SYI) model to examine land use in India. This index rationalizes sediment input to the water body as a multiplicative function of the potential soil erosivity factor and the value of the distribution ratio. Both the SDR and SYI models ignored some important parameters in particular, the type of rocks exposed within the basin and their degree of fracturing (Abdel Monsef, 2015).

Arekhi et al. (2012) applied the modified universal soil loss equation (MUSLE) in predicting sediment production in the Kengir watershed (Iran) by replacing the rainfall erosivity factor R in the RUSLE equation with the power model: 11.8 (Q.qp)0.56 such that, Q and qp represent the volume of rainfall runoff (m3) and peak discharge (m3/s), respectively.

In Algeria, Touaibia et al.(2000) modelled the mean suspended sediment concentration at the flood scale for the Wadi Mina. In 2001, this author refined his approach by grafting to remote sensing data a model based on the laws of physics. By comparing the results obtained by their model with some 50 measurements taken during a single rainfall event, they demonstrated the model's effectiveness. However, this model requires a wealth of data that is not always available.

Also in the Mina watershed, Touaïbia (2000) examined on a monthly scale the relationships linking solid flows (Qs) to liquid flows (Ql) for the Haddad wadi sub-watershed and the El-Abtal wadi sub-watershed. Among the different models explored, the power model (Qs = aQb) was the most efficient where the values of the coefficients a and b vary according to the month and the location of the watershed.

Meddi et al. (1998) used stepwise multiple regression to establish relationships between specific degradation (explained variable) and the explanatory parameters: mean annual liquid flow and catchment area.

I.6.1.5 Siltation and sediment accumulation measurements: bathymetry

Bathymetry is a set of measurements of the depth of the dam's water impoundment. The purpose of these measurements is to determine the topography of the submerged bottom (CEHQ, 2008). Usually, this technique at the impoundment is done by spot soundings of the bottom of the impoundment, following cross-sections between the two banks of the dam.

Thus, this method for evaluating solid transport at the outlet of the basin was developed based on regular measurements of the bathymetry of the hilly lakes and monitoring of the water balance of the reservoir.The ends of each crossbar are levelled and positioned on the restraint's reattachment plane. A digital terrain model is produced.Comparison of the tank volumes at the spill rating from one measurement to the next allows the quantity of material retained to be estimated. The volumes spilled are assigned an average concentration of suspended solids obtained by sampling.

The solid transport between two bathymetric measurements is thus obtained from the following equation (Albergel et al., 2004):

$$T = V_s \times d + \sum_{1}^{n} SI \times CI$$

T: total solid transport between two bathymetric measurements (t)

Vs: measured vessel volume (m3) d: density of the mud

n: number of floods spilled between two measurements

Si :volume spilled during flood i (m3) Ci: average suspended solids concentration measured during flood i (t/m3).

This method, which is simple to implement, makes it possible to obtain a good estimate of solid transport at the outlet of a catchment area equipped with a reservoir. It aggregates soil losses due to the three forms of water erosion:

- Sheet erosion from rainfall runoff on slopes.
- Gullying caused by linear flow on steep slopes.
- Bank and bottom erosion produced by flows in the main river system. Recently, and consistent with the use of spatial tools and their products, many methods for determining and mapping the bathymetry and topography of aquatic systems have been suggested at the outlet of watersheds (Dongeren et al., 2008; Babonneau et al., 2013; Pattanaik et al., 2015; Muto et al., 2016; Chen et al., 2017).

Image processing techniques that involve multi-spectral remote sensing data are considered very attractive for bathymetry applications. They provide a cost-effective and time-efficient solution for water depth estimation (Doneus et al., 2012; Jagalingam et al., 2015; Pattanaik et al., 2015; Profe et al., 2016).

1.6.2 Qualitative methods

1.6.2.1 Rain simulator

This measurement technique makes it possible to examine the textural behaviour of the soil over time (during the experiment) with respect to infiltration and runoff as a function of the quantity and intensity of rainfall.The experiment is repeated, under controlled conditions, depending on the variables of the terrain such as: slope, vegetation cover, soil type, initial soil moisture... etc..... Depending on the simulator used, the area involved can be from one to several square metres and the drop height from a few decimetres to a few metres.

(*Site web : www.alismiri.com/uploads/coursces1.pdf*consulté le 13/10/2017)

Planche 5. Dispositif de parcelles expérimentales d'un simulateur des pluies

This device (Photo 5) makes it possible to accurately monitor the dynamics of infiltration and to test the detachability of the soil surface, but not erosion because the short length of the slope does not allow the energy of runoff to express itself. Thus, the results remain valid only for comparing the reactions of different soil types under different land uses on different slopes.For it is practically impossible to bring together all the factors influencing water erosion over an area of a few square metres, in particular wind speed and direction, the energy and angle of the raindrops, etc., in a single area.

On the other hand, the irregularity of its rainfall and the Mediterranean climate, with different rainfall events from one region to another, makes it impossible to extrapolate the results obtained over large areas.

1.6.2.2 Mapping Methods

The mapping method consists of dividing the surface of the watershed into differentiated units. Prioritizing them according to their vulnerability to erosion makes it possible to identify the most fragile areas potentially providing sediment (Sadiki, 2004).It is based on thematic maps, each of which corresponds to a factor influencing erosion. The values of each factor are distributed in different classes according to their order of importance .Overlaying thematic maps with their databases in a GIS environment results in a synthetic erosion map. The areas with high degrees of influence correspond to those most vulnerable to erosion.

Soti (2003) developed a decision tree for the soil erosion sensitivity map based on slope gradient, soil erodibility and vegetation cover .First of all, a hierarchy of the slope factor in three classes according to its influence on the erosive phenomenon is defined. A gradient of 0 to 10% represents low sensitivity to erosion, 10 to 25% medium sensitivity, and more than 25% high sensitivity .Then a grouping of soil erodibility values into three classes (low, medium and high) was defined .Finally, plant cover values were grouped into three classes according to the degree of protection of the land use (poorly protective, protective and very protective).The overlay of these maps and the different combinations (27 in total) result in a map of sensitivity to water erosion.

In the Ghats catchment in India, Pradeep et al (2015) assessed the vulnerability of soils to water erosion using the multi-criteria Analytical Hierarchy Process (AHP) method.The result obtained by this technique shows that soil losses differ from one sector to another. In fact, 44.2% of the area shows a zero to low risk of soil loss, 33.2% has a low risk and 22.6% has a high to dangerous risk. Jaiswal et al (2015)in a Multi Criteria Decision Analysis (MCDA) study showed that the rate of water erosion varies from one sub-watershed to another. This study led to a prioritisation of the areas to be treated as a priority.

In Morocco, Sadiki et al (2004) integrated thematic maps of different USLE factors into the GIS environment. The results obtained showed a hierarchical ranking of the catchment areas with regard to the degree of vulnerability.

Chapter II

Material and methods

2 Material and methods

The PAP/RAC directive was widely used in North African regions ([18]; [19]). , 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 (fig.2).

2.1 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 outcrops.A geological study carried out by [21] revealedthat 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.

WadiM'zi forms by far, the most important river with its principal affluents: WadiZlagh in the northern sector and WadiEl_Ghicha and its secondary stream such asWadiLoutiowit and Rekik in the southern sector. The analysis of the hydrographic network of the study area explains 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). Precipitations are naturally a rare occurrence

(296 mm/year); that occurs predominantly between June and September, and comes in the form of short, heavy bursts rainfall.

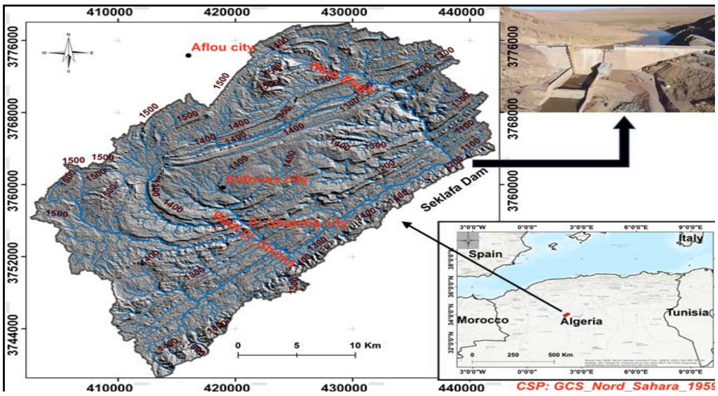

Planche 1.2 Study area

2.2Data collection and PAP/RAC approaches

To achieve this goal, the integration Remote sensing technology (RS), Geographic 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/).

2.2.1 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 $NDVI^2$.

2.2.2 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 / # /.

2.2.3 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).

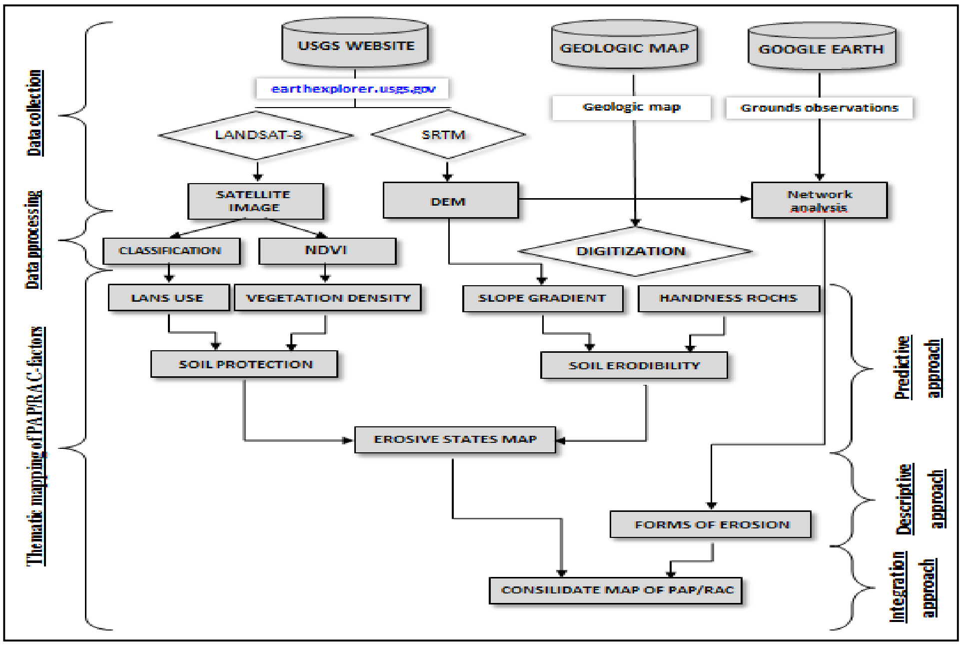

Planche 2.2. The methodology followed in this research

2.3 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 / RAC) for 325 observations. XLSTAT 2014 statistical software was used for data processing.

Chapter III

Results and discussion

3. 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].

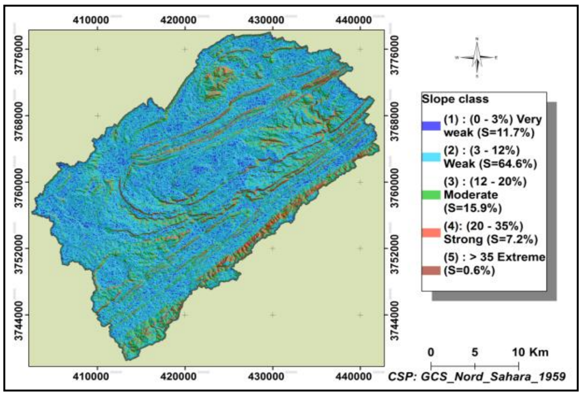

planche 1.3. Slope classes

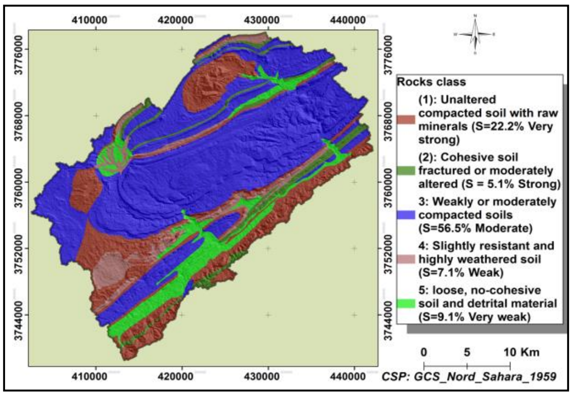

planche 2.3. Rocks classes

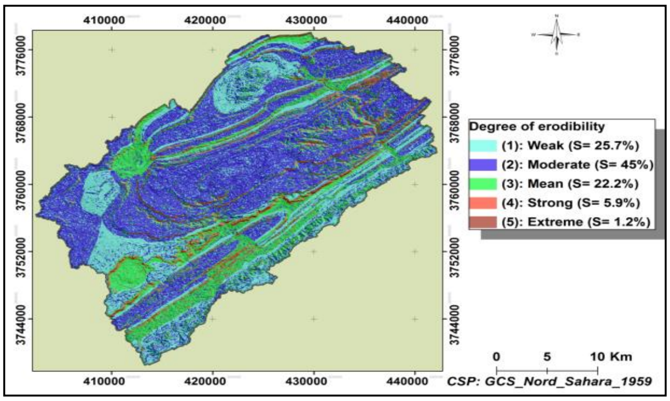

planche 3.3 Degree of erodibility

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.

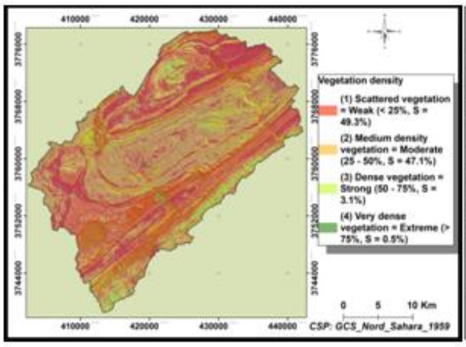

planche 4.3 Vegetation density classes

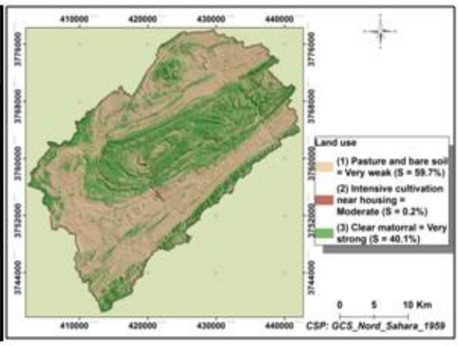

planche 5.3 Land use classes

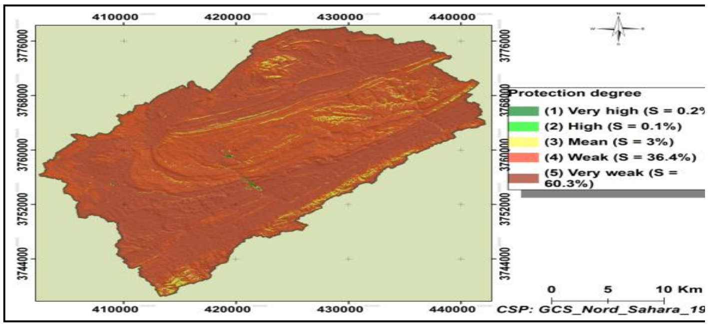

planche 6.3 Protection degree

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.

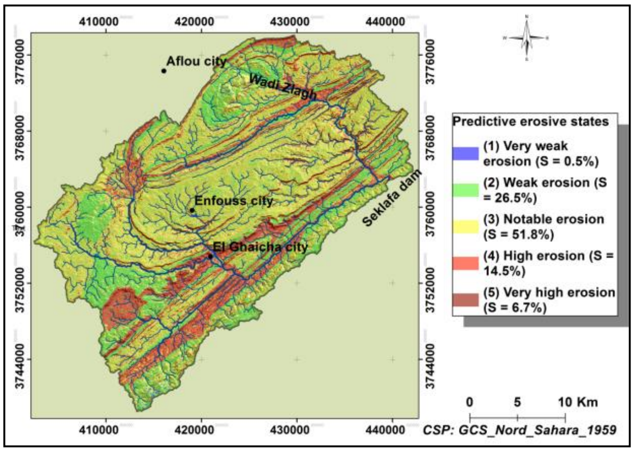

planche 7.3 Predictive erosive states map

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. 7). 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.

III.2. PCA

Table 3. 1Matrice 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 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.

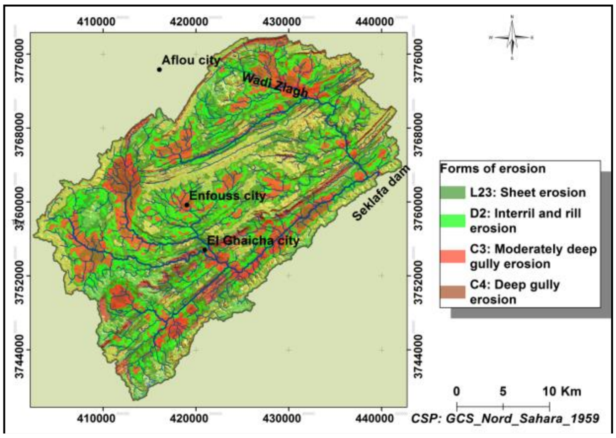

planche 8.3 Descriptive approach map

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. 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.

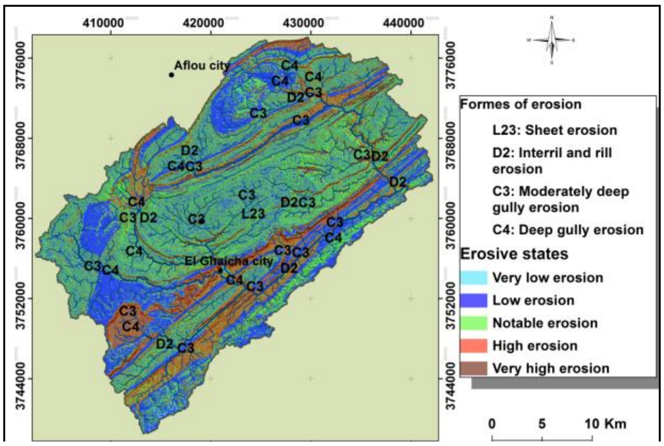

planche9.3 Consolidated erosion map PAP/RAC

Figure 9 deduces that the areas at risk of low and moderate soil erosion correspond to inter-channel 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-Ghichawadi as well as in the northern part along the wadiZlagh 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 wadiSeklafa catchment are affected by several interdependent factors influencing the phenomenon of erosion. Thus, the lithological nature is made up of rocks sensitive to erosion (marlylimestones 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 4.3 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 torrentialcorrection 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 *Atriplexcanescens* and the rehabilitation of degraded land based on *Juniperusphœnicea* (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 *Pinushalepensis* (Photo. 13).

Planche10.3: Gully landslide

Planche 11.3: 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.

conclusion

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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