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Evaluation of the erosion risk by means of the RUSLE model case the region of catchment SEKLAFA laghouat algeria

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ABSTRACT

The Seklafa watershed, with an area of 787 km², which is part of the Jebel Amour region (Algeria), is characterized by a spatio-temporal rainfall irregularity, a fairly high thermal gap, a degraded marly lithology and a weak vegetation and inadequate cover, which makes it prone to severe erosion in all its forms. The combination of thematic maps of the different erosive factors according to the Revised Universal Soil Loss Equation (RUSLE) in the GIS by ArcGIS 10.2 software provided a reliable forecast of the annual rates of soil loss by delineating the areas prone to erosion risk in the watershed mentioned above. The estimated average potential annual soil loss is 7.56 t / ha / year. About 70.7% of the watershed was predicted to have a very low to low erosion risk, with soil loss of between 0 and 7.5 t / ha / year. The risk of erosion is moderate over 17.7% of the watershed, where the calculated soil loss is between 7.5 and 12 t / ha / year. The risk of erosion is high to dangerous over 11.6% of the watershed, where the calculated soil loss is greater than 12 t / ha / year. From this study, it became clear that there is a need for rapid action using reliable and effective conservation techniques.

Keywords: Seklafa watershed, Algeria, RUSLE, GIS, Erosion.

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Introduction

Soil erosion is a natural phenomenon which causes depletion of soil materials by several natural factors such as wind, water, sollifluxion but often accelerated by human activities (Gunawan et al., 2013; fayas, 2019). Thus, the total land area subjected to this last is estimated at about 2 billion hectares. By this, the land area affected by soil degradation due to erosion is estimated at 1100 million hectares by water erosion and 550 million hectares by wind erosion (Saha, 2003; Ganasri, 2015).According to Fayas et al. (2019),soil erosion contributes negatively to agricultural production, quality of source water for drinking, ecosystem health in land and aquatic environments, and aesthetic value of landscapes. Moreover, the erosion led siltation reduces the storage capacity of dams at a rate of about 1% per year (Saha, 2003; Ganasri, 2015).This environmental factor, not only damages land resources, but also deteriorates aquatic ecological environments(Wu et al., 2016a)(Wu, 2020). Thus, the degradation by erosion is a serious problem worldwide(Almaw, 2020). The Mediterraneanmountains are facing great environmental and socioeconomic challenges in the current framework of Global Change(Martinez et al., 2020). The Maghreb countries which represent an important region of the latter are subject to the most vulnerable to soil erosion, due to its semi-arid climate and the poor vegetation(Megnounifet al., 2003; Benkaci, 2018)and inappropriate human activities.In Algeria, the soil erosion has amajor effect on the agricultural sector and siltation of reservoirs(Benchettouh et al., 2017; Remini, 2018).The annual volume of sediment deposited in dams is estimated at 45 million m^3 (Remini and Hallouche, 2007) and 14 million hectares of land are threatened by water erosion (Meddi et al. 2016).

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 (Toumi et al. 2013). However, soil erosion is a direct product of the complex interactions between natural factors (e.g. rainfall, soil vulnerability, hillslopes and cover and management) and that anthropogenic. These factors vary spatiotemporally, making the assessment of soil erosion even more difficult (Phinzi et al., 2018). In this context, several physical-based models such as SWAT, WEPP, AGNPS, ANSWER and SHETRAN (Pandey et al., 2016) have been developed to estimate at the basin scale soil erosion. Although, these empirical models give reliable results, but will not be generated it in the overall of the watershed (Benchettouh et al., 2017).The Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) model provide a rather simple and yet comprehensive framework for assessing soil erosion and its causative factors. It presents how climate, soil, topography, and land use affect rill and interrill soil erosion caused by raindrop impact and surface runoff (Renard et al., 1997).The RUSLE model is one of the most widely applied empirical models for assessing the sheet and rill erosion in the Mediterranean region (Benchettouh et al., 2017). It makes it possible totreat on a hierarchical basis the surface of an area catchment inunits distinguished according to the vulnerability with hydrouserosion and to determine the zones potentially the most fragileproviders of sediments (Sadiki et al., 2012). It is based on acartography set of themes of the factors of erosion, in particularthe Rainfall runoff erosivity(R), the soil erodibility (K), slope length and steepness (LS), cover and management(C) and conservation practices (P).

In Algeria, there are few regions where the RUSLE model has been used. The objective of this study is to develop a methodology that combines remote sensing data and geographical information system (GIS) with the universal soil loss equation (RUSLE) to estimate the spatial distribution of soil erosion at the basin scale of wadiSeklafa, region of Laghouat.

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).

The objective of this chapter is first of all to expose the factors influencing the erosive risk. Next, we will present models for quantifying soil losses due to water erosion. Finally, through a bibliographical synthesis, we will try to present some results of soil losses through the application of the universal RUSLE model integrated in a GIS environment throughout the world and in Algeria.

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 that water erosion depends on the intensity, height and energy of rainfall (Rooseet al., 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 RUSLE 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).In addition, 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 of erosion.

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 water availability. The developments thus proposed can be divided into two parts:

☞ a first component which concerns biological developments, represented by reforestation, revegetation of bare land, continuous soil covering and the installation of quickset hedges to delimit and protect the plots from erosion.

☞ As for the second component, it concerns the so-called rural engineering works with different techniques for storing water and braking run-off, such as the installation of dry stone barriers on gently sloping slopes, terraces, sills and gabions, etc. These developments can be effective in preventing siltation of dams.

The erosion control practice factor P in the USLE / RUSLE model is rarely taken into account in soil erosion risk modelling on a sub-continental scale, as it is difficult to estimate it for large areas (Panagoset al., 2015).

The literature reports various tables and formulas proposing values of the antierosive factor for conservation practices adopted in different environmental contexts (e.g. Wischmeier and Smith, 1978; Renard et al., 1997).For example, typical values range from about 0.1 for crops grown in split ridge; 0.75 for contour tillage; and 1 where no erosion control practices are used (Roose, 1977).In the USLE/RUSLE model, these values are obtained from experiments on plots and small watersheds. Lufafaet al (2003), have suggested an alternative approach for approximating the P factor based on empirical equations including the Wener method, where $P = 0.2 + 0.3\ \theta$, and θ represents the degree of slope in %. However, it is difficult to quantify the impact of the different anti-erosion practices applied in very large areas, particularly earthworks and ploughing (Panagoset al., 2015).

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).

Photo 1.The splash effect followed by the displacement of soil particles by runoff(Le Bissonnais*et al.*, 2002)

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).

Photo 2. Gully erosion photo 3. 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).

Tableau 1 Linear erosion incision shapes

forms	Trace	length	width	Profoundness
label	Sinuous	<1 m	< 10 cm	5-6 cm
Rill	Straight	hundreds of metres	10-20 cm	5-10 cm
laughs	Sinuous	dozenmeters	5-70 cm	10-30 cm
gully	Smoothly	hundreds of metres	50 cm to 1m	30-50 cm
smallgully	Smoothly	hundreds of metres	50 cm to 1m	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 m^3, 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/Km^2 and 7,200 t/Km^2 (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 m3 /capita, which placed the country in a comfortable situation. It was only 720 m3 in 1990, 630 m3 in 1998 and 500 m3 today (Morgan and Alexis, 2013).to be compared with the 3600 m3 per inhabitant in France and more than 3 200 m3 in Italy (Truchot, 2006), the 950 m3 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.

Photo 4. 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).

1.6.1.4 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 WatershedEnvironmentResponse Simulation) (Moehansyah et al., 2004; Ahmadi et al., 2006; Singh and Frevert, 2006) and SHETRAN (Europian-TRANsportHydrological 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 (m^3) and peak discharge (m^3/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.

1.6.1.5 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):

$$\boldsymbol{T = Vs * d + \sum_{1}^{n} SI * CI}$$

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)

Photo 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

2.1 Data collection

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 2019.

(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 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 Taibi (2018), 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 Nouar (2005) 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) (Taibi 2018) and lower and middle Lias limestone which rest on impermeable Triassic terrains, composed of red clays with intercalations of altered doleritic basalts.

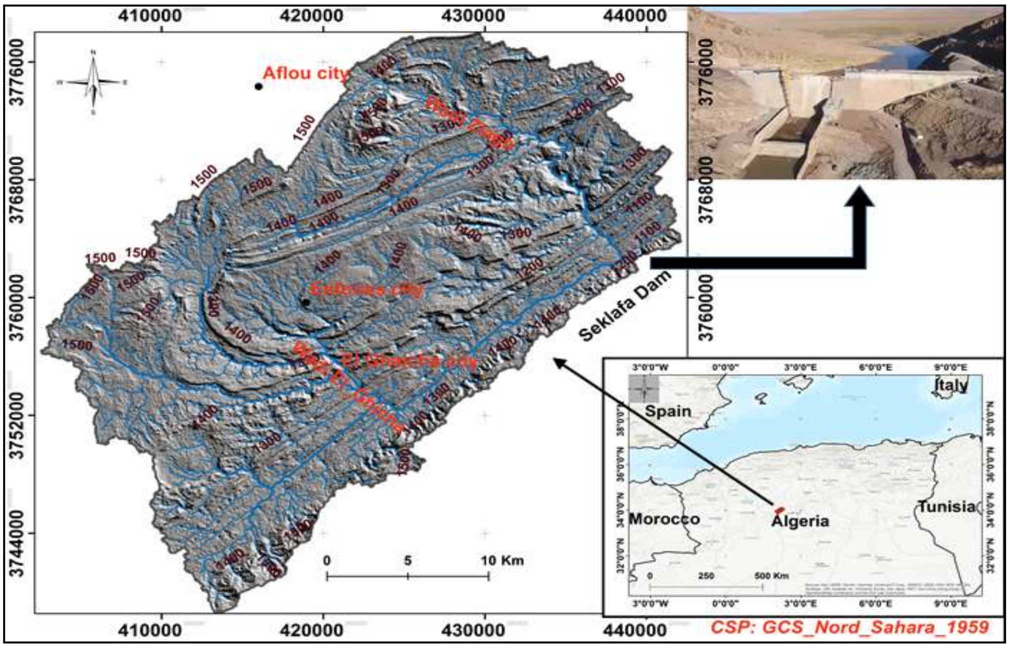

Figure 1 Study area

Wadi M’zi forms by far, the most important river with its principalaffluents: 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 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.

2.3 Methods for Studying Erosive Hazard in the Study Area

2.3.1 The RUSLE model

Since the 1940s, several authors have worked on the development of empirical models to quantify soil losses. Renard et al. (1997) describe the evolution of studies on mathematical modelling for erosion prediction.

The development of empirical models for estimating soil loss began with Zingg (1940) who formulated soil loss at slope length as well as slope. Smith (1941) determined factors for the influence of crops and conservation practices on soil loss (Laflen and Flanagan, 2013).

In 1947, Browning and his collaborators added the soil erodibility factor to Smith's equation, and prepared several tables of relative values of each factor for different soil types, crop rotations, and slope lengths. Smith and Whitt (1947) provided extensive data on clay soil losses on different slopes and for a wide range of cropping systems. Musgrave (1947) introduced the precipitation factor.

In 1948, Smith and Whitt proposed a "rational" equation for estimating soil losses, but on clay soils and under certain conditions (Sadiki, 2004).

The Universal Soil Loss Equation, USLE itself, was developed in the United States at the National Runoff and Soil Loss Data Center established in 1954. In 1958, cooperative research projects between the University of Perdue and the Federal State led to the development of an empirical land loss prediction model by Wischmeier and Smith. Twenty years later, i.e. in 1978, a more complete version of this formula was developed and published by these two researchers.

In 1997, Renard et al. proposed the RUSLE model, which has the same formula as the USLE of Wischmeier and Smith (1978). However, a number of improvements are being made in the determination of the various erosive factors. These include a different approach to soil erodibility K, a new equation for the topographic factor LS, and a new value for the C factor and conservation practices.

2.3.2 Use and objectives of RUSLE

Like the USLE model (Sadiki, 2004), the revised RUSLE universal land loss equation has been used around the world in parallel with the development of GIS and the rapid mapping and calculation capabilities it offers.

The RUSLE/GIS approach adopted for this work combines the Wischmeier model and the GIS mapping tool. It enables the potential for soil loss to be assessed at any point in the watershed. Better still, it provides an opportunity to compare the various actions or factors that need to be taken to limit the phenomenon of water erosion.This approach has the advantage of visualizing the territory, managing existing CES practices and reasoning about development opportunities (Renard et al., 2011; Jebari et al., 2012).

Some authors have used the equation on its own to quantify erosion, among others: Kouli et al.(2009); Grauso et al. (2010); Pradhan et al. (2012); Tanyas et al. (2015); Benchettouh et al.(2017).

Others have adapted RUSLE as a combined approach with solid transport in basins, for example; Arekhi et al.(2012); Marques Da Silva et al. (2012); Saygın et al. (2014); Abd-ElMonsef (2015).

2.3.3 The principle of the model

The soil loss equation is expressed by the following formula: A = R. K. LS. C. P

Where;

A: is the annual rate of soil loss in t/ha.

R: is the rain erosivity factor expressed in Mj.mm /ha.h.

K: is the soil erodibility, expressed in t. ha/Mj.mm.

LS: is a dimensionless factor that represents the slope (S in %) and the length of slope (L in m).

C and P : are dimensionless factors that represent, respectively, the effect of ground cover and the ratio that takes into account anti-erosion cultivation techniques

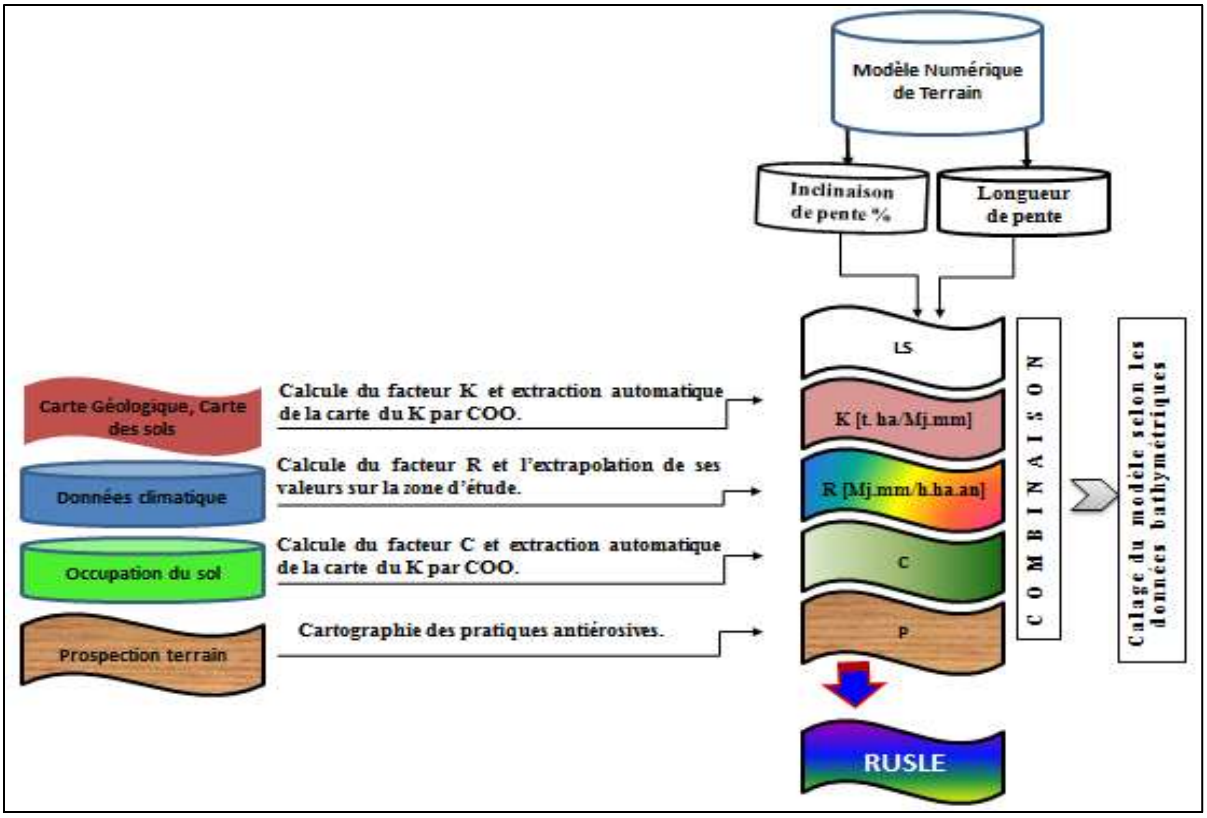

Figure 2 Methodological flowchart of the RUSLE/GIS approach (Benchettouh et al., 2017)

The various RUSLE factors are all ratios of soil loss relative to the influence of each factor, so that the product of the whole is the total soil loss rate for the study area. If one of the ratios tends towards 0 the soil losses tend towards 0. The various RUSLE factors are all ratios of soil loss relative to the influence of each factor, so that the product of the whole is the total soil loss rate for the study area. If one of the ratios tends towards 0 the soil losses tend towards 0.

The model of each factor has been highlighted under conditions where all other factors are equal to 1, so that the change in loss recorded is related only to the factor being varied.

The application of RUSLE for the modelling of soil losses through water erosion using spatial tools requires the calculation of the different factors involved in the erosive processes and their representation in the form of thematic maps (fig. 2).

2.4 The factors of the model

2.4.1 Erosivity of the rains

Precipitation erosivity (the R factor or Ec.I30) (in Mj.mm/ha.h.yr) in the RUSLE model is defined as a long-term average of the product of kinetic energy. The latter is responsible for the detachment of soil particles under the impact of raindrops (Ec) multiplied by the maximum intensity of rainfall in 30 minutes (I30) which expresses the effect of runoff.

The annual R-factor is the sum of the calculated R-factors of all showers exceeding 12.7 mm (Wischmeier and Smith, 1978). These showers should be separated from each other by more than 6 hours, during which less than 1.27 mm of rain falls. Wischmeier and Smith (1978) suggested a measurement period of 22 years for the estimation of rainfall erosivity to be meaningful (Sadiki et al., 2012).

The calculation of the R-factor by the direct method of Wischmeier and Smith (1978) can only be applied in areas that are equipped with a rain gauge that instantly records rainfall, but in the majority of cases, rainfall stations only record the daily average (Jebari, 2009).

The majority of authors who have used the RUSLE/USLE model for the quantification of water erosion, have adopted, for the calculation of the R factor, alternative equations based on easily collected data.

Numerous studies around the world show that rainfall erosivity is significantly correlated with annual precipitation (Van der Knijff and Jones, 1999; Lin et al., 2002; Yang et al., 2003; Torri et al., 2006; Xin et al., 2010; Dumas and Olivier, 2015). According to Lee and Heo (2011), the Modified Fournier Index (MFI) developed by Arnoldus (1977; 1980) for Morocco is a good example of this approach (Lahlaoi et al., 2015).

Recently, this index has been widely used in Europe (Ozsoy et al., 2012; Demirci and Karaburun, 2012) and Asia (Pandey et al., 2009; Prasannakumar et al., 2012).

Other approaches carried out in Mediterranean countries have been based on hourly, daily, monthly and annual data, such as in Italy (Diodato, 2004; Diodato and Bellocchi, 2010; De Paola et al., 2013), Spain (Nekhay et al., 2009) and Algeria (Meddi et al., 2016; Benchettouh et al., 2017).

To overcome this problem, in this work we used a simplified model to estimate the erosivity of rainfall R based on available data (annual precipitation and maximum daily rainfall/year). This model uses the concept of Diodato (2004; 2005) which is expressed as follows:

$$R_{Med}REM= b_0.P.\sqrt{}d\ (\alpha+b_1.L)\ (Mj.mm/ha.h.an)$$

Where:

b_0 =0,117 at Mj ha^{-1} h^{-1}.

b_1 = - 0,015 ($d^{0,5}$ $mm^{-0,50-1}$).

α = 2,00.

L : is the longitude of the study weather station expressed in decimal degrees.

P : is the mean inter-annual precipitation in millimetres and d is the maximum daily precipitation per year in millimetres.

2.4.2 K: Soil erodibility

Soil erodibility refers to its susceptibility to erosion processes (Benslimane, 2013).

It is a function of the soil's physical properties (texture, structure, permeability and organic matter content) and the cohesion between its particles. Low cohesion will lead to high erodibility (Govers et al., 1990; Poesen and Govers, 1990). Heusch (1970) and Demmak (1984) found that there is a close correlation between lithology and runoff intensity.

The K factor is therefore an empirical measure of soil erodibility conditioned by its intrinsic properties (Fu et al., 2005). It is related to permeability rate, texture type, organic matter content and other granulometric parameters such as clay, silt and fine sand (Renard et al., 1997).

2.4.3 LS:Topography

The L and S factors in RUSLE reflect the effect of topography on erosion. According to Wischmeier experiments, the rate of erosion increases with slope length. Indeed, the accumulation and acceleration of runoff on longer slopes increases its capacity to detach and transport particles (Zhang et al., 2013).

The length of the slope can be defined as the distance from the point of origin of the runoff to the point where the decrease in the degree of slope marks the beginning of sedimentation. It is measured in horizontal projection and not parallel to the ground surface (Wischmeier and Smith, 1978). Le facteur topographique (LS) a été calculé à partir de l'inclinaison des pentes et de leur longueur (Renard et al., 1997). Il est déterminé empiriquement à partir du modèle numérique de terrain (Kinnel, 2000; Van Remortel et al., 2001 ; Wang et al., 2002).

2.4.4 C: The vegetation cover

In the RUSLE model, the effect of vegetation cover is incorporated into the canopy management factor (El Garouani et al., 2008). It is defined as the ratio of soil losses on land cultivated under specific conditions to the corresponding soil losses on fallow land (Wischmeier and Smith, 1978). It is determined using empirical equations that contain field measurements of land cover (Wischmeier and Smith 1978; Renard et al., 1997). Recently, and with the evolution of remote sensing, researchers have developed many methods to estimate the C-factor using NDVI values (Wang et al., 2002; Lin et al., 2002). Ces méthodes utilisent le modèle de régression en faisant des analyses de corrélation entre les valeurs de facteur C mesurées sur le terrain ou obtenues à partir de tables de guidage et celles du NDVI dérivé des images satellitaires. The Normalized Difference Vegetation Index (NDVI), is an indicator of vegetation vigour and activity. The NDVI is a vegetation index that estimates leaf density and chlorophyll intensity. It is widely used in vegetation analysis because of its ability to reveal differences in vegetation cover that are not otherwise readily visible. The calculation of this index is based on the reflectance property of the vegetation cover in the visible red (RED) and near infrared (NIR) spectrum. It varies between (-1) (soil devoid of vegetation) and (+1) (high chlorophyll activity).

2.4.5 P :Anti-erosion techniques

Factor P explains the different agricultural and agro-forestry techniques that reduce the erosive potential of the soil; by their influence on drainage patterns, on the speed and concentration of runoff, and on the hydraulic forces resulting from surface soil runoff (Renard et al., 1991). It is a numerical expression of the overall effects of anti-erosion practices (contour ploughing, strip cropping, terracing, subsurface drainage, etc.) on soil losses in a particular site. For these practices affect water erosion by modifying the direction of surface flow by reducing the volume and speed of runoff (Renard et al., 1997). He quantifies these practices with values ranging from 1 for bare soil where no erosion control practices are used to 0.0001 for a dense mixed coniferous forest or a dense broadleaf forest (Panagos et al., 2015).

Indeed, contour tillage directs the roughness of the soil perpendicular to the slope in such a way as to slow runoff by reducing soil losses by up to 75% (Roose et al., 2012). A network of infiltration benches on slopes below 6% associated with an olive fruit tree, for example, reduces the erosive effect from 1 t/ha/year to 0.0227 t/ha/year (Panagos et al., 2015). A series of low walls built on slopes exceeding 12% with intensive cultivation can reduce erosion from 1 t/ha/year to 0.02 t/ha/year. When the slope of the land is gentle (< 12%), it is clearly preferable to use the dry-stone cord technique. the installation of the latter on steep slopes with the installation of weirs in the gullies suppress the runoff of small showers. And consequently reducing peak flows and thus the solid transports that silt up the dams (Albergel et al., 2004; Bergaoui et al., 2008). Well-protected rangelands, which reduce soil losses from 1 t/ha/yrto 0.0903 t/ha/yr, are also more effective than dry stone strips in an open rangeland where losses are estimated at 0.38 t/ha/yr (Panagos et al., 2015).

2.5 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 6 variables (R, K, LS, C, P and E) for 722 observations. XLSTAT 2014 statistical software was used for data processing.

Chapter III

Results and discussion

3 Results and discussion

3.1 RUSLS Factors

3.1.1 Rainfall erosivity(R-factor)

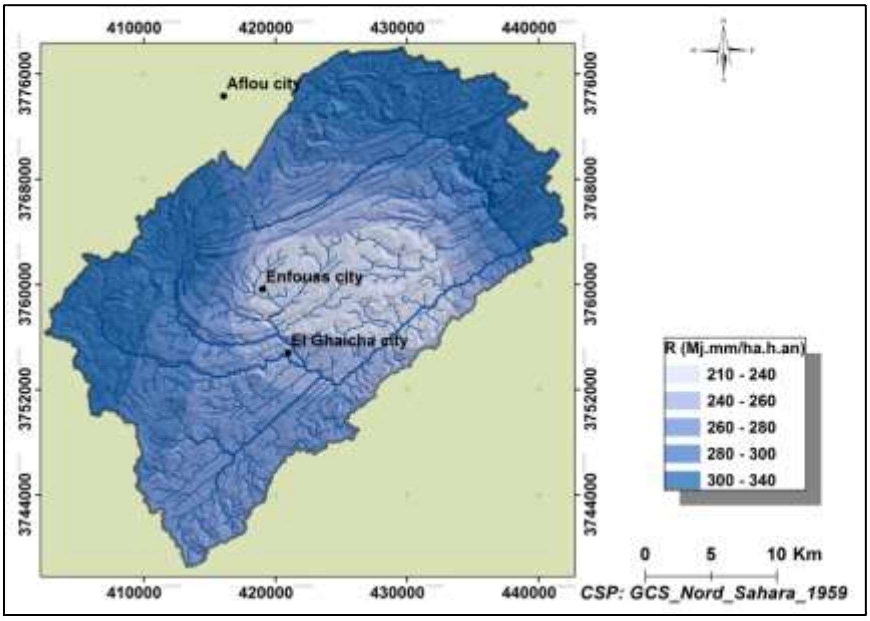

Figure 3 . Rainfall erosivity at 22 weather stations for the period 1978–2014

The highest R value (339 Mj.mm/ha.h.yr) was recorded in the north and west sectors, while the minimum value was recorded (210.6 Mj.mm/ha.h.yr) in the central sector of the watershed.

3.1.2 Soil erodibility (K-factor)

Tableau 2 Soil types and their K-factor values

Soil series (types)	K (t h MJ^{-1} mm^{-1})	Area Km²	Area %
Unaltered compacted soils with raw minerals	0.02	174.6	22.2
Cohesive soils fractured or moderately altered	0.05	39.7	5.0
Weakly or moderately compacted soils	0.10	444.9	56.5
Slightly soils resistant and highly weathered soils	0.15	55.7	7.1
Furniture soil, no-cohesive and detritic material	0.25	72.1	9.2
	Totals	787	100

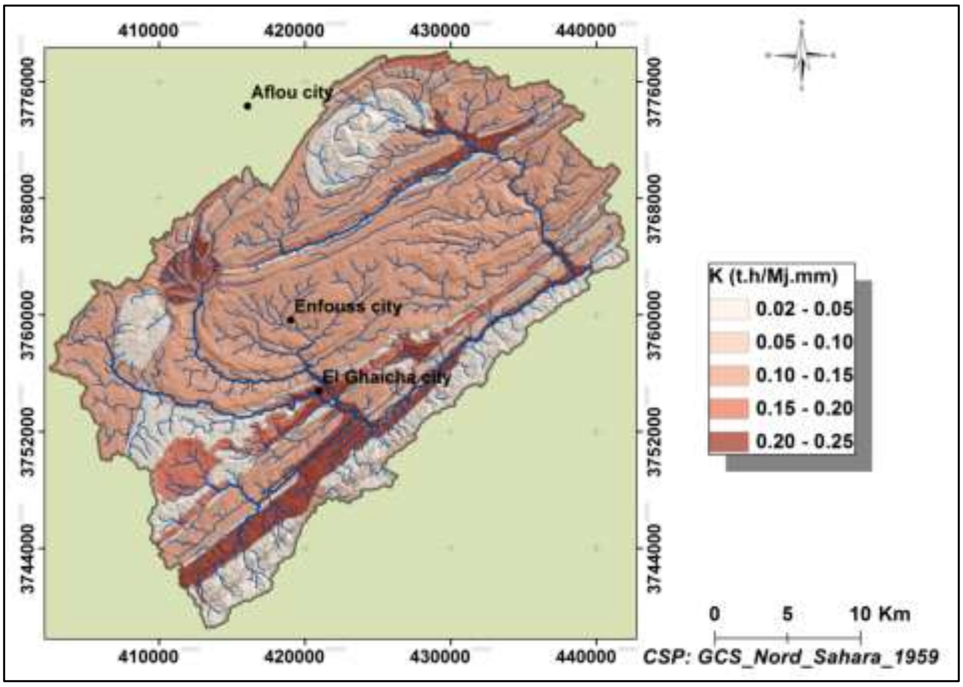

Figure 4 The K-factor map of Seklafa catchment

The estimated K values for the textural groups vary from 0.02 t h $MJ^{-1}.mm^{-1}$ of u*naltered compacted soils with raw minerals* (22.2% of area study)to 0.25 $t.h.MJ^{-1}.mm^{-1}$ for *furniture soil, no-cohesive and detritic material* (39.8% of study area) According to French classification suggested by Dumas (1964), 83.8% of study area is characterized by slight erodibility ($K < 0.1$ $t.h.MJ^{-1}.mm^{-1}$).

3.1.3 Topography (LS-factor)

The terrain factors in RUSLE represent slope length (L) and slope steepness (S). The amount of erosion increases as the slope length increases (Renard et al. 1997). The slope length is defined as the distance along the flow path from the origin of the overland flow to the point where deposition begins to occur (on concave slopes) or to a concentrated flow channel (Wischmeier and Smith 1978). The LS factor was calculated from the slope and its length. The LS factor is estimated from a DEM (Wang et al. 2002).

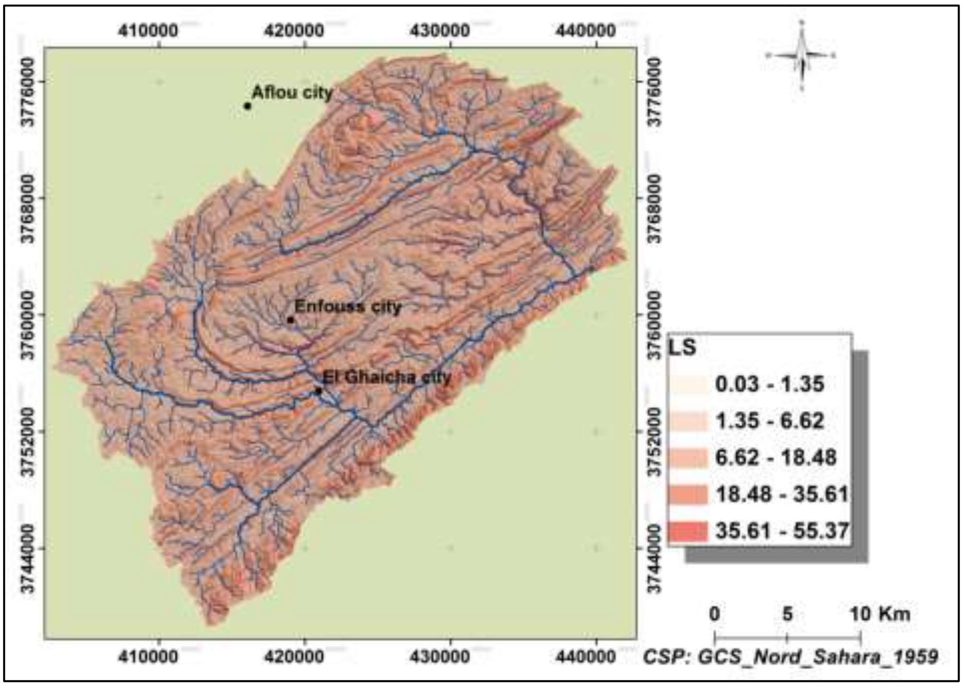

Figure 5 . The LS-factor map of Seklafa catchment

Where accumulation flows is the grid layer of flow accumulation expressed as the number of grid cells, and CellSize is the length of a cell side. The LS-factor was computed from a DEM of the study area by using ArcGIS 10.2 software (figure 5).

Tableau 3 LS classes of Saklafa catchment

LS Class	Area	
	Km²	%
0.03 - 1.35	15.1	1.9
1.35 - 6.62	188.0	23.9
6.62 - 18.48	474.3	60.3
18.48 - 35.61	108.3	13.8
35.61 - 55.37	1.3	0.2
	787	100.0

According to (Table 3) the LS factor values in the Saklafa watershed are between 0.03 and 55.37 with an average and a standard deviation of about 2.8 and 3.3 respectively. The majority of the surface (60.3%) of the study area included in the range of LS classes between 6.62 and 18.48.

3.1.4 Crop management (C-factor)

Tableau 4 Land use C-factor values

Land use	C-values	Area Km²	Area %
Agricultural land (intensive cultivation)	0.27	1.6	0.2
Pasture and bare land	0.32	469.8	59.7
Clear matorral	0.34	315.6	40.1
		787	100

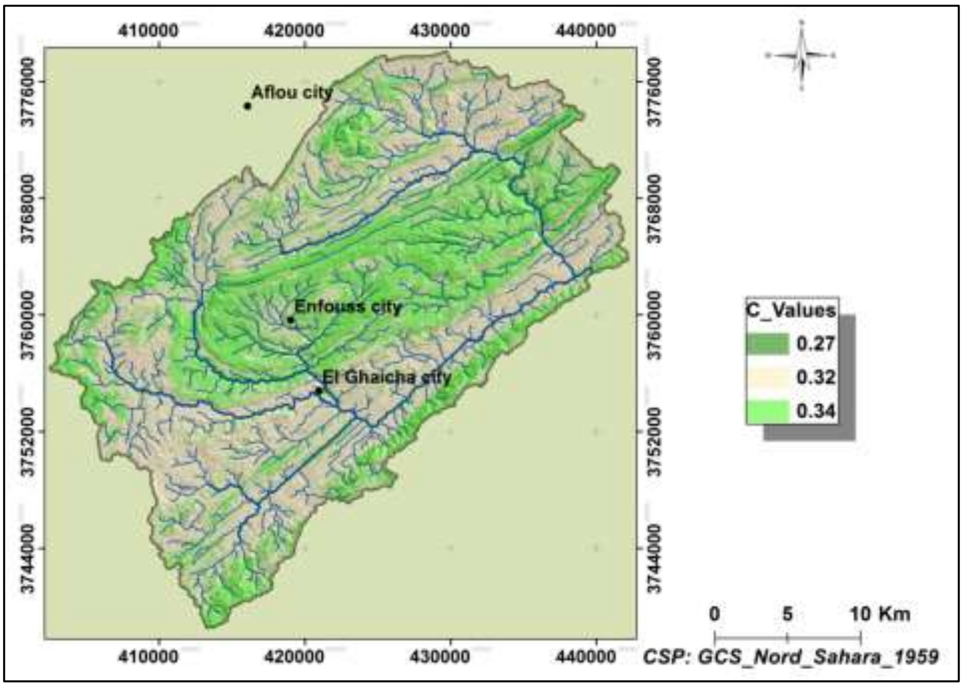

Figure 6 The C-factor map of Seklafa catchment

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.6) 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.

3.1.5 Support practices (P-factor)

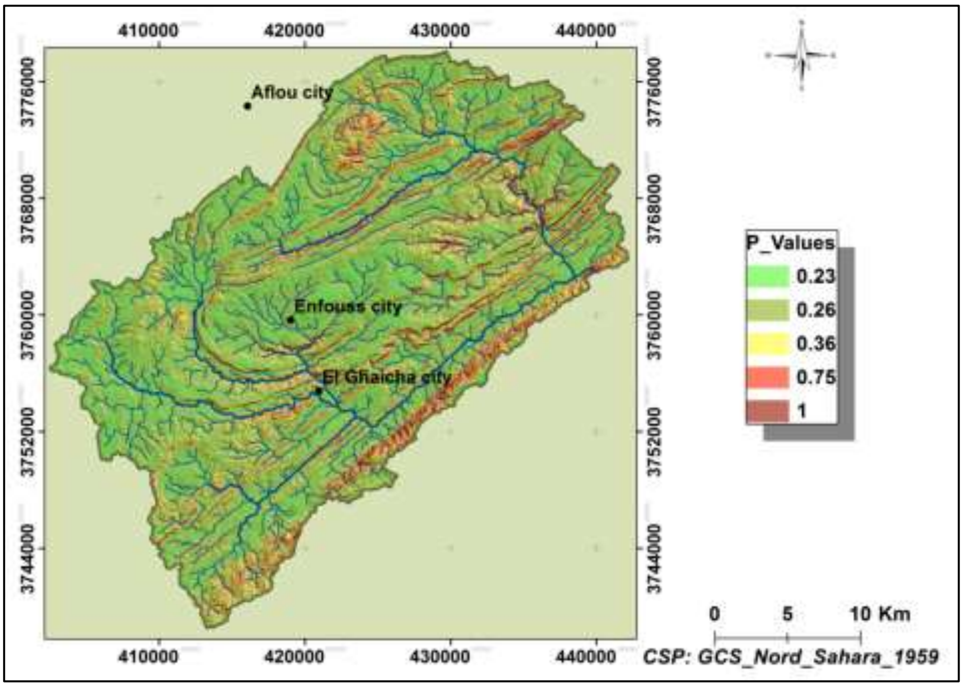

Figure 7 The P-factor mapofSeklafa catchment

3.2 The estimate of the soil loss

RUSLE is a predictive model based on empirical formulas relative to the five factors which control water erosion such as, the rainfall erosivity, the soil vulnerability, the topography, vegetable cover, and the conservation practices (Prasannakumaret al., 2012).The data layers (maps) extracted for R, K, LS, C, and P factors of the RUSLE model were integrated within the raster calculator option of the ArcGIS 10.2 spatial analyst tools in order to quantify, evaluate, and generate the maps of soil erosion risk and severity for Seklafa cachment. The synthetical map of soil loss (figure 8), shows that rate of erosion differs from zone to another according to the influence of each factor which controls the water erosion. The average soil erosion rate estimated for the upland watershed ranges from 0 to + 430.2 t/h/yr with an annual average of 7.56 t/ha and a standard deviation of 9.63 t/ha/yr.

In Algeria, no classification of soil loss was announced. According to Wischmeier and Smith (1978), the soil can support a loss going up to 12 t/ha/yr. In Tunisia, Masson (1971) noted that the average soil loss will not have to exceed a threshold 10 t/ha/yr. This observation is in agreement with some study relating to this aspect in the Mediterranean basin (Demirci and Karaburun, 2012; Ozsoyet al., 2012). Other researchers announce that the tolerable soil loss threshold cannot be more than 5 t/ha/yr (Prasannakumaret al., 2012). In Morocco, areas similar to our study area, such as, the basins of the WadiTlata and the WadiBoussouab their soils can support soil loss higher than 7.4 t/ha/yr while supporting durably an elevated level of agricultural production (Sadiki, 2004; Yjjouet al., 2014). According these authors, if soil lossexceeds a threshold 20 t/ha/yr, they can become strong and dangerous. In Tunisia, according tothe study of Jebariet al. (2012) carried out on the watershed WadiJannet, a tolerance level 8/ha/yrwas suggested, above, the erosion risk level will be high.

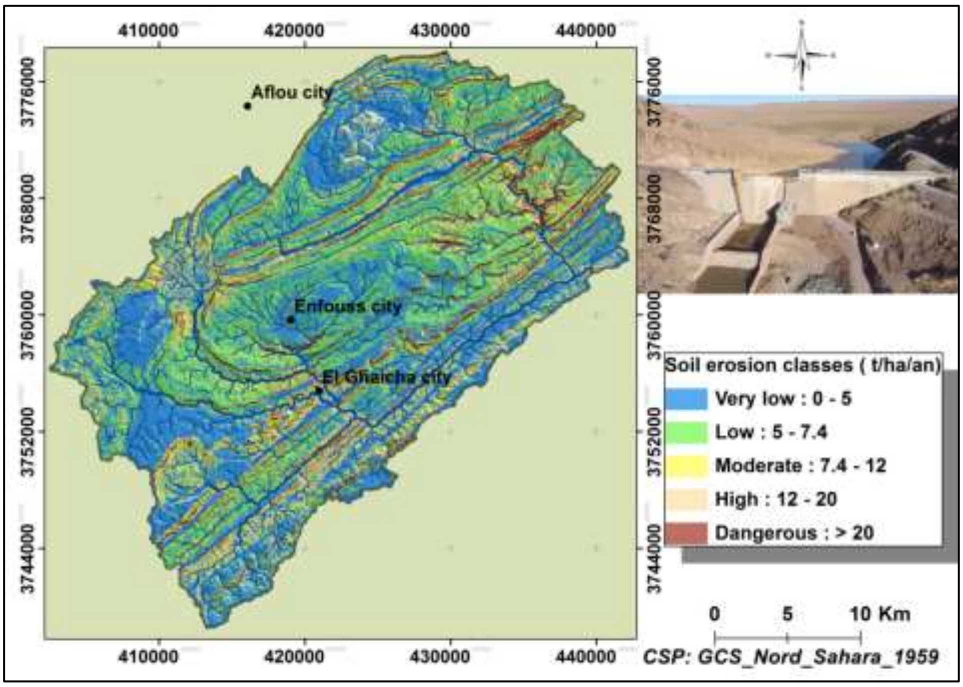

Figure 8 Soil erosion map in Seklafa catchment

Tableau 5 Soil erosion severity zones with erosion rate and area covered

Erosion classes	Area	
	(Km²)	%
Very low : 0 - 5 t/ha/an	353.9	45.0
Low : 5 - 7.4 t/ha/an	202.1	25.7
Moderate : 7.4 - 12 t/ha/an	138.7	17.7
High : 12 - 20 t/ha/an	35.2	4.5
Dangerous : > 20 t/ha/an	56.0	7.1
Totals	785.9	100

Taking into account the goal pursued aiming at identifying the areas participating to silting the dam Seklafa; we took into account all thresholds so that we can divide our study area into sectors treated by priority according to degree of erosive risk.The assessed average annual soil loss of Seklafa catchment was grouped into different classes based on the minimum and maximum values. The results presented in (table 5) show that about 45 % of the study area is classified asvery low potential erosion risk (< 5 t/ha/yr), 25.7 % of study area is classified as low potential erosion risk (between 5 and 7.4 t/ha/yr), 17.7 % of study area is classified as moderate potential erosion risk (between 7.4 and 12 t/ha/yr), 4.5 % of study area is classified as high potential erosion risk (between 12 and 20 t/ha/yr) and 7.1 % of study area is classified as high potential dangerous erosion risk more than 20 t/ha/yr. The mean soil loss rate estimated at 7.56 t/ha/yr is located in sectors at the moderate erosive risk.

3.3 Statistical analysis PCA: effect of erosive factors

Principal component analysis (PCA) is a widely used statistical technique (Eslamian et al., 2010), consisting of representing as much graphical information as possible in a table. It reduces the number of variables to those which are the most significant among a set of variables used in order to find a link between these and individuals to group them into homogeneous regions (Baba Hamed and Bouanani, 2016).

In this statistical approach, we submitted six quantitative parameters (variables) (including the erosion product), explaining water erosion. The purpose of this statistical analysis is to determine the effect of five factors constituting erosive risk by deducing the most characteristic parameters. To do this, a correlation matrix was used and the components were determined according to the type of rotation of the orthogonal axes explaining the percentage of inertia.

Tableau 6 Eigenvalues of the correlation matrix of the explanatory parameters

	F1	F2	F3
Valeur propre	2.1607	1.3159	0.9974
Variabilité (%)	36.0111	21.9325	16.6229
% cumulé	36.0111	57.9436	74.5665

(Table 6) shows that the first three factors represent the maximum amount of information. Thus these first three factor axes express 74.57 % of the total variance, with 36.01% for the first factor (F1), 21.93% for the second factor (F2) and 16.62% for the third factor (F3). This percentage of inertia allowed us to deduce that we have an excellent summary which almost perfectly synthesizes the ten variables.

Tableau 7 Correlation matrix (Pearson (n)

Variables	R	K	LS	C	P	E
R	**1**					
K	**0.0966**	**1**				
LS	**0.1428**	0.0186	**1**			
C	**0.3893**	**0.1537**	**0.1334**	**1**		
P	0.0521	**-0.0736**	**0.2307**	**0.0969**	**1**	
E	**0.1639**	**0.2215**	**0.7765**	**0.1276**	**0.4473**	**1**

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

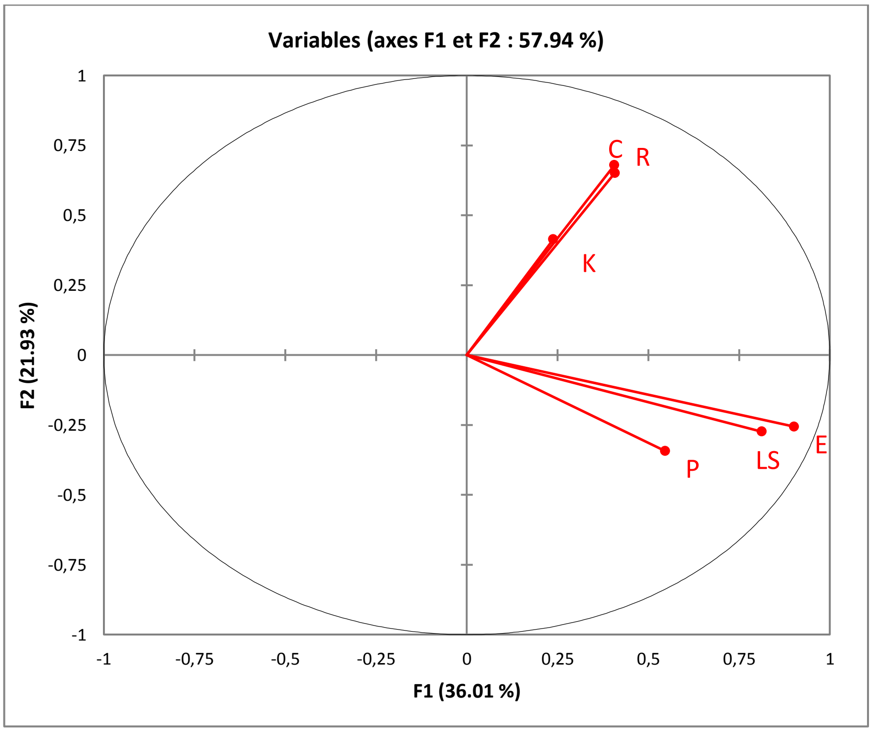

Figure 9 Erosive parameters correlation circle

Analysis of the correlation matrix (Table 7and fig. 9) shows that the erosion risk (E) is strongly and positively correlated with topography (LS) (0.776%) and management factor (P) (0.447%) and is moderately positively correlated with the erodibility (K) (0.22%), rainfall (R) (0.164%) and cover crop (C) (0.128%).

conclusion

Traditional methods of determining areas at risk of erosion, even for a small watershed, would require an enormous amount of data and would demand enormous computational work. RUSLE is a very effective technique for quantitatively assessing the average soil loss in a watershed. In order to spatially visualize areas prone to erosion, RUSLE could be integrated into the GIS platform. This allows us to quantitatively assess soil erosion, pinpoint areas at risk and develop appropriate planning measures for the implementation of better land-use management practices. The catchment of Seklafa covers an area of 787 km^2. The mean soil loss rate estimated at 7.56 t/ha/yr is located in sectors at the moderate erosive risk as high potential dangerous erosion risk more than 20 t/ha/yr is covering 7.1%. The estimated annual average soil loss in the Seklafa catchment area has been classified into five the various classes, from very low potential erosion risk to high potential dangerous erosion risk. These different land categories require intervention measures to control the rate of soil erosion. The results can be used as basic data to assist in slope management and land use planning, but the methods used in the study are valid for generalized planning and evaluation purposes. However, in order to optimise the allocation of resources for the reduction of siltation of the SEKLAFA dam in the short term, we propose that only these priority areas receive special attention in terms of erosion control. Suggested erosion control interventions in these areas are reforestation, planting of fruit trees and some resistant species - Opuntia to increase vegetation cover on the slopes. In addition, to reduce the effect of erosive runoff, these areas also require the placement of hedges, logs, stones, logs and drains, and outlets on slopes and ravines.

bibliograph

1. Abercrombie, D., Akchurin, N., Akilli, E., Maestre, J. A., Allen, B., Gonzalez, B. A., ... & Backović, M. (2020). Dark matter benchmark models for early LHC run-2 searches: report of the ATLAS/CMS dark matter forum. *Physics of the Dark Universe*, *27*, 100371.

2. Bouguerra, S., Bouanani, A., & Baba-Hamed, K. (2016). Transport solide dans un cours d'eau en climat semi-aride: cas du bassin versant de l'Oued Boumessaoud (nord-ouest de l'Algérie). *Revue des sciences de l'eau/Journal of Water Science*, *29*(3), 179-195.

3. Bouguerra, S., Bouanani, A., & Baba-Hamed, K. (2016). Transport solide dans un cours d'eau en climat semi-aride: cas du bassin versant de l'Oued Boumessaoud (nord-ouest de l'Algérie). *Revue des sciences de l'eau/Journal of Water Science*, *29*(3), 179-195.

4. Bravo, R., Montaner, T., & Pina, J. M. (2012). Corporate brand image of financial institutions: a consumer approach. *Journal of Product & Brand Management*.

5. Chrigui, M., Gounder, J., Sadiki, A., Masri, A. R., & Janicka, J. (2012). Partially premixed reacting acetone spray using LES and FGM tabulated chemistry. *Combustion and flame*, *159*(8), 2718-2741.

6. Defurne, M., Mazouz, M., Ahmed, Z., Albataineh, H., Allada, K., Aniol, K. A., ... & Brossard, M. (2016). Rosenbluth separation of the π 0 electroproduction cross section. *Physical review letters*, *117*(26), 262001.

7. D'souza, V. P. C., & Morgan, R. P. C. (1976). A laboratory study of the effect of slope steepness and curvature on soil erosion. *Journal of agricultural engineering research*, *21*(1), 21-31.

8. Fayas, C. M., Abeysingha, N. S., Nirmanee, K. G. S., Samaratunga, D., & Mallawatantri, A. (2019). Soil loss estimation using rusle model to prioritize erosion control in KELANI river basin in Sri Lanka. *International Soil and Water Conservation Research*, *7*(2), 130-137.

9. Ganasri, B. P., & Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. *Geoscience Frontiers*, *7*(6), 953-961.

10. García-Ruiz, J. M., Nadal-Romero, E., Lana-Renault, N., & Beguería, S. (2013). Erosion in Mediterranean landscapes: changes and future challenges. *Geomorphology*, *198*, 20-36.

11. Hoffmann, M., Kleine-Weber, H., Schroeder, S., Krüger, N., Herrler, T., Erichsen, S., ... & Müller, M. A. (2020). SARS-CoV-2 cell entry depends on ACE2 and TMPRSS2 and is blocked by a clinically proven protease inhibitor. *Cell*

12. Pandey, M. K., Lin, Y. C., & Ho, Y. K. (2016). Positronium formation in collisions between positrons and alkali-metal atoms (Li, Na, K, Rb and Cs) in Debye plasma environments. *Journal of Physics B: Atomic, Molecular and Optical Physics*, *49*(3), 034007

13. Poesen, J. W., van Wesemael, B., Bunte, K., & Benet, A. S. (1998). Variation of rock fragment cover and size along semiarid hillslopes: a case-study from southeast Spain. *Geomorphology*, *23*(2-4), 323-335.

14. Reda, A. A., Almaw, G., Abreha, S., Tadeg, W., & Tadesse, B. (2020). Bacteriospermia and Sperm Quality of Cryopreserved Bull Semen Used in Artificial Insemination of Cows in South Wollo Zone, Ethiopia. *Veterinary Medicine International*, *2020*

15. Remini, B., & Benfetta, H. (2015). LE BARRAGE RESERVOIR DE GARGAR EST-IL MENACE PAR L'ENVASEMENT?. *LARHYSS Journal P-ISSN 1112-3680/E-ISSN 2602-7828*, (24), 175-192

16. Renard, K. G. (1997). *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. United States Government Printing.

17. Roose, S. P., Glassman, A. H., Attia, E., & Woodring, S. (1994). Comparative efficacy of selective serotonin reuptake inhibitors and tricyclics in the treatment of melancholia. *The American journal of psychiatry*.

18. Taylor, A., Rockall, A. G., & Powell, M. E. B. (2007). An atlas of the pelvic lymph node regions to aid radiotherapy target volume definition. *Clinical oncology*, *19*(7), 542-550.

19. Toubal, A. K., Achite, M., Ouillon, S., & Dehni, A. (2018). Soil erodibility mapping using the RUSLE model to prioritize erosion control in the Wadi Sahouat basin, North-West of Algeria. *Environmental monitoring and assessment*, *190*(4), 210.

20. Toumi, H., Boumaiza, M., Millet, M., Radetski, C. M., Felten, V., & Férard, J. F. (2015). Is acetylcholinesterase a biomarker of susceptibility in Daphnia magna

21. Villani, F., Civico, R., Pucci, S., Pizzimenti, L., Nappi, R., De Martini, P. M., ... & Amoroso, S. (2018). A database of the coseismic effects following the 30 October 2016 Norcia earthquake in Central Italy.

22. Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning* (No. 537). Department of Agriculture, Science and Education Administration.