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Presented by

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Assessment of management strategies to control water erosion: A GIS based RUSLE approach.

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DEDICATION

I dedicate my dissertation work to the soul of my father and my mother Abed-Elhamid and Rebaia (May Allah be merciful to hem), and to my wonderful family. A special feeling of gratitude to my Biological parents: Abed-Elkrim and Fatima. To all my sisters, and my brothers: Zino, Abed-Elmadjid, Soufien who have always encouraged me. I also dedicate this work to my friends and all my other family members who have supported me through the period. I will always appreciate all that you have done for me.

STATEMENT OF THE AUTHOR

I NOUARI Ali, hereby declare that this thesis represents my original work and has not been submitted to another institution for the award of a degree, diploma, or certificate. I also declare that all words and ideas from other works presented in this thesis have been duly cited and referenced in accordance with the academic rules and regulations.

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ABBREVIATIONS

USLE: Universal Soil Loss Equation

MUSLE: Modified Universal Soil Loss Equation

RUSLE: Revised Universal Soil Loss Equation

GIS: Geographical Information System

NDVI: Normalized Difference Vegetation Index

FAO: The Food and Agriculture Organization

WEPP: The Water Erosion Prediction Project

DEM: Digital Elevation Model

USGS: United States Geological Survey

MFI: The Modified Fournier Index

OM: Organic Matter

SDGs: Sustainable Development Goals

UN: The United Nations

ANBT: L'Agence National des Barrages et Transferts (The National Agency for Dams and Transfers)

MENA: Middle East and North Africa region

ABH: Agence de Bassin Hydrographique (watershed agency)

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ABSTRACT

The aim of this study is to assess the management strategies used to control soil erosion over the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha; three adjacent watersheds in the northeast of Algeria. The assessment of soil loss amounts at an annual basis was conducted through a GIS-based RUSLE approach using data from both open access databases and field observations. The performances of three common types of support practices (Terracing, Strip cropping, and Agroforestry) were evaluated and compared. For a better assessment, the modelling of soil loss amounts was performed in two ways “without” and “with” integrating the existing support practices. In both cases, the application of the RUSLE model showed in general acceptable soil loss amounts due to the dense vegetation cover that characterizes the studied areas. Yet, the results indicated that the application of erosion control measures in agricultural areas was successful, especially in Ain Berda watershed where the reduction in the annual soil loss was estimated at about 14.79%. Concerning, the watersheds of Oued El-Aneb, and Oued Fregha the participation of these support practices in the reduction were relatively low, of 7.72 % in Oued El-Aneb and 2.42% in Oued Fregha. By comparing the techniques among themselves, it appears that terracing is the most applied technique in the three watersheds and logically gave the greatest reduction rate which was about 12.96%, 5.86%, and 1.42% in Ain Berda, Oued El-Aneb, and Oued Fregha respectively. The study comprised, also a patience of the farmers’ opinions about their views of erosion problems and their conservation knowledge and practices.

Key words: soil erosion, RUSLE, GIS, support practices, watershed.

RÉSUMÉ

L'objectif de cette étude est d'évaluer les stratégies utilisées pour contrôler l'érosion des sols dans les bassins versants de Ain Berda, Oued El-Aneb, et Oued Fregha ; trois bassins versants voisins dans le nord-est de l'Algérie. L'évaluation des taux de perte de sol sur une base annuelle a été réalisée à travers l'intégration du modèle RUSLE dans le SIG et en utilisant des données provenant de bases de données en libre accès et d'observations sur le terrain. Trois types de pratiques antiérosives ont été identifiés dans les trois bassins étudiés (Terrasse, Culture en bandes et Agroforesterie). Leurs performances en termes de réduction des taux d'érosion ont été évaluées et comparées. Pour une meilleure appréciation, la modélisation a été réalisée en deux phases : " sans " et " avec " l'intégration des trois pratiques suscitées. Dans les deux cas, l'application du modèle RUSLE a montré des taux de perte de sol généralement acceptables dans tous les bassins versants étudiés en raison de la couverture végétale dense qui les caractérise. Toutefois, les résultats ont indiqué que l'application des trois pratiques antiérosives dans les zones agricoles a été un succès, en particulier dans le bassin versant d'Ain Berda où la réduction de la perte annuelle de sol a été estimée à 14,79%. En ce qui concerne les bassins versants d'Oued El-Aneb et Oued Fregha, la participation de ces pratiques à la réduction était relativement faible, de 7,72 % à Oued El-Aneb et de 2,42 % à Oued Fregha. En comparant les techniques entre elles, il apparaît que le terrassement est la technique la plus répondue dans les trois bassins versants et a logiquement donné le plus grand taux de réduction qui était d'environ 12,96%, 5,86%, et 1,42% à Ain Berda, Oued El-Aneb, et Oued Fregha respectivement. L'étude comprenait également une patience des opinions des agriculteurs sur l'étendue de leurs connaissances du phénomène, ses conséquences et des pratiques de conservation.

Mots-clés: Érosion du sol, RUSLE, SIG, pratiques de soutien, bassin versant

CHAPTER 1

INTRODUCTION

1.1 Background to the problem:

Soil erosion ranks among the major environmental problems that hydrologists are dealing with, nowadays. It decreases the productivity of agricultural lands, leads to the loss of storage capacity of dams and reservoirs, and deteriorates the water's quality, etc. The accentuation of soil degradation depends on several anthropogenic and climatic factors favouring the start and the development of erosion processes, for instance, the increase of drought frequency, the expansion of urban areas, deforestation and inappropriate management of agricultural lands has led to an increased risk of soil erosion.

Globally, around 1643 million ha of land area has been affected by soil erosion (Lal, 2003), causing profound impacts on the quality of soil and surface water (Keesstra et al., 2016; Mukundan et al., 2013). In developing countries, soil erosion is becoming a limiting factor in agricultural productivity. About 65% of Africa's agricultural land is degraded owing to soil erosion (Arekhi, 2008).

The Mediterranean Basin has the reputation of being subject to very high erosion risks (Hudson, 1991), especially in the Maghreb countries (Algeria, Tunisia, and Morocco) (Tachi et al., 2020). The specific erosion rate in the northern part of these countries exceeds tolerance thresholds; for instance Demmak, (1982) observed an erosion rate at the level of Oued Agrioum (north-eastern Algeria) of 50 [ton/ha/year]. In Tunisia, about 3 million hectares of land is really affected by this phenomenon, half of which is severely affected by medium to strong erosion risk (Achouri. et al, 1995). In Morocco, the specific degradation of land is often greater than 35 [ton/ha/year] has been observed at the watershed levels of the Oued Telata, Oued Lebène, and Oued Ourgha (Ismaili and Tribak, 2004).

In these last decades, a considerable number of predictive models have been developed in these last decades to evaluate soil erosion such as WEHY (Kavvas et al., 2006) , SWAT and GWLF (Qi et al., 2017), SEDEM (Feng et al., 2010), to mention a few. The most widely used model for this purpose is USLE/RUSLE model which is an empirical and spatialized model that was firstly introduced by Wischmeier and Smith (1978) as the Universal Soil Loss Equation “USLE”. Later on, it was modified by Renard et al. (1997) and, consequently, renamed as the Revised Universal Soil Loss Equation “RUSLE”. The RUSLE kept the basic structure of the USLE and included new research findings on the estimation of the factors conditioning the erosion process. The RUSLE presents a major advantage, which is the possibility to link with the remote sensing (RS) and the Geographical information system (GIS) technologies, which makes it very useful for analysing the spatiotemporal evolution of soil erosion potential (Giandon, 2015).

In Algeria, USLE/RUSLE model was employed by Bouguerra et al., (2017) to evaluate soil loss in the Bouhamdane watershed feeding Hammam Debagh dam and by Bouhadeb et al. (2018) for assessing soil erosion in the Bou-Namoussa watershed (North-eastern Algeria) that feeds Cheffia dam's reservoir. In both cases, the model gave an estimation of the spatial distribution of the average annual soil loss rates and highlighted the most vulnerable regions to soil erosion. Furthermore, the results were validated in both watersheds by comparing the quantities of sediments simulated by RUSLE to those deposited in the dam's reservoirs.

1.2 Problem statement:

Algeria is classified among the countries with the most erodible soils in the world. According to Heddadj, (1997) approximately 6 million hectares is exposed to active erosion, which makes them highly vulnerable to several types of risks such as the loss of crop productivity, the deterioration of water quality and the sedimentation of water bodies. The annual loss in the storage capacity of dams due to sedimentation is about 65 million m^3 (Remini, 2017).

In front of this situation, during these last years, the concerned authorities established a number of decisions and actions especially over dam basins. Several strategies and techniques (mechanical, biological, and agricultural) used to improve water and soil conservation (WSC) (Habi and Morsli, 2013). These strategies are based on the mobilization, collection, conservation, and dissipation of runoff such as: The systems of mobilization and storage of runoff and flood water. These are surface storage structures for small and medium capacity (an earth dam). They have a multitude of uses: irrigation of small areas, water supply for rural populations and livestock, regulation of the river flows, and retention of sediments, especially in the gully erosion. Runoff capture systems on drainage and valleys: The function of these systems is to capture or collect water runoff and their sediment load from the tops of the hills, and the uncultivated areas. The collected water is distributed on agricultural fields or oriented toward stones delimiting basins at the foot of the trees systems to improve infiltration. It is applied generally on agricultural areas for the management and conservation of water and soil. These systems involve structures such as terracing and different farming practices and technologies that reduce the risk of water and increase production and income. The system of dissipation of runoff energy is mostly used on sloping land by installing some techniques like (hedges, stone columns, stone walls, slopes covered with trees, and various herbs: olives, almond, acacia), the main reason for applying this system is to reduce the velocity (the kinetic energy) of the overflow during the rainfall season. Lastly, flood waters bypass systems are currently used in the steppe zones (arid) to control floods during storm rainfall. Diverted water is redistributed through channels or artificial waterways for irrigation of cultivated areas.

These strategies are classified according to their functions in five classes (mobilization, storage, capture, dissipation of runoff, flood water bypass, improving infiltration). But the main question that arises: Are those techniques sufficient to improve water and soil conservation? And what is the limitation of their application?

1.3 Objective of the research:

1.3.1 Main objective:

The main objective of the present study is to assess the effect of several forms of soil conservation practices on soil erosion rates at a watershed scale through the combination of a variety of techniques mainly the geographical information system GIS, and the empirical model RUSLE.

1.3.2 Specific objectives:

The specific objectives of this study are:

1) Estimate the P-factor values for arable lands in Algeria based on the Agricultural Policy implementation.

2) Assess the impact of conservation practices such as; Terracing, Strip-cropping, and Agroforestry in reducing soil loss.

3) Investigates the degree of awareness of farmers towards the risk of soil erosion.

1.4 Research questions and the working hypothesis:

1.4.1 Research questions:

1. What data are needed to assess soil erosion?
2. How can we recognise and localize the different types of soil conservation practices?
3. How can we identify the region most vulnerable to erosion?
4. How important are conservation practices in reducing soil erosion?
5. What are the problems encountered by farmers in applying soil conservation practices?
6. What are the most efficient soil conservation practices in the study areas?

1.4.2 Working hypothesis:

It is universally known that farmers may find many difficulties in implementing soil conservation practices in particular due to the lack of information regarding the location of steep slopes, most erodible soils and permanent and intermittent watercourses. Moreover, the majority of farmers worldwide do not have an idea about soil conservation practices or which practice is efficient for a given land. Accordingly, we believe that the development of GIS decision-making tool will help in understanding the soil erosion process and may help in improving soil conservation strategies and thus the amount of soil loss can be significantly reduced.

1.5 Significance of the research:

This study is supposed to provide policy-makers in Algeria with useful information to promote food security, empower public participation in natural resource management, and propose simple and efficient methods to conserve and protect the environment. Through the combination of advanced technologies and fieldwork, the present study investigates the effects of different existing erosion control strategies in three different watersheds located north-eastern Algeria. Besides this study demonstrates through real study cases the current situation in terms of soil conservation policy and its real-time application and highlights the main problems encountered by farmers in applying soil conservation practices. The findings of this study can help the decision-making authorities in the establishment of erosion management strategies. In addition, they will assist farmers and herders to cope with soil erosion risk.

1.6 Thesis organization

The content of this thesis is organized into six chapters:

- The first chapter presents an overview of the study, it including the scientific problem statement, the research questions and the scope of the study.
- The second chapter presents a literature review of soil erosion process along as well as the various tools and methods generally employed in modelling soil erosion.
- The third chapter describes the studied watersheds in terms of geographic localization, topography and climate.
- The fourth chapter presents the methodology adopted in implementing the study.
- The fifth chapter focuses on results and discussions.
- Finally, the sixth chapter presents a summary of the major findings as well as the recommendations and conclusions.

1.7 Limitation of the study:

1. The number of visited points is limited because of:
   - Health condition, and confinement
   - Some areas are rugged and there are no paths to arrive to.
   - During the period of study, the country has faced a large number of forest fires which made visits to some areas very difficult.
2. Data availability,
3. Difficulty in getting approval to pass an internship in companies or administrations related to water sector, and collecting the necessary data to enhance this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction:

Soil is the earth's fragile skin that anchors all life. All kinds of vegetation are cultivated or managed in the soil to provide the food that we and many animals eat. The same holds for fibres used in textile production, such as cotton. Plants are also used as fuel like firewood or ethanol fuel. Soil is not only the medium for plants to grow. We depend on soil also to build our homes and cities, support transportation, and enable recreation. Yet we disregard this crucial and precious resource that lies right under our feet.

According to the FAO (Food and Agricultural Organization of the United Nations), human well-being and the soil are intrinsically connected. Soil are the foundation of food production and food security .soil are the earth's largest water filter and storage tank, Soils also supply plants with nutrients, water and support for their roots, contain more carbon than all above ground vegetation, and host a huge diversity of organism key for healthy ecosystems. The intergenerational technical panel on soils and 200 soil scientists from 60countries worked on the first status of the world's soil resources report. The report provides a global perspective on the current state of soil, while there is cause for optimism in some regions. Today 33% of global soils are exposed to moderate to high degradation, most significant threats to soil globally are erosion, loss of organic carbon, nutrient imbalances, and soil sealing. Loss of soil resources and functions can be stopped by the use of: Sustainable soil management, scientific and local knowledge, and proven approaches and technologies can increase nutritious food supply, reduce climate change impacts, and help safeguard ecosystem services.

Soil erosion ranks amongst the major environmental hazards that hydrologists are dealing with nowadays (Tachi et al., 2020). Soils can be degraded physically, chemically and biologically. According to Pimentel, (2006) it is one of the most serious environmental and public health problems facing human society. Humans obtain more than 99.7% of their food from the land and less than 0.3% from the oceans and other aquatic ecosystems. Each year about 10 million ha of cropland is lost due to soil erosion, thus reducing the cropland available for food production. Overall soil is being lost from land areas 10 to 40 times faster than the rate of soil renewal imperilling future human food security and environmental quality.

2.2 Water erosion types:

According to Blanco-Canqui and Lal, (2008), on global level, most severe type of soil erosion is water erosion. Water erosion refers to the detachment of soil particles from its original place due to movement of water (rain, runoff, irrigation and snowmelt). The transportation of soil organic and inorganic particles with the water flowing along the slope is subsequently deposited in surface water bodies and at lower landscape locations. The new soil reservoirs, streams or simply fill lakes are formed from these transported materials. Water erosion is very widespread in the humid and sub-humid areas of the world that are characterized by repeated rainstorms as well as in the arid and semiarid regions that have limited precipitation in the form of torrential rain. There are many types of water erosion: splash, sheet, rill, gully, tunnel, and mass movement erosion.

2.2.1 Splash erosion:

Splash erosion is the first stage of the erosion process. It occurs when raindrops hit bare soil. The explosive impact breaks up soil aggregates so that individual soil particles are 'splashed' onto the soil surface. The splashed particles can rise as high 60 cm above the ground and move up to 1.5 metres from the point of impact. The particles block the spaces between soil aggregates, so that the soil forms a crust that reduces infiltration and increases runoff.

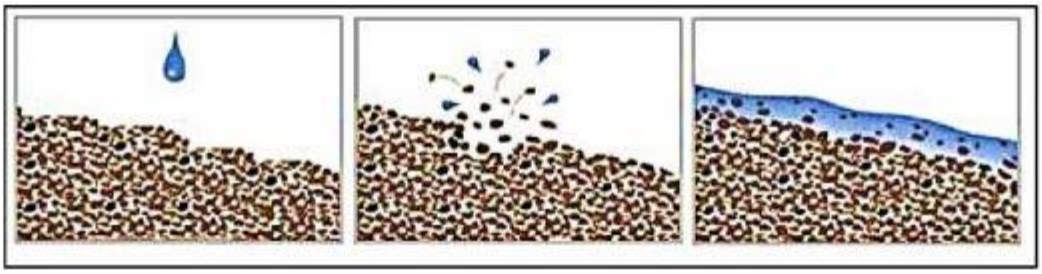

Fig.2.1. Splash erosion

2.2.2 Sheet erosion:

Sheet erosion is the removal of soil in thin layers by raindrop impact and shallow surface flow. It results in loss of the finest soil particles that contain most of the available nutrients and organic matter in the soil. Soil loss is so gradual that the erosion usually goes unnoticed, but the cumulative impact accounts for large soil losses. Soil most vulnerable to sheet erosion are overgrazed and cultivated soils where there is little vegetation to protect and hold the soil.

Early signs of sheet erosion include bare areas, water puddling as soon as rain falls, visible grass roots, exposed tree roots, and exposed subsoil or stony soils. Soil deposits on the high side of obstructions such as fences may indicate active sheet erosion. Vegetation cover is vital to prevent sheet erosion because it protects the soil, impedes water flow and encourages water to infiltrate into the soil. The surface water flows that cause sheet erosion rarely flow for more than a few metres before concentrating into rills.

Fig.2.2. Sheet erosion

2.2.3 Rill erosion

Rills are shallow drainage lines less than 30 cm deep. They develop when surface water concentrates in depressions or low points through paddocks and erodes the soil. Rill erosion is common in bare agricultural land, particularly overgrazed land, and in freshly cultivated soil where the soil structure has been loosened. The rills can usually be removed with farm machinery. Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, ripped mulch lines, and contour drains. Rill erosion is often described as the intermediate stage between sheet erosion and gully erosion.

Fig.2.3. Rill erosion

2.2.4 Gully erosion:

Gullies are channels deeper than 30 cm that cannot be removed by normal cultivation. They can be spectacular to look at but over time actually lose less soil than sheet and rill erosion. Gullies occur when smaller water flows concentrate and cut a channel through the soil. Most gullies extend up slope as a result of the head of the gully being continually undercut and collapsing. However, collapse and slumping of sidewalls usually contribute a greater proportion of soil loss.

Fig.2.4. Gully erosion

2.2.5 Tunnel erosion

Tunnel erosion occurs when surface water moves into and through dispersive sub-soils. Dispersive soils are poorly structured so they erode easily when wet. The tunnel starts when surface water moves into the soil along cracks or channels or through rabbit burrows and old tree root cavities. Dispersive clays are the first to be removed by the water flow. As the space enlarges, more water can pour in and further erode the soil. As the tunnel expands, parts of the tunnel roof collapse leading to potholes and gullies. Indications of tunnel erosion include water seepage at the foot of a slope and fine sediment fans downhill of a tunnel outlet. Remediation actions include breaking open existing tunnels, revegetation, and increasing soil organic matter. Extensive earthworks may be required.

Fig.2.5. Tunnel erosion

2.2.6 Mass movement:

Mass movement is the downward movement of soil and rock under the influence of gravity. It is most frequent on slopes above 25 degrees with little vegetation and annual rainfall over 900 mm and often occurs after heavy storms when soil becomes waterlogged and heavy. Mass movement is a major form of natural land degradation in some regions. Types of mass movement include soil creep, earth flow, slumps, landslips, landslides and avalanches. Factors increasing mass movement include erosion or excavation undermining the foot of a slope, weight loads of buildings or embankments, and loss of stabilising roots through removal of vegetation. Vegetation removal may also increase soil water levels and soil water pressure, reducing the cohesive strength of the soil. In clay soils with high shrink-swell capacity water enters the soil through cracks and then swells the subsoil, increasing its weight on the slope. Early signs of mass movement include previous movement, bare soil 'scars' across slopes, and stock tracks causing cracks or minor terracing. Old or dormant landslips are characterised by long, uneven hummocky slopes and bent tree trunks on steep slopes. Because gravity is the principal force in mass movement expert advice is needed to remedy affected land. Remediation actions include diverting water away from slip-prone areas, fencing off suspect areas, and revegetating with trees and perennial pastures.

Fig.2.6. Mass movement erosion

2.3 Factors influencing erosion:

Soil erosion is influenced by several conditions: climate, land use and management (human activities or the anthropogenic conditions .e.g. farming) and topography (slope, soil texture and structure), and also political, economic, social conditions. Where poverty level can directly relates with soil erosion in developing countries. There is no way to measure conservation practices for poor farmers that have limited resources (Ackermann, 1976). The risk of soil erosion is decreased by the elimination of implementing conservation practices and for year after year food production on small agriculture farms (0.5-2 ha) compel farmers to use over exploiting practices by subsistence farming.

For more understand the factors that influenced the soil erosion we can quote the explanation from Velthuis et al., (2010) “the longer and steeper the slope, the more erodible the soil, and the greater the transport capacity of runoff under an intense rain. The role of vegetation on preventing soil erosion is well recognized. Surface vegetative cover improves soil resistance to erosion by stabilizing soil structure, increasing soil organic matter, and promoting activity of soil macro- and micro-organisms. The effectiveness of vegetative cover depends on plant species, density, age, and root and foliage patterns”.

2.3.1 Land use and management:

Summarizes all human activities that affect either directly or indirectly the soil and make it vulnerable to different kinds of water erosion, through its diverse use of land, whether by agriculture (e.g. Deforestation, Overgrazing, Cultivation of steep slopes, and all kinds of soil mismanagement) or reconstruction (e.g. Urbanization and all kinds of infrastructure).

2.3.2 Topography:

The topographic of the land has a critical role in water erosion phenomena by two important factors which are the slope and the properties of soil (texture and structure). Where the steepness of the hill-shed impact the velocity of the over land flow and the transport process of the materials removed such as soil and sediment from a landscape. As for the soil characteristics their effect is by welded soil molecules and their permeability. Infiltration excess overland flow occurs when rainfall at the soil surface is greater than the soil's infiltration capacity. In other words, the rainfall is greater than the ability of the land to soak up or absorb the rainfall.

2.3.3 Climate:

Two main aspects of climate directly impacting soil erosion are precipitation and wind velocity. Precipitation includes rain, snow, ice and fogs. Among these, rain is the commonest type affecting water erosion. Soil erosion is controlled by features, such as rain distribution, amount, and intensity. Other aspects indirectly affecting soil erosion are temperature and humidity through the soil water regime.

2.4 Water erosion processes:

Water erosion is the removal of soil by water and transportation of the eroded materials away from the point of removal. Erosion involved three processes: detachment (from the ground), transportation (via water), and deposition. The deposition is often in places we don't want the soil such as streams, lakes, reservoirs, or deltas.

2.4.1 Detachment:

Detachment is pretty much as it sounds. It means to initially get moving or to mobilize from an existing stationary location. So it is the starting point for any water erosion to take place. Detachment can occur in a number of ways, these can include: Rain-splash or raindrop impact, flowing water trampling by people or livestock and tillage practices. These detachment processes provide the sediment to be transported by overland flow.

2.4.2 Sediment transport:

Sediment transport by water is a complex process driven largely by gravitational forces moving sediment downslope by overland or river flows from a source area to a sink area where sediment is eventually deposited. Where, how much and how far sediment is transported, is a very tricky thing to determine. Sediment transport occurs in shallow overland flow and in stream or river channels. However, where overland flow is generated and there is sufficient sloping land with readily available sediment, such as recently ploughed paddocks then sediment transport is very likely to occur. This now leads us to the final of the three water erosion processes deposition.

2.4.3 Deposition:

Deposition can be triggered by changes in the speed or velocity of overland flow through reductions in surface slopes. This reduction in slope reduces the speed of overland flow and also the ability of the flow to continue transporting its sediment load. Thus, resulting in deposition when ploughed fields exposed to a rainfall event and leads in shallow overland flow from the upslope areas move down-slope from left to right due to gravity. The land cover protects soil by the effect of the grass strip by impeding or slowing down the overland flow which reduces the transport capacity or the ability of the water to keep transporting sediments.

2.5 Sustainable soil management:

The Food and Agriculture Organization has mentioned in ("Voluntary Guidelines for Sustainable Soil Management," n.d.) an accurate definition to this term "Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern". As in Pillar 1 (Departments, n.d. 2012)," requires balancing the needs for human purposes with those for environmental conservation and functioning soil quality /health is reduced through human-induced degradation processes (erosion, nutrient mining, compaction, acidification, pollution, etc".

2.6 Soil conservation:

Soil conservation basically means a way of keeping everything in place, literally as well as in a more abstract sense of maintaining the functions of the soil in sustaining plant growth (Ackermann, 1976). Soil conservation practices involve managing soil erosion and its counterpart process of sedimentation, reducing its negative impacts. Young, (1989) defined soil conservation as a combination of controlling erosion and maintaining soil fertility. In the past the focus has often been on trying to keep the soil at its place by the same activities only. Currently, the attention has switched to landscape level approaches where sedimentation is studied along with erosion, and the role of channels (footpaths, roads and streams) is included as well as the 'filters' that restrict the overland flow of water and/or suspended sediment.

2.7 Sustainable development goals and soil degradation:

There are some aspirational targets in the united national "UN" Sustainable Development Goals (SDGs) which express the UN's vision for a positive future for everyone everywhere. Of the 17 SDGs, 13 of them involve soil resources(Keesstra et al., 2016). Four of the SDGs contain targets specifically related to soil and land degradation.

- ✓ **Target 2 (Zero hunger),**
- ✓ **Target 3 (Good health and wellbeing),**
- ✓ **Target 12 (Responsible consumption and production), and**
- ✓ **Target 15 (Life on land)**

2.8 Soil conservation measures:

Certain conservation measures can reduce soil erosion. Soil / land management practices such as tillage and cropping practices, directly affect the overall soil erosion problem and solutions on a farm. When crop rotations or changing tillage practices are not enough to control erosion on a field, a combination of measures might be necessary. For example, contour plowing, strip cropping, or terracing may be considered. Generally, there are three major types of conservation measures:

2.8.1 Agronomic:

Undertaken within the cropping area for crop production purposes (rotations, intercropping, contour cultivation, minimum tillage, mulching, manuring, soil amendment....etc.). It is applied to crops repeated routinely each season or in a rotational sequence, which don't lead to changes in the slope profile.

2.8.2 Vegetative:

Measures involving deliberate planting of trees, shrubs, grasses…etc, or retention of areas of natural vegetation (e.g. reforestation, contour hedgerows, and natural vegetative strips). The most important features of this conservation measure are the use of perennial grasses, shrubs, or trees, with spacing that varies according to the slope.

2.8.3 Structural:

It involves the construction of physical structures (e.g. graded banks or bunds, contour stone lines, level bench terraces, artificial waterways, and drop structures). This conservation measures lead to a change in the slope profile for permanent or long term duration, they are carried out primarily to control runoff and erosion.

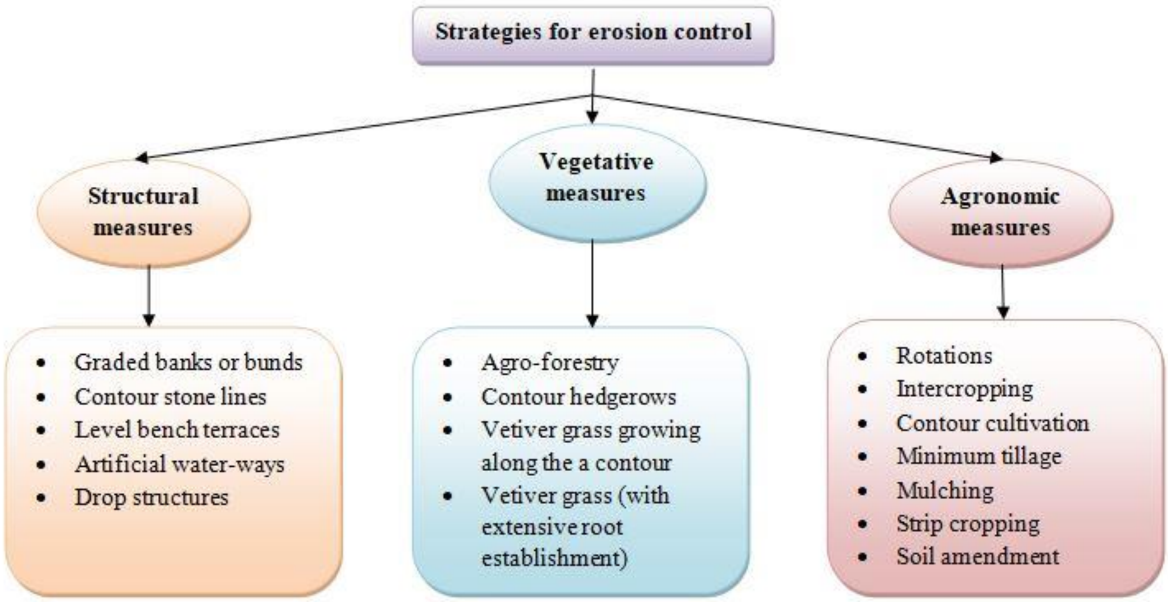

Fig .2.7. Soil Conservation Measures

2.9 Support practices:

2.9.1 Terracing:

It is an engineering or mechanical measure, used to control soil loss at highly sloping lands. Terraces are usually more expensive to install than techniques that depend on vegetation because they mostly require more labour, materials, and technical skill to set up.

Terracing is one of the most effective alternative measures for the land which has high erodibility, a steep slope, and elevated amount of rainfall intensity, where the use of agronomical measures is not ineffective. It is the most efficient and extensively used field method for reducing erosion and regulating runoff. Terracing also aids in soil moisture conservation, as well as improved groundwater storage and crop yields.

The terracing implementation is based on break up a long slope into a series of short graduals. Each one works to collect and control the excess water from the slope above it. Water gathered in a terrace channel can be directed to outlets, through natural or artificial streams, where it will not cause damage. Terraces can be built flat and water allowed standing and penetrating into the ground if the soil in a field is porous enough.

Bench terraces, one of the a few terracing types, and it considers as the oldest methods used in erosion control, by transforming steep land into steps running across the slope. It makes cropping in the steep slopes possible and safe; the steps are separated by almost vertical risers of rock or earth protected by a heavy growth of vegetation.

Terraces, even when built appropriately, will not provide long-term erosion protection if they are not adequately maintained, in many countries this technique was a failure not because of faulty terrace design but a result of poor maintenance. A crucial time for terrace maintenance should be following each heavy rain during the first year after construction, when soil may settle. Breaks or low spots should be repaired as soon as possible to avoid further harm. Terraces, if not properly maintained, may cause more erosion than if they were never created.

Fig.2.8. Terracing by Satellite imagery

2.9.2 Strip cropping

Strip cropping has been advocated and adopted by conservationists and agricultural technicians in Grenada since the late 1950s as a soil conservation practice in response to the detrimental effects of Hurricane Janet in 1955 (FAO). Strip cropping is a profitable farming strategy that offers benefits beyond simply increasing yields. Strip cropping has been shown to be effective in reducing soil erosion, especially on sloped fields. Neighbouring species that have been carefully chosen have a favourable impact on each other, increasing field productivity. However, strip cropping benefits also involve certain efforts, which are simpler to implement with smart farming tools.

The name of the procedure suggests what it does. Strip cropping refers to the practice of planting multiple cultures in alternating strips in a crop rotation. On sloped lands, it is a common method to control soil erosion. Strip cropping in agriculture, on the other hand, relates to even terrains when two or more species are farmed together. Alternative species grow in between the cash plants, comparable to intercropping. Grasses (e.g., hay, wheat) and corn, pepper, tomato, and other crops are common pairings.

The strip cropping strategy has multiple advantages such as (reduce soil erosion, increasing crop productivity from the boosted of soil health and fertility, improving water quality, and raising water infiltration). It is also considered the cheapest soil conservation technique because the implementation of this technique doesn't require additional work, it depends basically on the way the crops are organized and ranged.

Strip cropping makes farmlands available for use in the future by preventing soil erosion, maintaining field fertility, and removing pollutants. As a result, the method is not only good for the soil and yields, but it also fits into the category of sustainable farming techniques, as it achieves the fundamental goal of soil conservation and resource management. Strip cropping agriculture deployment becomes much more feasible with smart agricultural software.

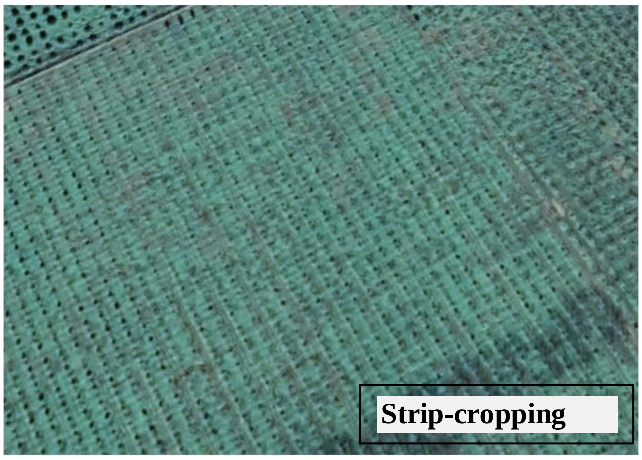

Fig.2.9. Strip-cropping by Satellite imagery

2.9.3 Agroforestry:

The agroforestry is an agro-economic practice (Vegetative measures)**.** Technically, Agroforestry refers to land-use systems in which trees or shrubs are planted alongside agricultural crops, pastures, or livestock, and where the trees and other components interact both ecologically and economically. Its key feature is that it encompasses combinations of trees with plants or animals, as well as interactions between tree and non-tree components of the system. The greatest distinguishing aspect is the ecological interactions.

The FAO estimates that to fulfil food demand by 2050, production will have to expand by more than 60% due to its multifunctional qualities. These figures, when combined with current problems resulting from past and current non-sustainable land-use practices, make the case for changing the way we manage lands and produce agricultural and tree goods. Agro-forestry is an important part of the solution to these issues, whether they are environmental, economic, or social.

Many countries are paying more attention to agroforestry as a land-use strategy to safeguard the land from various sorts of deterioration. Agroforestry technologies and practices have significant long-term agricultural sustainability benefits; it is a tool for achieving sustainable agricultural farming and improving the quality of life of affected communities while simultaneously reversing the process of environmental and land degradation, and it is a dynamic ecologically based natural resources management system.

Agroforestry contributes to protecting land and controlling soil erosion by fulfilling the functions of stabilizing conservation structures and making productive use of the land with these occupied. This applies mainly to the practice here called 'trees on erosion-control structures'. In direct use, the trees, shrubs, or hedgerows are in themselves a major method of reducing erosion. This applies particularly to the practices of plantation crop combinations, multi-storey tree gardens, hedgerow intercropping, windbreaks and shelterbelts, and reclamation forestry with multiple uses.

Fig.2.10. Agroforestry by Satellite imagery

2.9.4 Crop rotation:

Crop rotation is based on growing a variety of different types of crops in the same location in sequential seasons. The planned rotation may vary from a growing season to a few years or even longer periods. Farmers usually do not follow one specific crop rotation strategy. They choose to alternate crops based on their specific needs, capabilities, environmental conditions and financial constraints.

Fig.2.11. Crop rotation technique

Source; https://greentumble.com/

2.9.5 No-Till farming:

It's also known as direct drilling farming or zero tillage farming, and it's a method of growing crops or pasture from year to year without disturbing the soil with tillage. It is an agricultural technique that increases the amount of water that infiltrates into the soil, as well as the retention of organic matter and nutrient cycling in the soil.

It can prevent soil erosion in many agricultural areas. It increases the number and diversity of organisms in and on the soil, including disease-causing and disease-suppressing species. The most significant advantage of no-tillage is an increase in soil biological fertility, which makes soils more robust.

Fig.2.12. No-Till farming technique

Source: https://regenerationinternational.org/

2.9.6 Contour ploughing:

Contour ploughing is a well-known agronomic practice that helps to conserve soil and water. Instead of plowing up and down, the land is ploughed along the contour. By concentrating water in the downhill furrows, this reduces runoff velocity and consequently soil erosion.

Contour plowing, on the other hand, is designed to create a barrier between precipitation flow and the furrows. The rate of infiltration increases, and more water is held in place. Contour plowing is particularly critical during the start of the rainy season, when biological conservation impacts are minimal. With increasing slope gradient and length, rainfall intensity, and erodibility of the soil, the efficacy of contour ploughing declines.

Fig.2.13. Contour ploughing technique

Source: https://www.fao.org/3/CA3549EN/ca3549en.

2.9.7 Stone lines:

Stone lines are a collection of stones arranged in a line and put following the contours. The stones can come in a variety of sizes. These lines are intended to slow down runoff water and break its velocity, with the purpose of soil conservation and runoff reduction. As a result, they increase infiltration and retain sediment and seeds, allowing crops to get water and nutrients. In semi-arid climates, stone lines are best for water gathering on slightly sloping plains (> 5%). Stone bunds can be used on slopes that are less than (5%).

Fig.2.14. Stone lines technique

Source: https://www.fao.org/3/au291e/au291e

2.10 Soil erosion modelling:

There are various models to choose from developed to estimate soil loss and sediment yield and to assess the impact of management practices on soil erosion that can be classified into three categories; empirical, conceptual, and physically-based (Mugiraneza, 2020). They are primarily used to forecast and comprehend various processes that occur inside the watershed, and are made up of a number of parameters that define their properties. These models, on the other hand, differ greatly in terms of usefulness, complexity, and applicability, as well as input data, process illustration, spatial and temporal variability, and the types of conclusions they provide.

They are based on inductive logic and are usually applicable to the conditions for which the parameters are calibrated.

Physically-based models provide the mechanisms needed to control erosion. In this regard, these models are based on solving fundamental physical equations, describing sediment fluxes, stream flows and their associated nutrient fluxes in a basin (Cama et al., 2020).

In conceptual models, sediment yield is evaluated based on spatially lumped forms of water and sediment continuity equations. These models lie somewhere between physically based and empirical models (Cama et al., 2020).

2.11 Quantitative models:

Empirical models are based on statistical observation and experiments, and they depend on the regression equation for simulating natural processes (Haji gholizadeh et al., 2016). The simplicity of empirical models is one of its advantages. They are easy to apply because those models are Based on coefficients calculated from observations or measured data.

2.11.1 Water erosion project manager:

The Water Erosion Prediction Project (WEPP) for predicting the soil erosion by water was developed by the U.S Agriculture Research Service and their co-operators as a new technology.

The new model technology estimates soil erosion in different ratio scale; single events, long-term soil loss from hill slopes (gully erosion) and soil detachment and deposition that occurs in small stream channels (Rill Erosion) in the watershed scale (Weltz et al., 1998).

2.11.2 Soil and water assessment tool:

The soil and Water Assessment Tool SWAT model has emerged as a viable catchment scale modelling tool for quantifying various hydrological fluxes and their influence on corresponding management aspects over a large heterogeneous watershed in a limited data availability scenario. The SWAT model works on the principle of dismantling the watershed first into sub-watersheds and then into Hydrologic Response Units (HRU) to make it computationally efficient (Dash et al., 2021). This model is capable enough in representing the physical processes happening inside the catchment with utmost accuracy.

2.11.3 Universal soil loss equation:

The Universal Soil Loss Equation (USLE) was developed by Wischmeier and Smith (1965, 1978) in the United States Agriculture Department in order to estimate soil loss in agriculture regions. The five major input parameters of the USLE equation are rainfall erosivity (R-factor), topography (LS-factor), soil erodibility (K-factor), vegetation cover (C-factor), and support practices (P-factor). The average annual soil loss is determined by multiplying the five above-mentioned factors.

2.11.4 The revised universal soil loss equation:

The Revised Universal Soil Loss Equation (RUSLE) is the most widely used empirical model for erosion prediction and control around the world. RUSLE developed by Renard et al. (1997), and it was used as a decision support system in soil conservation and land use planning (Panditharathne et al., 2019). It uses a set of mathematical equations Table (2.1) to describe ecological processes related to conservation practices and erosion in a given area. RUSLE is a flexible tool that has been adapted to watershed scales combined with Geographic Information Systems (GIS) in soil erosion assessments in the world (eg: Bonilla et al., 2010; Kouli et al., 2009; Onori et al., 2006; Teshome et al., 2021).

Tab.2.1. RUSLE/USLE Factor's

Factor	Formula	Parameters	References
R	$R = 143 \times \log\left(\frac{P.P^2 24}{10^6}\right) + 89.7$	R = rainfall erosivity factor (MJ·mm·ha–1·h–1·y–1) P = average annual precipitation (mm); P_{24} =maximum precipitation in 24 hours of 20 years return period (mm).	(Heusch B., 1971)
	$Ri = 0.01 * Ei * I_i^{30}$ $Ei = \sum_{i=1}^{n}\left(0.29\left[1 - 0.72\exp^{(-0.05Iji)}\right]\right).rj$ $Ra = \sum_{i=1}^{j}\frac{R_i}{N}$	Ri: is the storm erosivity factor (MJ mm/ha/h) Ri: is the storm erosivity factor (MJ mm/ha/h) Ei: is the total kinetic energy of the ith rainstorm (MJ/ha) I j: is the 30-min intensity of the jth interval into the ith storm r j:is the total rain (mm) R_a is the annual rainfall erosivity factor, then the sum of the individual storm erosivities. If more than 01 year is included in the calculation of rainfall erosivity N: numbers of years	(Foster et al., 2002) (Renard et al., 1996; Wischmeier and Smith., 1978)
	$\log R = 1.74\log\sum(P_I^2.P^{-1}) + 1.29$	P_i = is the monthly rainfall P = is the annual rainfall in mm	(FAO, 1987)
	$R = 0.04830.P^{1.1610}$	P: is the mean annual precipitation P < 850 mm	(Renard and Freimund, 1994)

	$R = 587.8 - 1.219P + 0.004105P^2$	P > 850 mm	
	$MFI = \sum_{i=1}^{12}\left(\frac{p_i^2}{p}\right)$	**MFI** : modified Fournier index is an approximation of R to which it is linearly correlated P_i: the mean rainfall amount in mm for month i. P: mean annual rainfall depth	(Arnoldus HMJ, 1980) modified by (Renard and Freimund, 1994)
LS	$LS = (\frac{Lenght}{22.1})^m.(65.41\sin^2\theta + 4.56\sin\theta + 0.065)$ $m = 0.65[1 - \exp(-35.835 * S)]$ $\theta = \tan^{-1}\frac{S}{100}$	S: is field slope (%) θ: is field slope steepness in degrees	
	$LS = L * S$ $L = \left(\frac{\lambda}{22.13}\right)^m$ $S = 10.8\sin\theta + 0.03 \quad \theta < 9\%$ $S = 16.8\sin\theta - 0.5 \quad \theta \geq 9\%$	λ: is the slope length (m) m: is a variable length-slope exponent m = β / (β +1) β : is a factor that varies with slope gradient $\beta = (\sin\theta) / [3*(\sin\theta)^{0.8} + 0.56]$ θ : is the slope angle	(Van Remortel et al., 2004)
	$L = 1.4\left(\frac{A_s}{22.13}\right)^{0.4}$ $S = \left(\frac{\sin\beta}{0.0869}\right)^{1.3}$	As: specific catchments area or upslope area per unit width of contour (m2/m) β: Slope angle in degree	(Heusch B., 1971; Schmidt and Persson, 2003)
	$LS = \left(\frac{X}{22.1}\right)^m \times (0.065 + 0.0456 \times S + 0.0065 \times S)$	X = is slope length (m) S = is angle of slope m = dimensionless exponent that depends on slope steepness as follow: S < 1% m = 0.2 1% ≤ S ≤ 3% m = 0.3 3% ≤ S ≤ 5% m = 0.4 S ≥ 5% m = 0.5	(Wischmeier and Smith., 1978)

	$LS = (0.4 + 1)\left(\frac{A_s}{22.13}\right)^{0.2}\left(\frac{\sin\beta}{0.0869}\right)^{1.3}$	β: is the average slope As: is the specific catchment area	(Moore et al., 1991)
	$LS = (m+1)\left(\frac{u}{1}\right)^{m}\left(\frac{\sin\beta}{\alpha}\right)^{n}$	LS = topographic factor (–), U = upslope contributing area per unit width (m2·m–1), l = length of the standard USLE plot (22.1 m), α = slope of the standard USLE plot (9%), β = angle of slope (°), m = exponent related to the ratio of rill to inter-rill erosion, n = exponent related to the steepness of the slopes.	(Mitasova et al., 1996)
	$C_{rA} = 0.1\left[\frac{(-NDVI+1)}{2}\right]$ $C_{vK} = \exp\left[\frac{(-\alpha.NDVI)}{(\beta - NDVI)}\right]$	C_{rA} and C_{VK} are the estimated C-factors α and β are parameters related to the shape of the curve that associates NDVI with the C-factor.	Van der Knijff et al., 1999)
	$C = e^{\left(\frac{-\alpha(NDVI)}{\beta-(NDVI)}\right)}$	α and β are unitless parameters that determine the shape of the curve relating to NDVI and the C factor	(Van der Knijff et al., 2000; Van der Knijff et al., 1999)
C	$C = (SLR1 \times EI1 \times EI2 + \cdots + SLRn \times EIn)$	LR_i is the value of SLR for the time period i, EI_i is the percentage of the annual EI during the time period i, n is the number of periods	(Renard et al., 1996). And (Foster et al., 2002)
	$C_{factor} = 1.02 - 1.21NDVI$ $NDVI = \frac{(NIR - RED)}{(NIR + RED)}$	NIR and RED are near-infrared and red bands, respectively.	(Jr et al., 1974)
K	$k = 0.0034 + 0.0405 \times \exp\left[-0.5\left(\frac{\log D_g + 1.659}{0.7101}\right)^2\right]$ $D_g = \exp\left(\sum f_i \, In\left(\frac{d_i + d_{i+1}}{2}\right)\right)$	Dg: is the geometric mean particle size, for each particle size class (clay, silt, sand), dI is the maximum diameter (mm), dI-1 is the minimum diameter and fI is the corresponding mass fraction	(Foster et al., 1997)

	$K = 27.66 \times m^{1.14} \times 10^{-8} \times (12 - \alpha) + 0.0043 \times (b - 2) + 0.0033 \times (c - 3)$	*m* = silt (in %) + very fine sand (in %) × (100−clay (in %)) *a* = organic matter (%) *b* = structure code in which (1) is very structured or particulate, (2) is fairly structured, (3) is slightly structured, and (4) is solid *c* = profile permeability code in which (1) is rapid, (2) is moderate to rapid, (3) is moderate, (4) is moderate to slow, (5) is slow, and (6) very slow	(Wischmeier and Smith., 1978)
	$\mathrm{K} = [2.1 \times 10^{-4}(12 - \mathrm{OM}) + 3.25(\mathrm{S_c} - 2) + 2.5(\mathrm{P_c} - 3)]$ $OM = N_1(100 - N_2)$	where *K* (t h MJ^{-1} mm^{-1}) represents soil erodibility, N_1 (0.002–0.1 mm) represents the percentage of silt (0.002–0.05 mm) plus very fine sand (0.05–0.1 mm), N_2 (<0.002 mm) is the clay fraction, *OM* is the soil organic matter content (%), S_c is the soil structure code, and P_c is the soil permeability code.	(Wischmeier and Smith., 1978)
	$K = \left(0.2 + 0.3e^{[-0.256SAN(1-SIL/100)]}\right) \times \left(\frac{SIL}{CLA + SIL}\right)^{0.3} \times \left(1 - \frac{0.25OM}{OM + e^{(3.72-2.95OM)}}\right) \times \left(1 - \frac{0.7SN_1}{SN_1 + e^{(22.9SN_1-5.51)}}\right)$	K Factor : capture where SAN = sand, SIL = silt, CLA = clay and OM = organic matter content of the soil while $SN_1 = 1 - SAN/100$.	(Sharpley and Williams, 1990)
P	$\mathrm{P} = \mathrm{P_C} \times \mathrm{P_{sw}} \times \mathrm{P_{gw}}$	P_c is the contouring sub-factor for a given slope of a field, P_{sw} is the stone walls sedimentation sub-factor (known as terrace sub-factor) P_{gm} is grass margins sub-factor	(Blanco and Lal, 2008)
	$\mathrm{P} = \mathrm{P_{struc}} . \mathrm{P_{cont}}$	where $P_{struc.}$ is the P value for SWC measures, $SL_{s,swc}$ is seasonal soil loss rate with SWC measures on the monitoring site, $SL_{s,cont.}$ is seasonal soil loss rate without SWC measures on the same	(Angima et al., 2003)

	$P_{struc} = \frac{SL_{S,SWC}}{SL_{S,cont}}$	control plot. $P_{cont.}$ is mainly determined by contour fluctuations, and its value is determined according to the method proposed by (Renard et al., 1996). When $P_{struc.}$ is 1.0, it means that there are no SWC measures.	

2.12 Application of RUSLE in Algeria:

The revised soil loss equation RUSLE was applied and validated by many researchers and gradient students in several watersheds in Algeria.

Fekir.Y et al.(2011) Combined universal soil loss equation RUSLE, The geographic information system GIS, and Remote Sensing (RS) to quantified and evaluated the soil erosion risk in the Western part of Algeria (Building, 2011). The modelling results showed an estimation of the total annual loss in the study area was of 94040.98 [ton.year^{-1}], where the erosion rates vary from region to region, depending on the influence of various factors controlling erosion. The study concluded that: maps of potential and current soil loss obtained appeared very useful to identify the most erodible area, and it's very compatible with what was observed on the real.

Bouguerra et al.,(2016) applied the RUSLE model through a GIS environment to map the erosion-prone areas in the watershed of Bouhamdane's dam (north-eastern Algeria). The obtained results indicated an annual average erosion rate of 11.18 [ton·ha–1·y–1], the soil loss amounts estimated by RUSLE were compared to the quantities of sediments deposited in the dam reservoir during a known period, which was derived from bathymetric surveys. The results indicated that rainfall erosivity, soil erodibility, and topographic factors are the key factors driving soil erosion in the Bouhamdane watershed. The erosion map was classified into five erosion-risk classes from very low to very high. As expected, most of the very high and high-risk erosion classes occurred in the areas of high agricultural activities. Thus, the study suggested reviewing the existing cropping systems, and applying alternative techniques such as terracing in the purpose of reducing sediment deposits in the reservoir.

Likewise**,** Bouhadeb et al., (2018) combined the RUSLE and GIS to estimate the annual rate of soil erosion and its spatial distribution in the watershed of Cheffia's dam (north-eastern Algeria). The modelling results indicated an average yearly erosion rate of 7.8 [ton.ha^{-1}.year^{-1}]. According to this study, the areas with moderate, high, or very high erosion rates account for more than half of the watershed's area, and they were found to be mostly in places with extremely high soil erodibility, steep slopes, and little plant cover. The results were also validated using observed sedimentation quantities deposited in the reservoir of Cheffia dam.

Bouamrane et al., (2021) applied the RUSLE model (as an empirical and quantitative model) along with two different other models; the Analytic Hierarchy Process (a qualitative model), and the Frequency Ratio (a statistical model) to identify and map soil erosion in the Mellah watershed (North-eastern Algeria). The study produced vulnerability maps with five levels of erosion risk, ranging from very low to extremely high. According to the obtained results, the high erosion risk areas were found to occupy 5.06%, 10.91%, and 12.57 % of the watershed area according to RUSLE, Frequency Ratio, and Analytic Hierarchy Process models, respectively. Thus, the study suggested protecting the basin area against anthropogenic activities, which represent a major cause of vegetation degradation and soil erosion acceleration. Results obtained by the three adopted models were validated using the Areas under the Curve (AUC), and the Receiver Operating Characteristic curves (ROCs). Generally, the three models gave similar and reasonably good results, with slightly better performance for RUSLE Model. This was justified by various amendments and extensions applied to the factors of the RUSLE model by several researchers over a long period to improve the model efficiency.

2.13 Conclusion:

Soil erosion due to rainfall and surface runoff has become a severe problem worldwide. Divers models were developed to model and asses soil erosion, such as WEPP, SWAT, USLE, and RUSLE. Based on the literature review conducted in this chapter we decided to use RUSLE model for our study since it was widely applied and validated in many regions across Algeria. Moreover, it has a capability to link with GIS constitute a significant advantage, which may help in the assessment of the role of different management strategies to control soil erosion

CHAPTER 3

CASE STUDY

3.1 Geographic and climatic characteristics:

This study concerns the watersheds of Oued Fregha, Ain Berda, and Oued El-Aneb. The first two belong to the large basin of Seybouse, while the last is a part of the large basin of Oued El-Kebir. According to the Hydrographic Basin Agency (ABH), the three watersheds belong to the Constantinos-Seybouse-Mellegue (CSM) ensemble under number 14.

The whole area is characterized by hot and fluctuating rainy winters and hot summers with high humidity due to its geographical location near to the Mediterranean Sea. The inter-annual average temperature is 17.95° C. In summer (from June to August) the average temperatures vary between 22.5° C and 26° C. While, the three winter months (December to February) are characterized by relatively low average temperature varying from 11.3° C to 12.5° C.

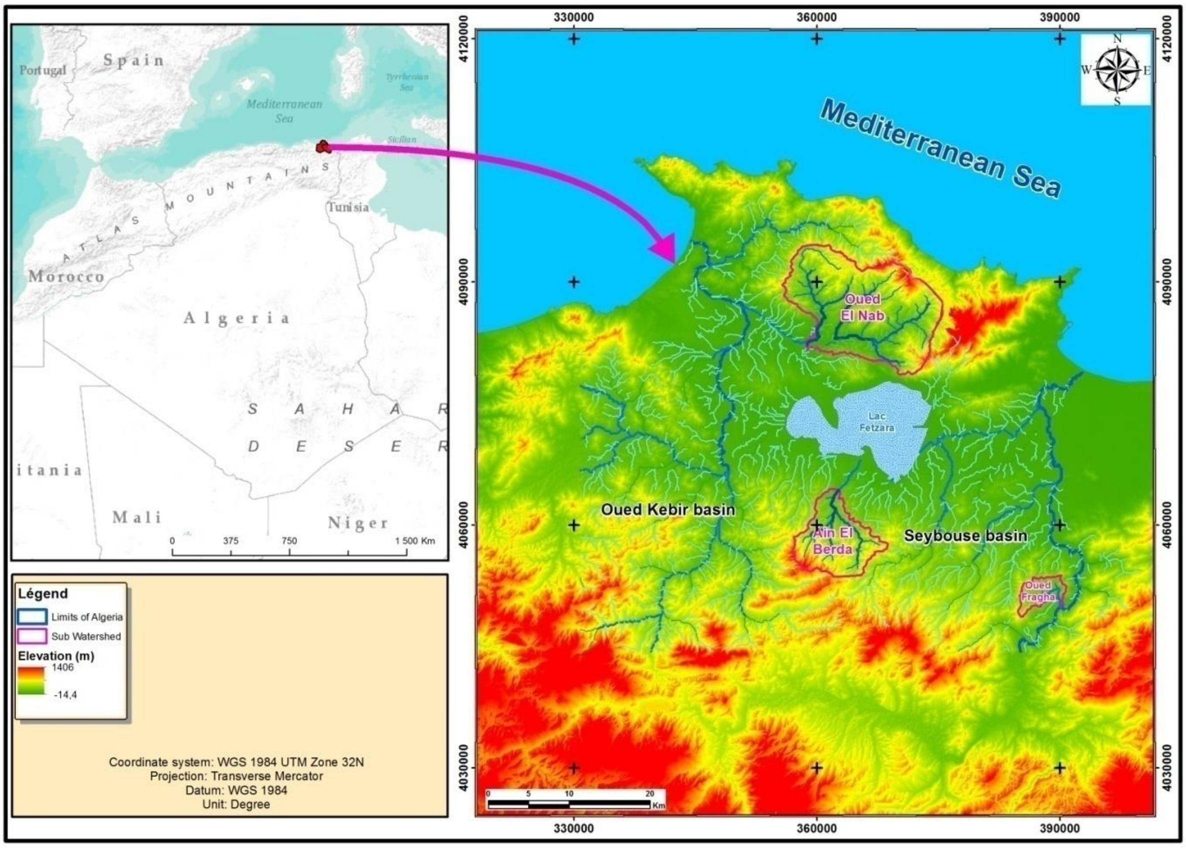

Fig.3.1. Study area location

3.1.1 Ain Berda watershed :

Ain berda watershed is located in the north-east of Algeria, between 7° 26' 54" and 7° 26' 25" East longitude, and between 36° 37' 24" and 36° 43' 43" north latitude, 10 km Oust of the Lac Fetzara, and 13 km south-east of Oued El-Kbir dam.

It covers an area of around 71 km² and has a perimeter of 42 km. Around 20 km^2 of the basin area is cultivated in which we can find a large variety of crops (tomatoes, peppers, watermelon and onions), and fruits trees (citrus, vineyards, pear and apple).

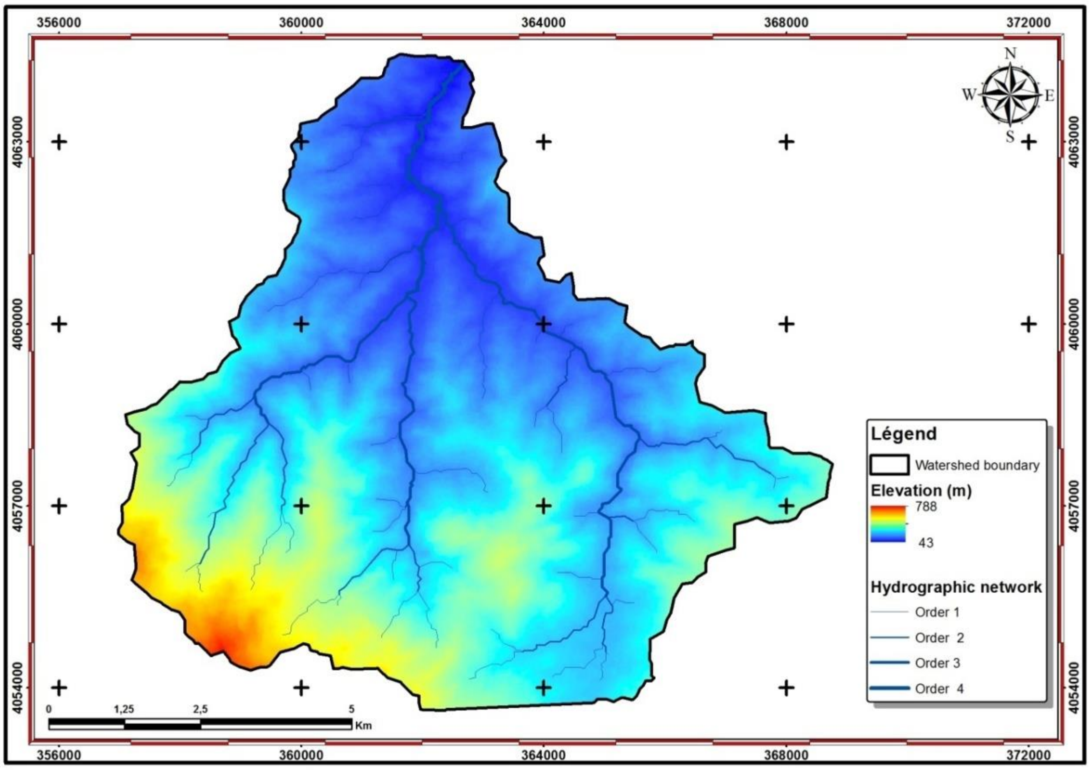

Fig.3.2. Ain Berda Watershed

3.1.2 Oued El-Aneb watershed :

This basin located in north-east of the Oued El-Kebir watershed, on the western side of Seraidi Mountain, and on the border between Annaba and Skikda, between 7°31' 07" and 7° 23' 39" East longitude, and between 36° 58' 42" and 36° 52' 54" North latitude. Far around: 47 km from the city of Skikda and 24 km from the city of Annaba. It occupies an area of 199 km^2, with a perimeter of 70.5 km. Around 30 km^2 of the basin area is cultivated.

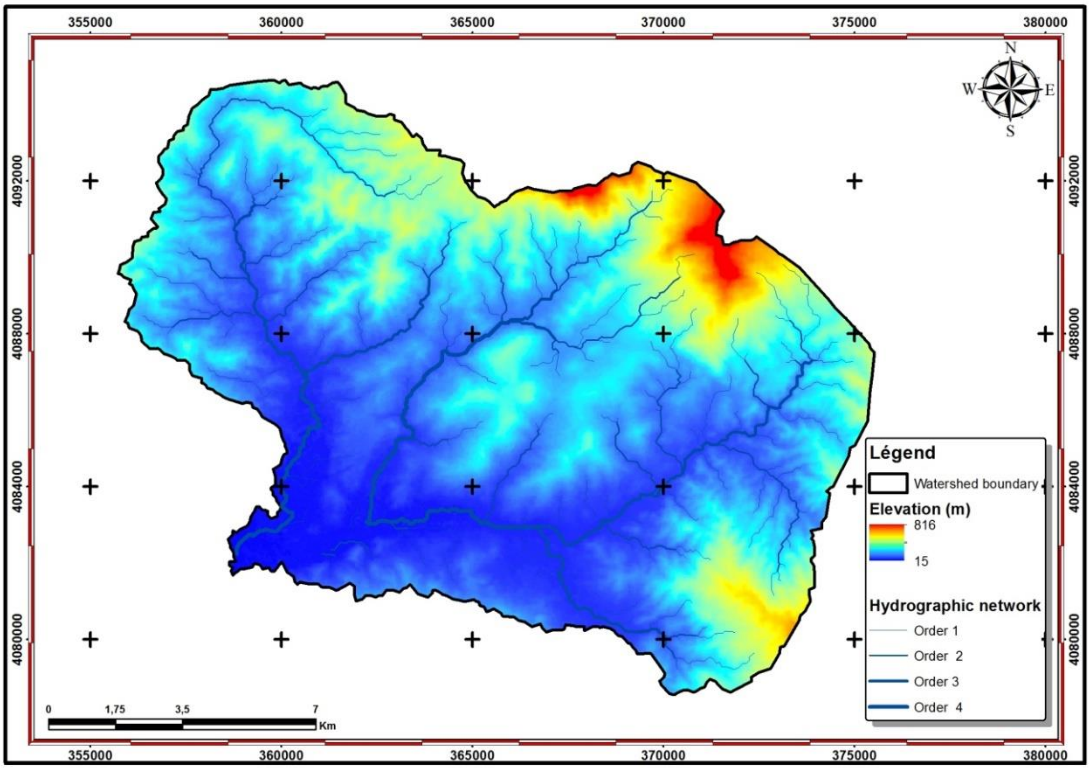

Fig.3.3. Oued El-Aneb Watershed

3.1.3 Oued Fregha watershed:

The watershed of Oued Fregha is located between 7° 45' 43'' and 7° 42' 27'' east longitude, and between 36° 35' 36'' and 36° 37' 15'' north latitude, 32 km far to Annaba city. It covers an area of about 17 km^2 and a perimeter of 23 km. Approximately 15% of this area is cultivated with different type of fruits and vegetation.

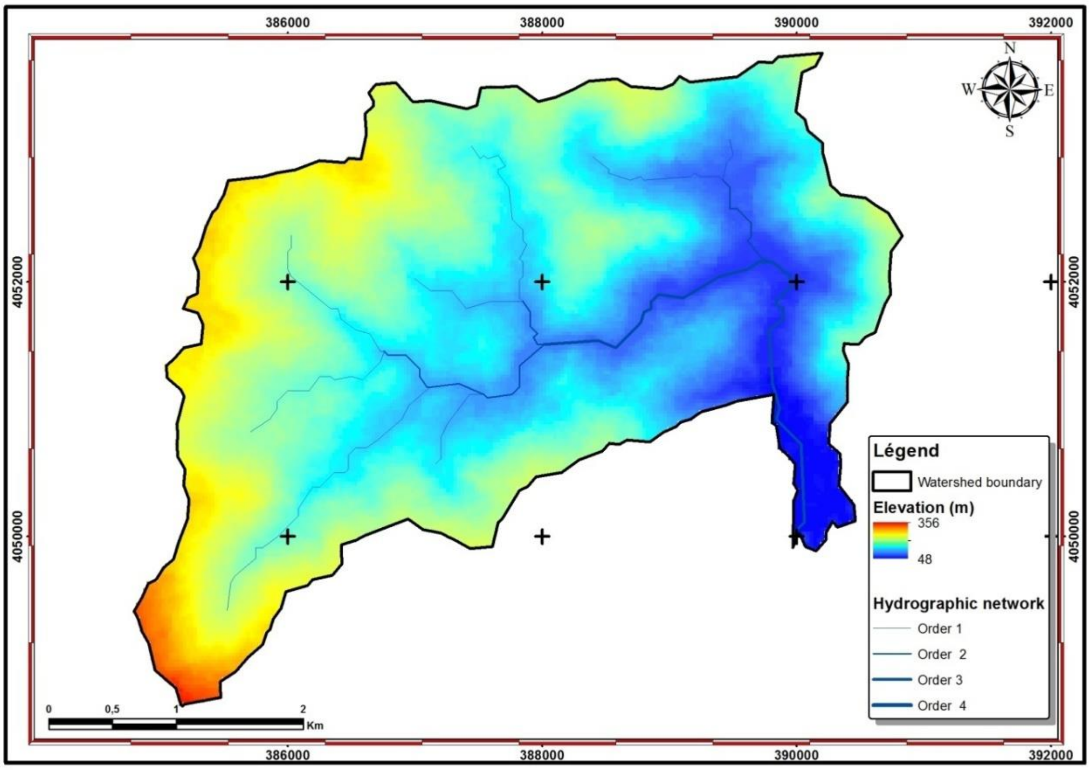

Fig.3.4 Oued Fregha Watershed

3.2 Description of physical environment:

3.2.1 Hypsometric curves:

The relief plays a fundamental role in the hydrological behaviour of a watershed. It has a strong influence on the flow regime, because the slope of the basin influences on runoff, infiltration, evaporation, etc (Bouanani. A, 2004).

It is characterized by the hypsometric curve, which gives the distribution of the surfaces included between the various level curves The hypsometric curve of a watershed is often derived from the topographic map (Musy, 2005).

The hypsometric curves of the three studied basins are presented in figure (3.5), figure (3.6), and figure (3.7). The partial surfaces, the cumulated surfaces and the corresponding altitudes for the three sub-basins are reported in the appendix (Tab.6.1), (Tab.6.2), and (Tab.6.3).

Fig.3.5. Hypsometric curve of the Ain Berda watershed

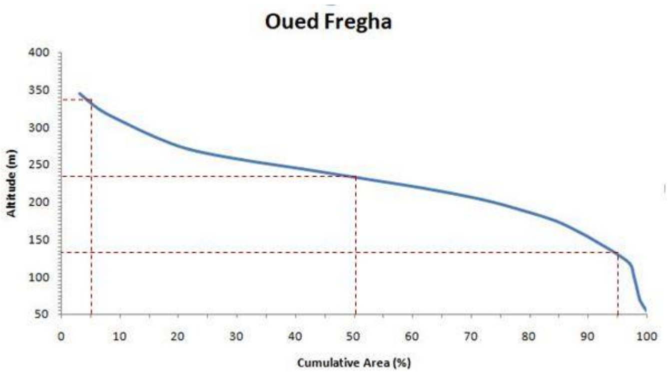

Fig.3.6. Hypsometric curve of the Oued Fregha watershed

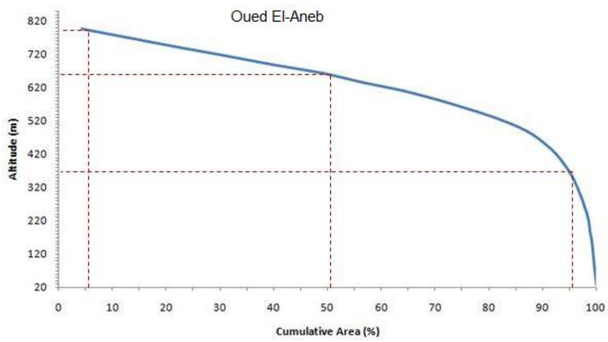

Fig.3.7. Hypsometric curve of the Oued El-Aneb watershed

3.2.2 Typical altitudes:

Typical altitudes are generally derived from the hypsometric curves of the watershed. The most commonly altitudes used in hydrological studies are:

1. **Minimum elevation (H_{min}):** This elevation represents the lowest point in the watershed, generally it measured at the outlet,

Tab.3.1. Minimum elevation of watersheds

Watershed	H_{min}[m]
Ain Berda	43
Oued Fregha	48
Oued El-Aneb	15

2. **Altitude at 95% of the surface ($H_{95\%}$):** It is directly obtained from the hypsometric curve; it corresponds to the altitude read at the point of abscissa 95% of the total surface of the watershed area.

Tab.3.2. Altitude at 95% of watersheds

Watershed	$H_{95\%}$[m]
Ain Berda	250
Oued Fregha	127
Oued El-Aneb	360

3. **Median elevation ($H_{50\%}$):** It is the elevation that includes 50% of the total watershed area on the hypsometric curve.

Tab.3.3. Altitude at 50% of watersheds

Watershed	$H_{50\%}$[m]
Ain Berda	525
Oued Fregha	232
Oued El-Aneb	660

4. **Altitude at 5% of the surface ($H_{5\%}$):** It corresponds to the altitude read on the hypsometric curve at the point of abscissa 5% of the total surface of the watershed.

Tab.3.4. Altitude at 5% of watersheds

Watershed	$H_{5\%}$[m]
Ain Berda	750
Oued Fregha	330
Oued El-Aneb	790

5. **Maximum elevation (H_{max}):** This elevation considers the highest point of the watershed.

Tab.3.5. Maximum elevation of watersheds

Watershed	H_{max}[m]
Ain Berda	788
Oued Fregha	356
Oued El-Aneb	816

6. **Average altitude (H_{aver}):** It is calculated from the following equation (3.1):

$$\mathbf{H}_{\mathbf{aver}} = \frac{1}{S} * \sum_{i=1}^{n} Si * \left(\frac{Hi+Hi-1}{2}\right) \quad (3.1)$$

Where:

$\mathbf{H}_{\mathbf{aver}}$: is the average altitude of the watershed expressed in m;

S: is the total area of the watershed expressed in km²;

Si: is the partial area between two successive altitudes expressed in km²;

n: is the number of contour lines.

Tab.3.6. Average altitude of watersheds

Watershed	H_{avr}[m]
Ain Berda	264.8
Oued Fregha	165.94
Oued El-Aneb	200.9

3.2.3 Hypsometric integral:

The hypsometric integral (HI) expresses the current volume of the relief which is not yet consumed by erosion, it is close to 0 for highly eroded watersheds (concave profile) and tends towards 1 for very slightly eroded watersheds (convex profile). The value of the hypsometric integral is therefore determined using the relation (3.2) developed by Pike and Wilson, (1971):

$$HI = \frac{Havr - Hmin}{Hmax - Hmin} \text{.......... (3.2)}$$

Tab.3.7. Hypsometric integral

Watershed	HI
Ain Berda	0.3
Oued Fregha	0.4
Oued El-Aneb	0.25

A strong hypsometric integral (greater than 0.60) with a strongly convex hypsometric curve indicates a non-equilibrium stage (youth). A hypsometric integral (between 0.35 and 0.60) associated with a concavo-convex hypsometric curve corresponds to an equilibrium phase (maturity). A low hypsometric integral (below 0.35) with an extremely concave curve explains a stage of late maturity i.e. the monadnock phase (Strahler, 1952).

The hypsometric curve of the watershed of Oued Fregha has a concavo-convex shape with a hypsometric integral of (0.4) shows that the relief of the basin is little evolved where about half of the initial relief has been consumed by erosion, it is a basin in dynamic equilibrium its erosive potential is average.

The watersheds of Ain Berda and Oued El-Aneb have a low hypsometric integral (0.3 and 0.25 respectively) and an extremely concave profile which corresponds to a considerably eroded relief. These basins have reached the monadnock phase, thus they are characterized by a high erosion potential.

3.2.4 Compactness index of GRAVELIUS (KG):

It is a morphological index, used to characterize the physical environment and to compare several watersheds between them. This index is defined as the ratio of the perimeter of the considered watershed (P) to the perimeter of the circle (P') having the same area (Boenisch, 2013, et Roche, 1963). It is obtained by the following formula (3.3):

$$KG = \frac{P}{P'} = \frac{p}{2\sqrt{\pi * S}} = 0.28\frac{P}{\sqrt{S}} \text{....... (3.3)}$$

Where:

P: Watershed perimeter [km];

P': Perimeter of the equivalent circle [km];

S: Watershed area [km²].

Tab.3.8. Compactness index of GRAVELIUS

Watershed	S[km²]	P[km]	K_G
Ain Berda	71	42	1.396
Oued Fregha	17	23	1.562
Oued El-Aneb	199	70.5	1.399

The Compactness index values close to 1 indicate watersheds with an almost circular shape, while values greater than 1 characterize watersheds of elongated shape. The shape of the watershed has an immediate influence on its hydrological behaviour, e.g., a rounded shape favours the rapid concentration of water and increases the peak flows at the watershed outlet.

The Compactness indices estimated for the three watersheds under study have all values greater than 1; which corresponds to elongated shapes.

3.2.5 Slopes:

The distribution of slopes over the studied watersheds was obtained by processing a digital terrain model (DEM) under a geographic information system (ArcGIS). The obtained slopes were then classified into five classes (Tab.3.9).

Tab.3.9.Slopes Classification

Class N°	Slope class	Slope[%]
1	Very low	0 to 5
2	Low	5 to 10
3	Moderate	10 to 20
4	Strong	20 to 35
5	Very strong	>35

Tab.3.10. Ain Berda Slopes Classification

Class N°	Slope class[%]	S_i[km]	S_i[%]
1	0 to 5	15.613	22
2	5 to 10	21.615	31
3	10 to 20	19.0182	27
4	20 to 35	10.93	15
5	>35	3.38	5

Tab.3.11. Oued Fregha Slopes Classification

Class N°	Slope class[%]	S_i[km]	S_i[%]
1	0 to 5	3.246	19
2	5 to 10	5.155	30
3	10 to 20	4.626	27
4	20 to 35	2.99	18
5	>35	0.959	6

Tab.3.12. Oued El-Aneb Slopes Classification

Class N°	Slope class[%]	S_i[km]	Si[%]
1	0 to 5	56.362	28
2	5 to 10	61.303	31
3	10 to 20	47.408	24
4	20 to 35	27.012	14
5	>35	7.772	4

All the watersheds have a heterogeneous relief. Approximately 50% of the watershed area has a low to very low slope class (less than 10%). The 5-20% slope class represents most dominating slope class at the three basins. Slope values greater than 20% affect important portion sat the watersheds with an average of 20% of their total areas. In all watersheds the results show a relatively low to moderate average slopes (Tab.2.18), (Tab.2.19), and (Tab.2.20).

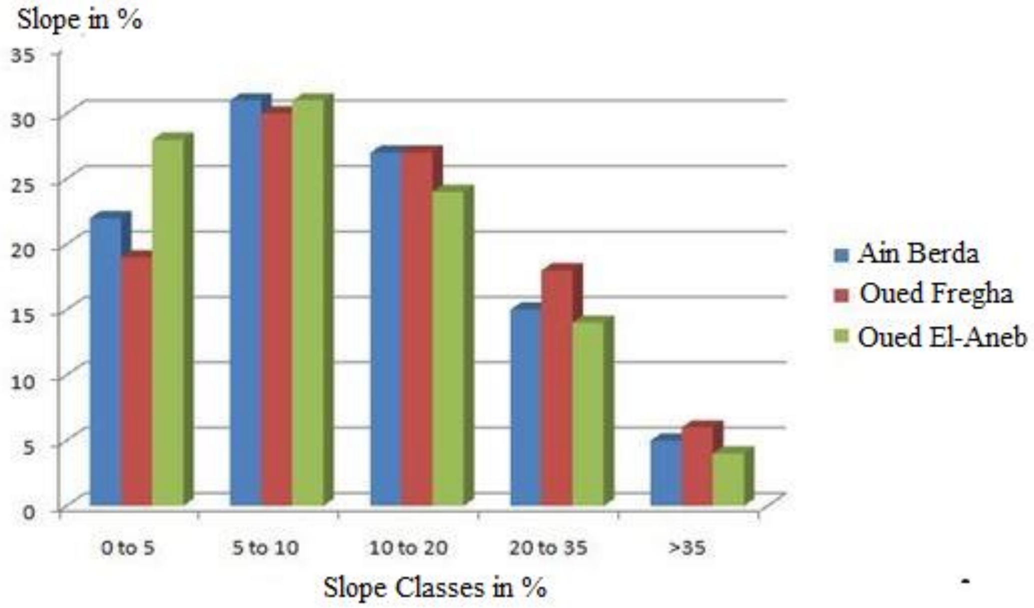

Fig.3.8. Distribution of slope classes over watersheds

CHAPTER 4

METHODOLOGY

PART01: RUSLE modelling

4.1 Overall methodology:

As above-mentioned, the empirical soil loss model RUSLE Renard et al. (1996) was used in this study to evaluate and compare the role of different support practices in controlling water erosion in the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha. The model enables to estimate the loss of land expressed in [ton/ha/year] at a pixel scale. The soil loss is obtained by the combination of five factors, namely: rainfall erosivity (R) in [Mj.mm/ha.h.an], topography (LS) in (dimensionless), soil erodibility (K) in [ton.ha.h/ha.Mj.mm], vegetation cover (C) in (dimensionless), and erosion support practices (P) in (dimensionless) according to the following equation:

$$\mathbf{A} = \mathbf{R} \times \mathbf{LS} \times \mathbf{K} \times \mathbf{C} \times \mathbf{P} \text{......... (4.1)}$$

All thematic maps of the RUSLE factors were prepared in a GIS environment and combined in a raster mode. All the steps carried out for these purposes are summarized in the following flow chart (Fig.4.1):

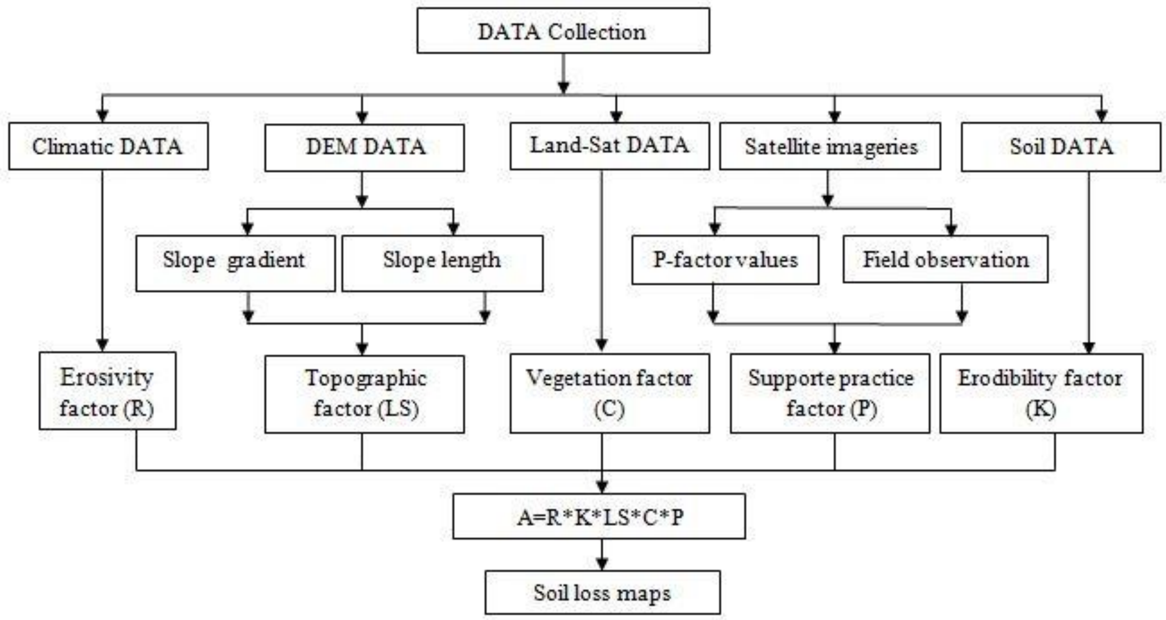

Fig.4.1. Methodology flowchart

4.2 Data sources:

The data used in this study are collected from different sources. The studied areas and periods were selected based on the availability of data. The table (4.1) presented below illustrates the details of these data:

Tab4.1. Details of the used data.

DATA	Data Utility	Type	Source and period
Rainfall data	Rainfall Erosivity (R)	Rainfall Maps	**worldclim**https://www.worldclim.org/data/worldclim21.html For period 200-2018
Soil Profiles	Soil erodibility (k)	Soil texture	**Soil-grid** **https://www.isric.org/explore/soilgrids**
Digital Elevation Model (DEM)	Topographic factor (LS)	SRTM 1ARC second global With 30 m resolution	**USGS earth explorer** **https://earthexplorer.usgs.gov/**
Satellite image	NDVI, Crop Management (C) and land cover	Land-Sat 8 WRS- Path =194 WRS-Row =035	**USGS earth explorer** **https://earthexplorer.usgs.gov/**
Land-Sat image Field visit	support practice (P)	Shapfile maps	**Google earth** **https://www.google.com/intl/fr/earth/versions/**

4.3 Estimation of the soil erosion conditioning factors:

4.3.1 Rainfall erosivity factor (R):

The R-factor it is a climatic factor that resume the rainfall intensity effects on soil erosion. The R-factor is the mostly common factor used in both equation USLE (Wischmeier and Smith 1965, 1978) and RUSLE (Renard et al., 1996). It is also defined by (Lal, 1990) as the aggressiveness of the rain to cause erosion by. The estimation of the R-factor can be made by many formulas (Tab.2.1).

To overcome the lack of detailed rainfall data, we used for this study the modified Fournier index (MFI) (Fournier.F, 1960) which only involve monthly and annual precipitation data. According to Renard and Freimund (1994) the R and MFI indices are correlated and have a good approximation. This method has been proved in different regions around the world (Bergsma 1980; Bolinne et al. 1980; Gabriels et al. 1986), and by (Meddi et al., 2016) in the northern part of Algeria, it is defined as.

$$\mathbf{MFI} = \sum_{i=1}^{12} \left(\frac{p_i^2}{p}\right) \text{...... (4.2)}$$

$$\mathbf{R} = \mathbf{0.264MFI^{1.5}} \text{...... (4.3)}$$

Where P_i: monthly mean precipitation (mm) P: annual precipitation (mm)

Rainfall data used to estimate the climatic factor (R) in this study was downloaded from the website [https://www.worldclim.org/data/worldclim21 .html] as monthly raster maps over an observation period extending from January 2000 to December 2018. These maps made it possible to spatialize the mean monthly and annual rainfall over the studied watersheds in a GIS environment. The spatial variability of annual rainfall over the three watersheds under study is shown in (Fig.4.2), (Fig.4.3), and (Fig.4.4):

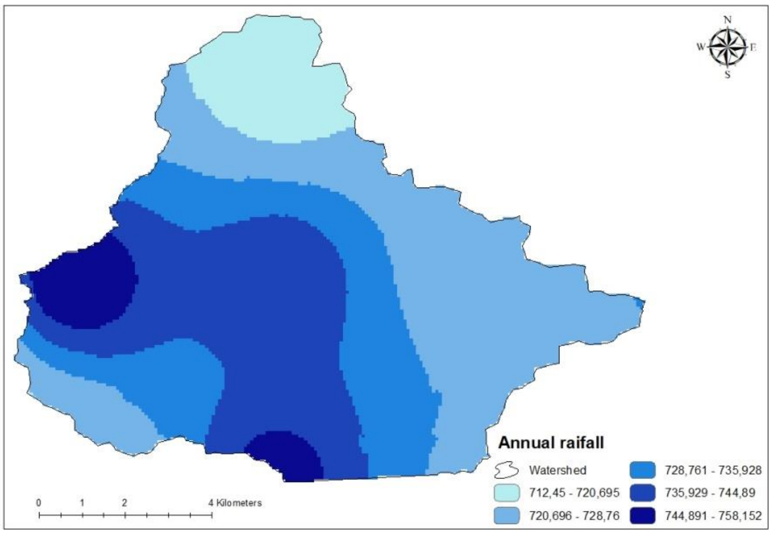

Fig.4.2. Annual rainfall across Ain Berda watershed

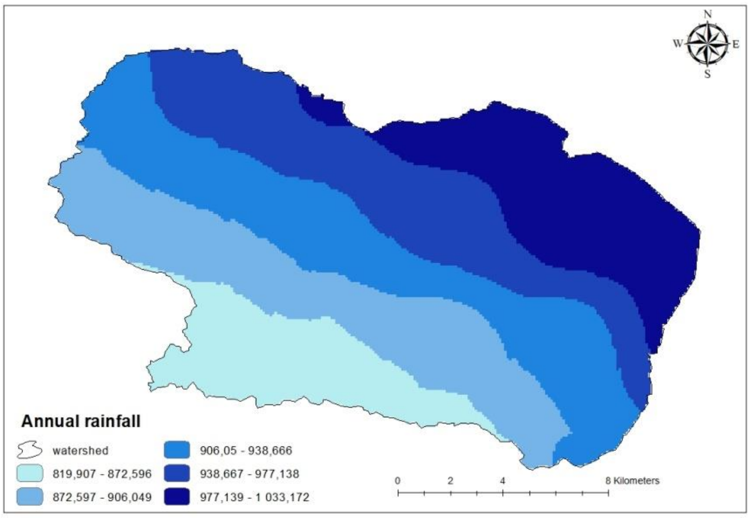

Fig.4.3. Annual rainfall across Oued El-Aneb watershed

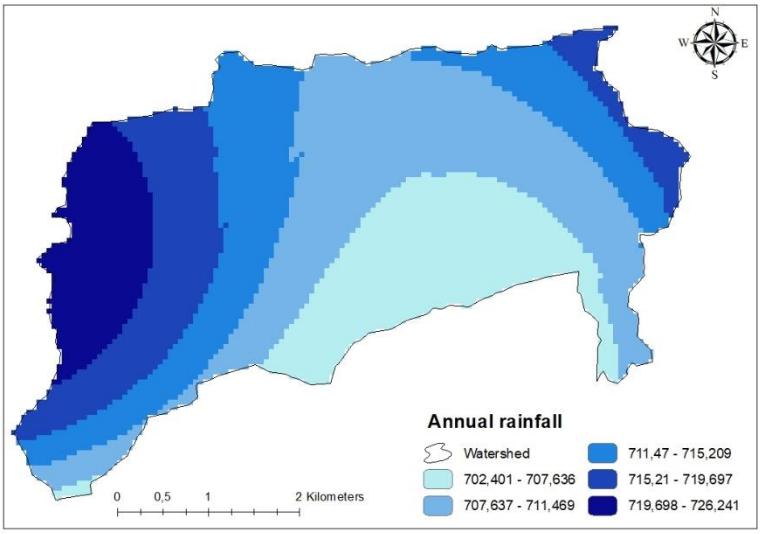

Fig.4.4. Annual rainfall across Oued Fregha watershed

4.3.2 Vegetation factor (C):

The C-factor recapitulates the influence of the vegetation cover and the cultivation techniques on water erosion; it is defined in the soil loss equation USLE Wischmeier and Smith., (1978) as the ratio of the erosion of a soil under a well-defined cover land. Overly the cover management factor (C) depends on the density of the vegetation (height of vegetation and the cropping system).

In this study, the C-factor map was developed based on the Normalized Difference Vegetation Index (NDVI), which was derived from the Land-Sat image of the study area. The image was generated from the earth explorer [**https://earthexplorer.usgs.gov/**], and acquired on 1**8**th September 2020 with a spatial resolution of 10 m.

The Normalized Difference Vegetation Index (NDVI) is an indicator of the energy reflected by the Earth related to various cover type conditions. NDVI values range between −1.0 and +1.0, and it was calculated and classified in GIS as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \quad \ldots\ldots \ (4.4)$$

Where: PIR: Band08 and RED: Band04 in Sentinel-02

After the generation of the NDVI image, we used the following formula to extract the (C-factor) surface from NDVI values (Van der Knijff et al., 2000; Van der Knijff et al., 1999):

$$\mathbf{C} = \mathbf{e}^{\left(\frac{-\alpha(\mathrm{NDVI})}{\beta-(\mathrm{NDVI})}\right)} \text{......} \quad (4.5)$$

where: α and β are unitless parameters that determine the shape of the curve relating to NDVI and the C-factor, they take values of 2 and 1 respectively (Van der Knijff et al., 2000; Van der Knijff et al., 1999)

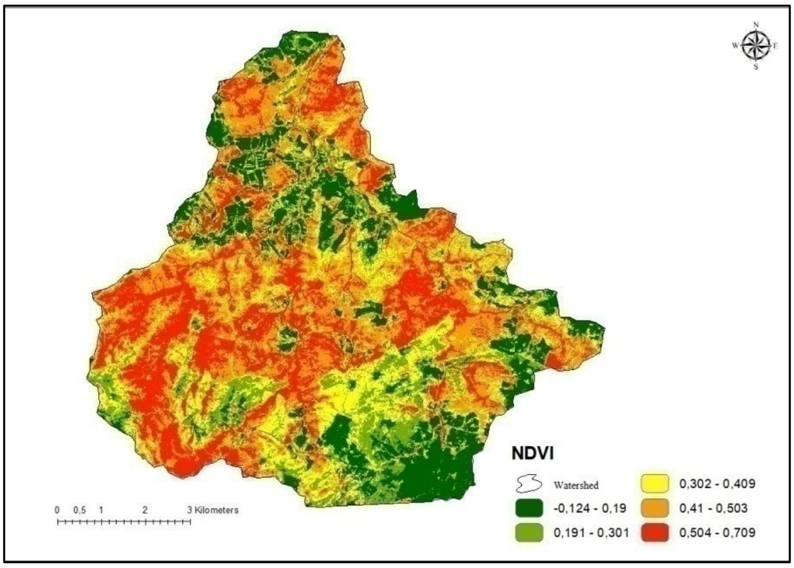

Fig.4.5. NDVI classification at Ain Berda watershed

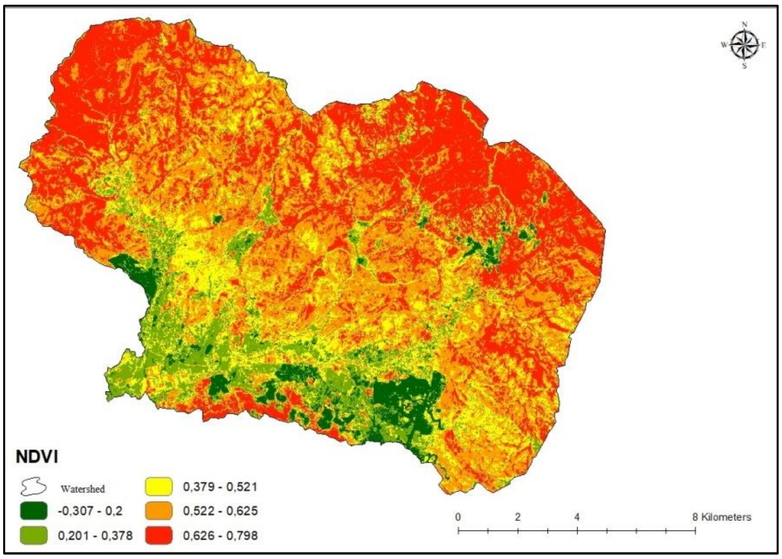

Fig.4.6. NDVI classification at Oued El-Aneb watershed

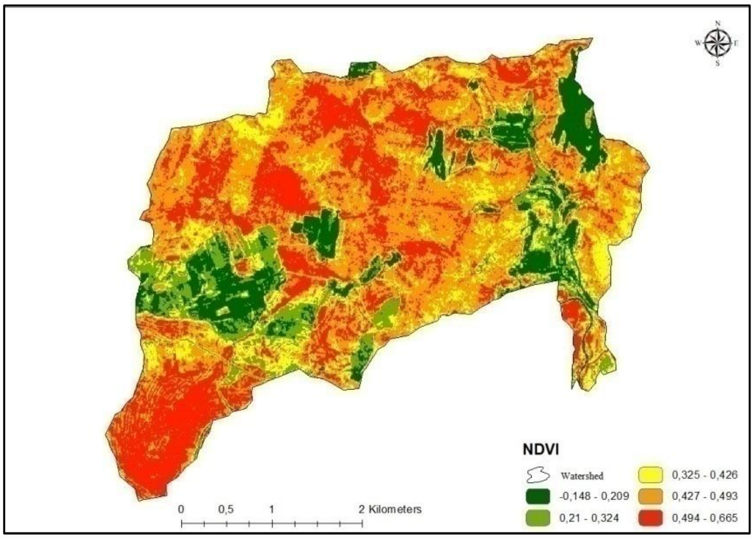

Fig.4.7. NDVI classification at Oued Fregha watershed

Distribution maps of NDVI at the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha, are illustrated in figure (4.5), figure (4.6), and figure (4.7) respectively, show that, about a quarter (1/4) the watersheds ‘areas are showing low NDVI values that range from -0.14 to 0.3 due to the relatively low vegetation; these lands are generally occupied by agricultural land (crops and crops associated with rangelands). The biggest parts of the watersheds’ areas show very high NDVI values. Those areas are generally non-cultivated and occupied by forests and scrubland.

4.3.3 Topographic factor (LS):

The LS-factor is a combination of two topographical parameters namely the length of the slope (L) and its inclination (S) which have a significant impact on the overland flow and therefore on water erosion on the hill shed, with a positive relationship. The runoff volume and velocity increase with increasing slope length and steepness of the land. In this study, the LS-factor was estimated according to the equation proposed by (Van Remortel et al., 2004) and based on digital elevation models (DEMs) of the three watersheds that were downloaded from [**https://earthexplorer.usgs.gov/**] with 30 m of resolution as follows:

- $LS = L * S$ .... (4.6)
- $L = \left(\frac{\lambda}{22.13}\right)^{m}$ .... (4.7)
- $m = \beta / (\beta + 1)$ .... (4.8)
- $\beta = (\sin \theta) / [3*(\sin \theta)^{0.8} + 0.56]$ .... (4.9)
- $S = 10.8\sin\theta + 0.03 \quad \theta < 9\%$ .... (4.10)

➢ $S = 16.8\sin\theta - 0.5 \quad \theta \geq 9\%$..................................(4.11)

λ: is the slope length (m). **m**: is a variable length-slope exponent. **β** : is a factor that varies with the slope gradient. **θ**: is the slope angle(%). RUSLE length standard parcel [22.1m]. RUSLE slope standard parcel [9%]

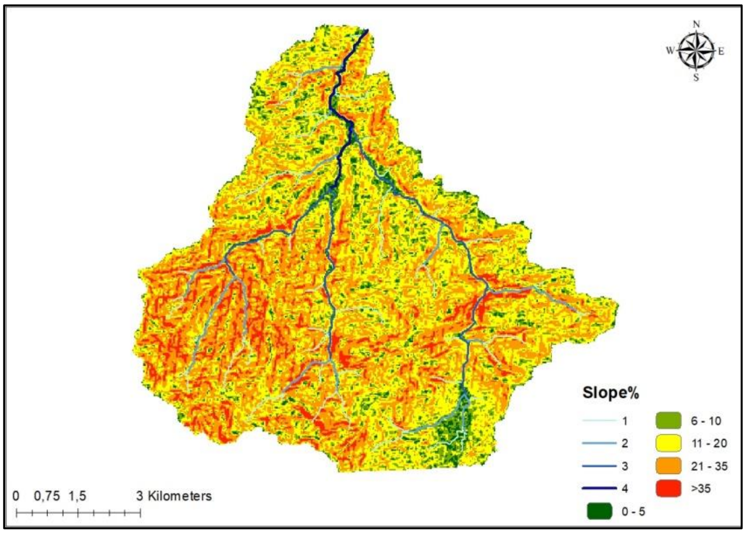

Fig.4.8. Slope classification at Ain Berda watershed

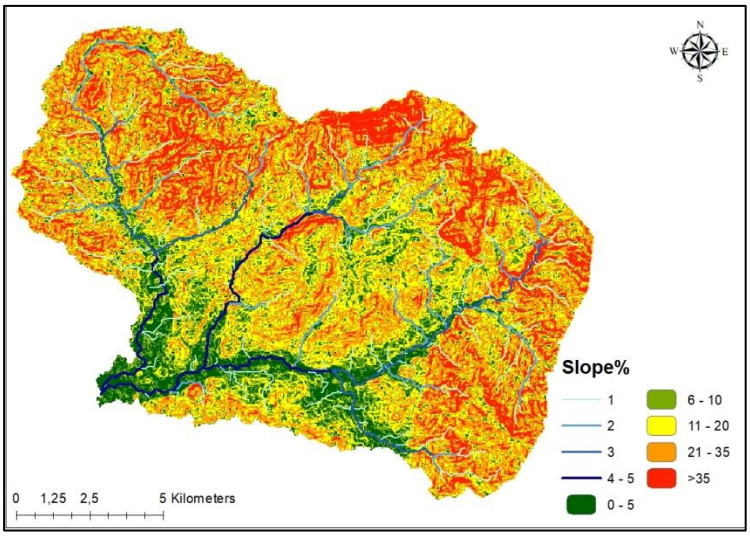

Fig.4.9. Slope classification at Oued El-Aneb watershed

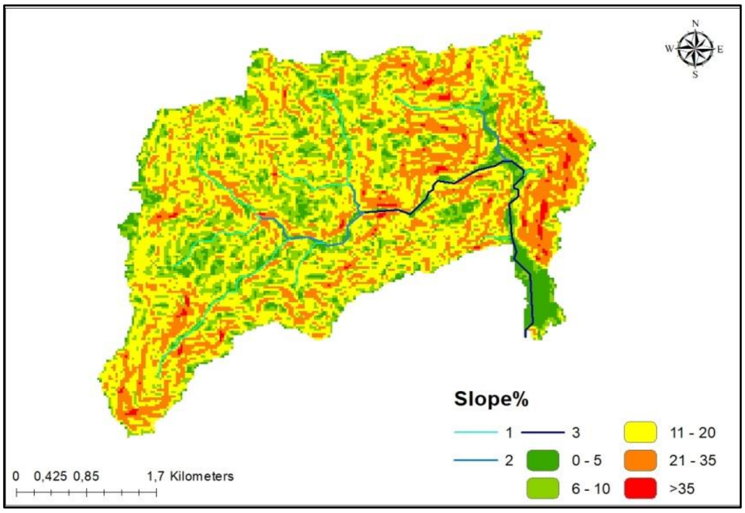

Fig.4.10. Slope classification at Oued Fregha watershed

4.3.4 The soil erodibility factor (K):

The soil erodibility K-factor characterizes the resistance of soil particles to the detachment and transport of particles by water. This factor also depends on the intrinsic properties of the soil and their evolution under the influence of cultivation techniques (Roose and Sarrailh, 1989).

To determine the soil erodibility we are particularly interested in the results of soil analyses at the level of the upper horizon (from 0 to 30 cm deep), because the phenomenon of water erosion particularly affects this layer.

A soil texture triangle is used to determine the texture classification. Soil texture classification is named according to the predominant individual mineral constituent or predominant combination in that soil, e.g. sandy, clay, silt or sandy clay, etc (Fig.4.11).

In this study, the K-factor was calculated using the following relationship of Renard et al. (1997), which is related to soil texture, organic matter, structure and permeability:

$$K = 2.8 * 10^{-7} * (12 - OM) * M^{1.14} + 4.3 * 10^{-3} * (s - 2) + 3.3 * 10^{-3} * (p - 3) \text{......} \quad (4.12)$$

Where:

K: is the soil erodibility factor,

OM: is the percentage of organic matter content, P: is the soil permeability code. The permeability code can have one of the following six values:

Fast"1", Moderate to fast"2", Moderate"3", Slow to moderate"4", Slow"5", Very slow"6".

S: is the soil structure code ranging from 1 to 4: Friable"1", Fine polyhedral"2", Medium to coarse polyhedral"3", Solid"4".

M: is the particle size parameter and can be written as:

$$\mathbf{M} = (\%\mathbf{silt} + \%\mathbf{very\ fine\ sand}) * (\mathbf{100} - \%\mathbf{clay}) \text{......... (4.13)}$$

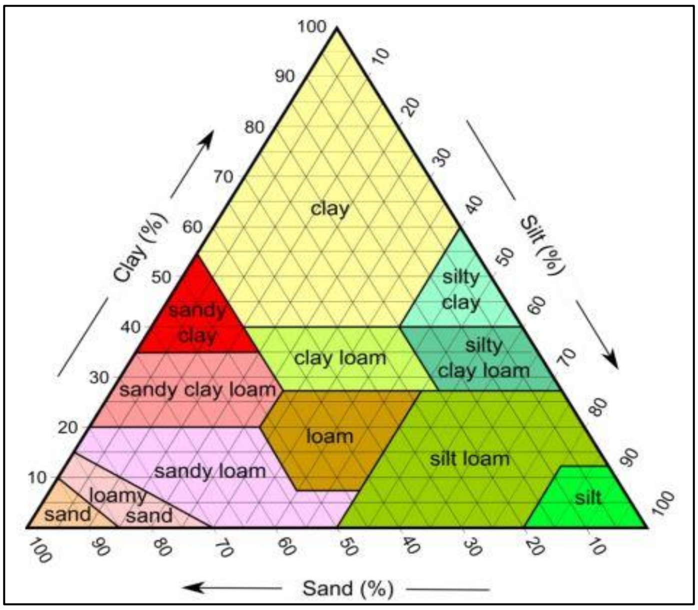

Fig.4.11. Soil texture triangle

Source: Mike Norton (Own work) [CC BY-SA 3.0] via Wikimedia Commons

4.3.5 The support practice factor (P):

The support practices P-factor was described by Renard et al., (1996) in the RUSLE model as a ratio of soil loss with a specific support practice to the corresponding soil loss due to way how the land is managed. It reflects the efficiency of cultivation techniques (land management methods such as; the method of tillage and the direction of crops) and soil conservation actions (re-vegetation of slopes), the lower the P-value the more soil loss reduced (Panagos et al., 2015).

The support practices consist to reduce the volume and the velocity of runoff water and promoting infiltration by modifying the structural state of the soil, which reduces the erosive impact. Existing common techniques over the study areas are: Terracing, Strip-cropping, and Agroforestry.

In this study, the assignment of P-factor was conducted in three steps:

- First, we tried to identify the existing support practice and agricultural developments in the three watersheds based on the analysis of satellite imagery.
- In the second step, field visits have been conducted to confirm the existence of the techniques, and validate the observations on the types of these techniques made from satellite images.
- Finally, P-factor values are assigned for each technique according to (Tab.4.2).

Tab.4.2. The value of support practice factor (P)

Techniques	Values	References
Grass margins	0.81	(Dabney et al., 2001)
perennial grass	0.5	(Vieira and Dabney, 2009)
stone walls	0.62	(Panagos et al., 2015)
Level bench terrace	0.14	(Wischmeier and Smith., 1978)
Reverse-slope bench terrace	0.05	
Level retention bench terrace	0.01	(Wischmeier and Smith., 1978)
Tied ridging	0.1-0.2	
Contour bunds	0.5	(Mir et al., 2015)
Contour strip cropping	0.5	
Outward-sloping bench terrace	0.35	
Terracing	0.42	(Debie et al., 2019)
Strip cropping	0.2	(Didoné et al., 2021)
Agroforestry	0.25-0.5	(Young, 1989)
Stone bunds	0.32	(Gebrernichael et al., 2005)
Agro-ecology	0.3	(Fenta et al., 2021)
Organic farming	0.82	

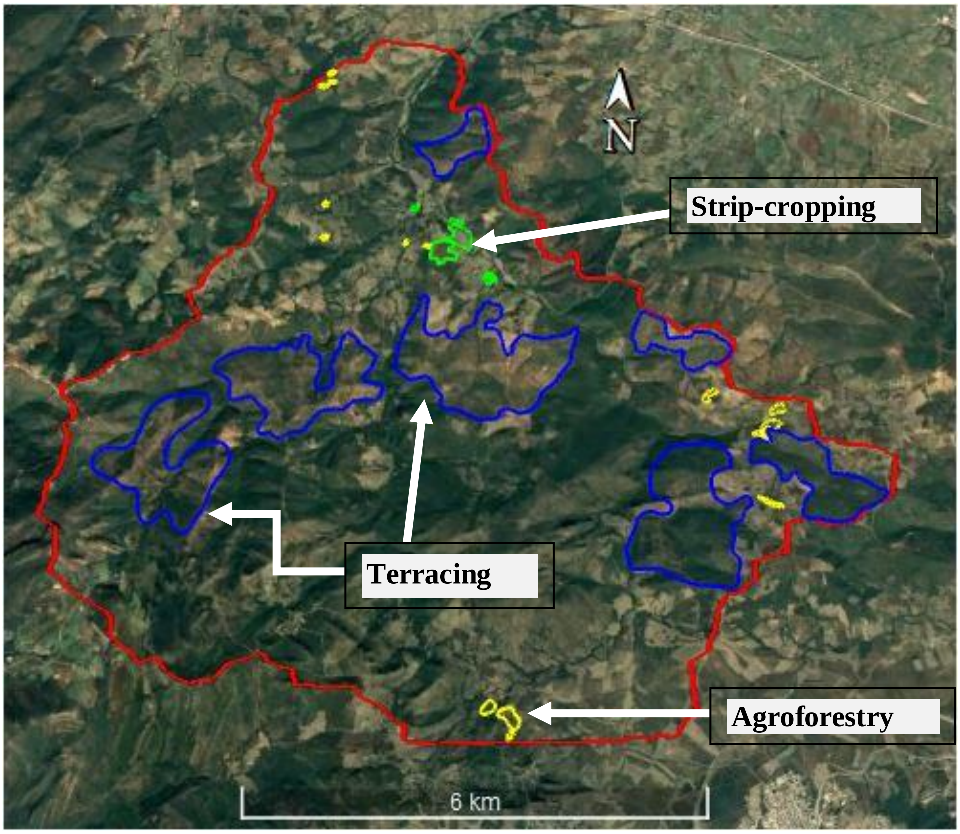

Fig.4.12. Support practices at the watershed of Ain Berda

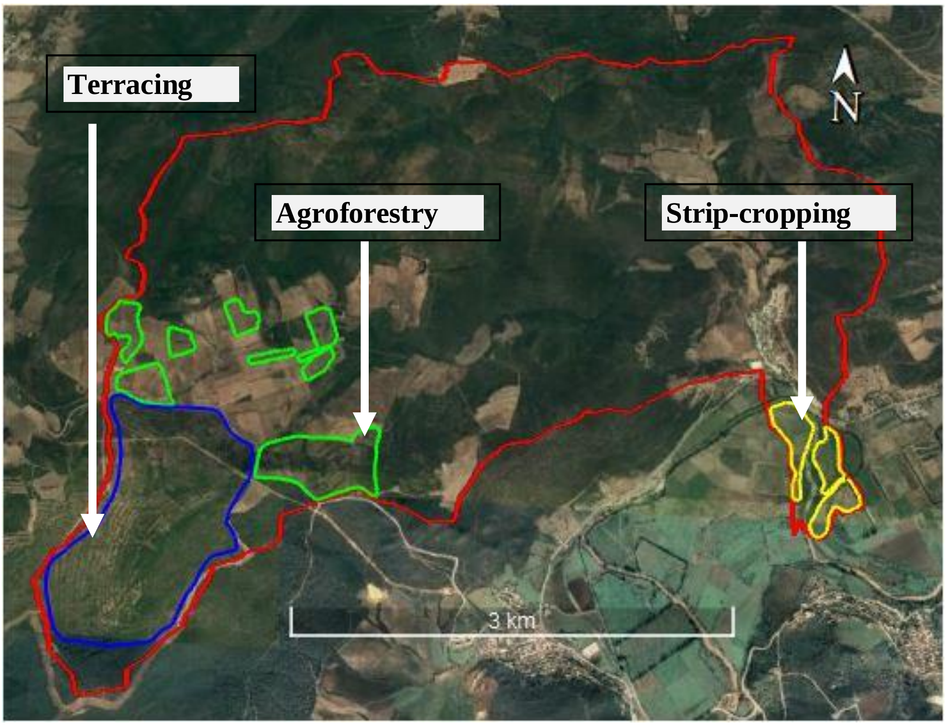

Fig.4.13. Support practices at the watershed of Oued Fregha

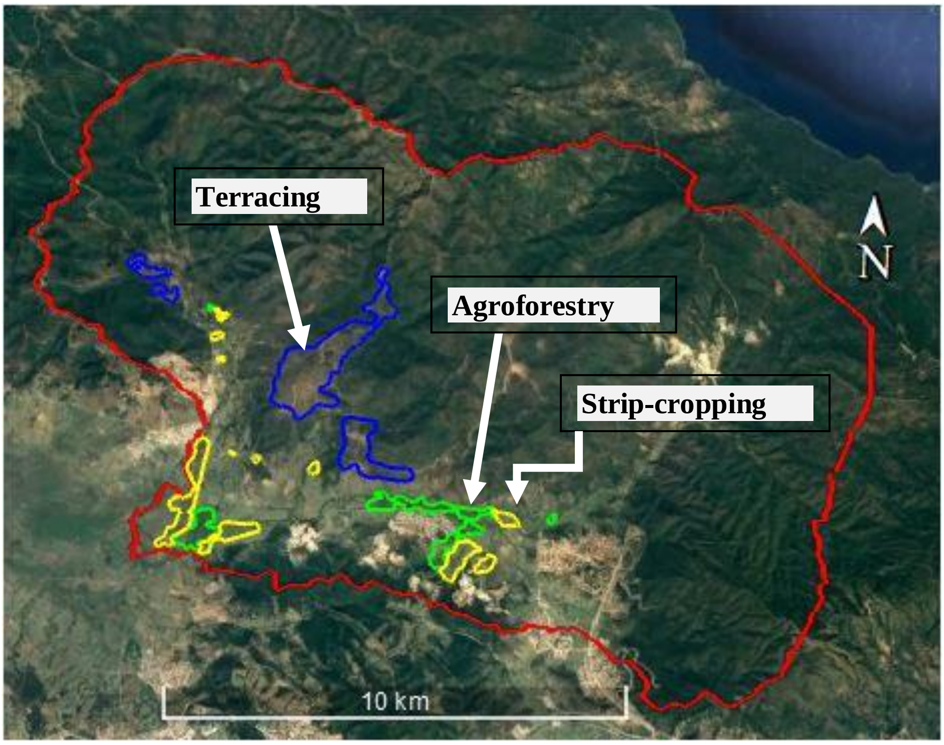

Fig.4.14. Support practices at the watershed of Oued El-Aneb

PART2: Patience of opinions:

Farmers' actions and decisions to conserve natural resources generally and soil and water particularly are largely related to their knowledge of the problems and perceived benefits of conservation measures (Amsalu and de Graaff, 2006).

In this context, during the field visits of the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha, some interviews and group discussions with the farmers and landowners were carried out in order to answer these main questions:

(i) What is their degree of awareness towards soil erosion?

(ii) Are they using specific techniques to control soil loss due to water erosion?

(ii) What is the role of the state and the concerned authorities?

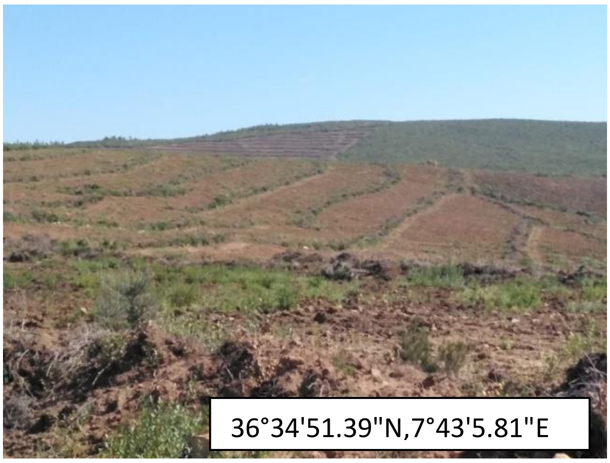

Fig.4.15. Terracing (Oued Fregha)

Fig.4.16. Terracing (Ain Berda)

Fig.4.17. Terracing (Oued El-Aneb)

Fig.4.18. Strip cropping (Oued Fregha)

Fig.4.19. Strip cropping (Oued El-Aneb)

Fig.4.20. Strip cropping (Ain Berda)

Fig.4.21. Strip cropping (Oued Fregha)

Fig.4.22. Agroforestry (Oued El-Aneb)

Fig.4.23. Agroforestry (Ain Berda)

Fig.4.24. Agroforestry (Oued Fregha)

Fig.4.25. Agroforestry (Oued Fregha)

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Results and discussions:

5.1.1 R factor:

The spatial distributions of R-factor estimated using the modified Fournier index (Fournier.F, 1960) over the three studied watersheds are depicted in figure (5.1), figure (5.2), and figure (5.3). The three watersheds show moderate rainfall erosivity. Generally, the R-factor values decrease spatially from north to south, which is mainly related to the decrease in rainfall amounts as we get far from the Mediterranean Sea. The same reason explains why the higher R-factor values were obtained in the watershed of Oued El-Aneb, while the lowest in the watershed of Oued Fregha. The table below presents minimum, average and maximum R-factor values estimated at the considered watershed in [Mj.mm/ha.h.year].

Tab.5.1. The erosivity factor (R)

Watershed	R_{min}	R_{max}	R_{mean}
Ain berda	207.173	226.181	213.82
Oued Fregha	201.623	216.531	206.66
Oued El-Aneb	279.889	397.177	338.38

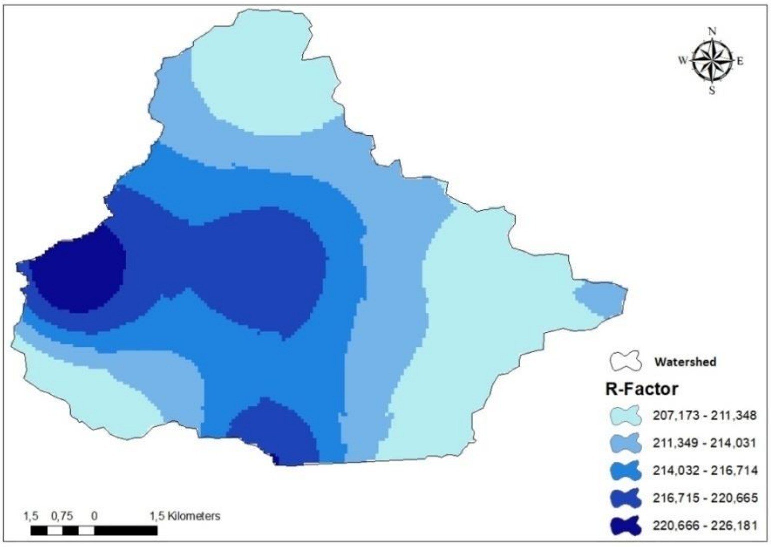

Fig.5.1. Distribution map of the R-factor in the watershed of Ain Berda

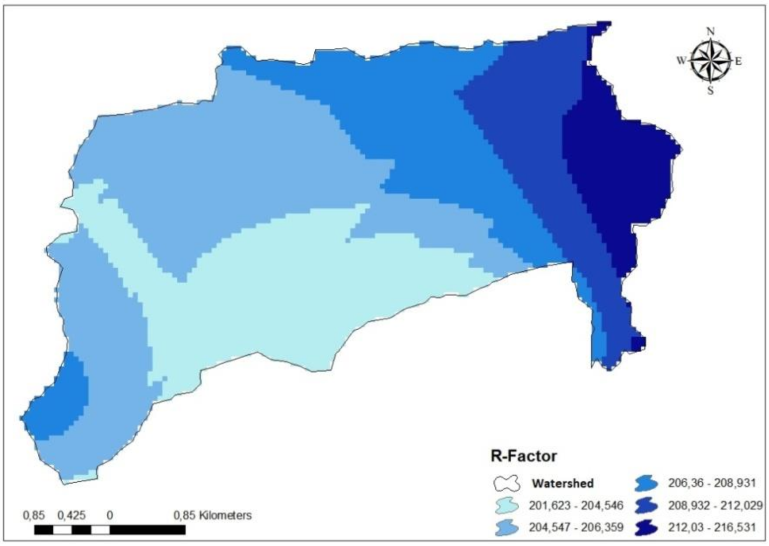

Fig.5.2. Distribution map of the R-factor in the watershed of Oued Fregha

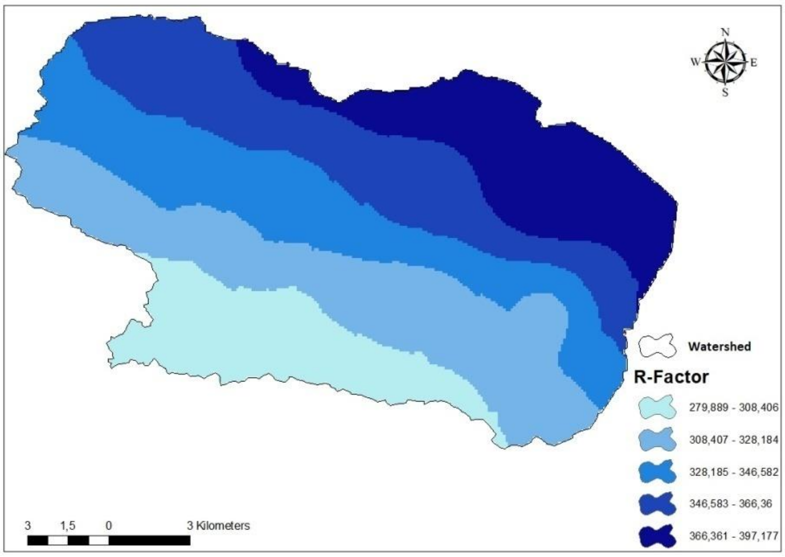

Fig.5.3. Distribution map of the R-factor in the watershed of Oued El-Aneb

5.1.2 LS factor:

The topographic LS-factor was estimated for each watershed using the formula of Van Remortel et al., (2004), the results are presented in (Fig.5.4), (Fig.5.5), and (Fig.5.6). The LS-factor values showed high spatial variability across the three watersheds; ranging from 0.03 to 74.47 at the watershed of Ain Berda, from 0.3 to 25.68 at the watershed of Oued Fregha, and from 0.03 to 90.37 at the watershed of Oued El-Aneb. This high variability is explained by the heterogeneity of the relief in the studied areas. On average, the estimations of LS-factor depict values of 9.79, 5.22, and 10.01 at the watersheds of Ain Berda, Oued Fregha, and Oued El-

Aneb respectively. The largest values are generally located in the western part of Ain Berda and Oued Fregha and the north-eastern part of Oued El-Aneb watershed; these areas are characterized by the domination of steep and very steep slopes.

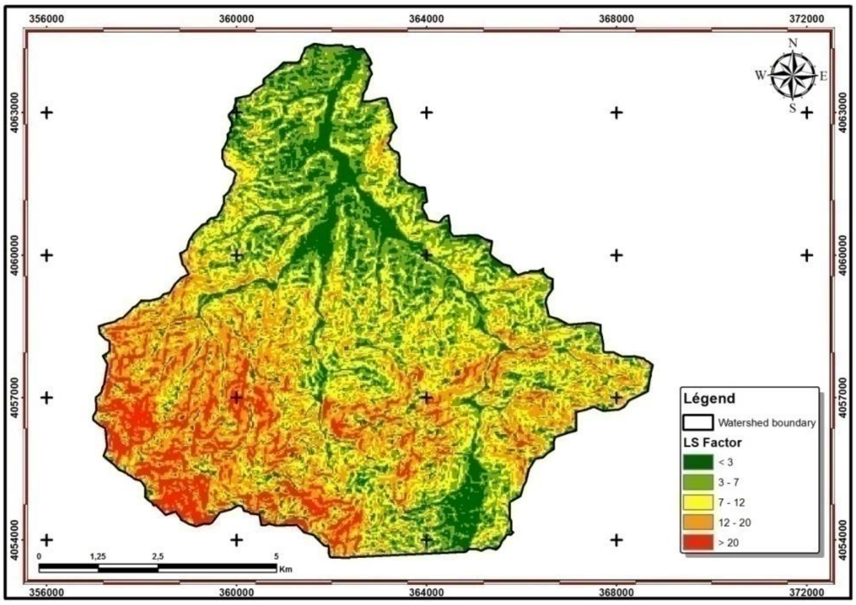

Fig.5.4. Distribution map of the LS-factor in the Ain Berda watershed.

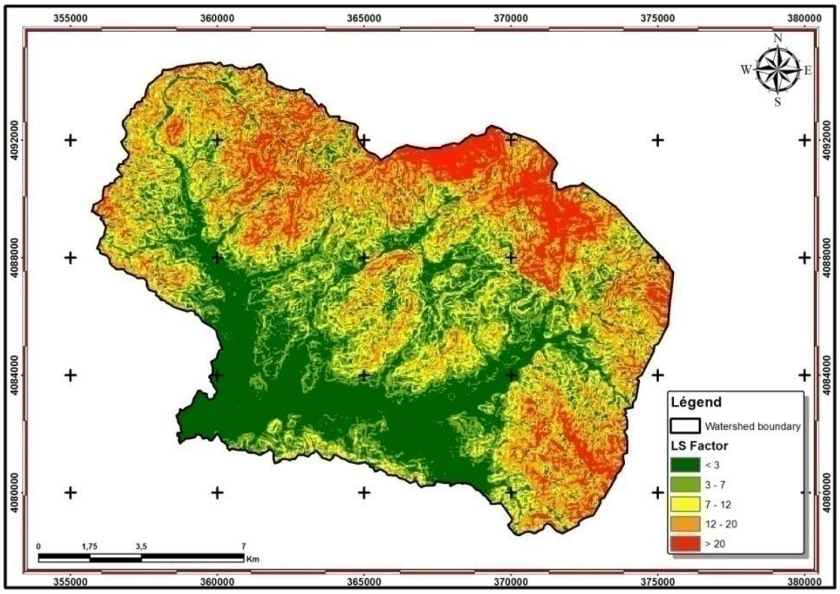

Fig.5.5. Distribution map of the LS-factor in the Oued El-Aneb watershed.

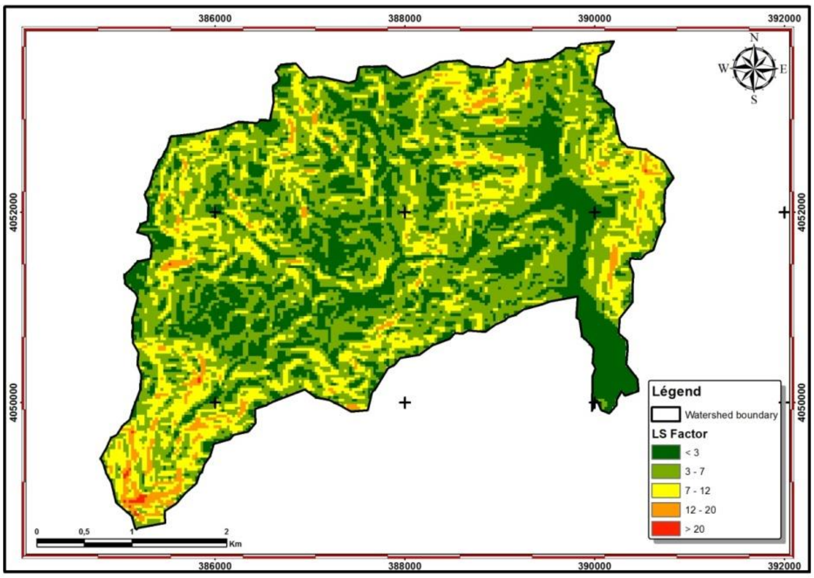

Fig.5.6. Distribution map of the LS-factor in the Oued Fregha watershed.

5.1.3 C factor:

The Vegetation C-factor was estimated across the three watersheds based on Van der Knijff et al., (2000); Van der Knijff et al., (1999) formula. The results are presented in figure (5.7), figure (5.8), and figure (5.9). The values of this factor vary between 1 on bare soil and 0.008 on soil protected by a dense forest cover. The table below presents minimum, average and maximum C-factor values estimated at the considered watershed. Compared to the watershed of Oued El-Aneb, the two other watersheds showed relatively high average C-factor values (0.33 at Ain El Berda and 0.26 at Oued Fregha), this can be explained by the existence of large agricultural areas at those watersheds. On the other hand, the low C-factor means value (0.14) observed over the watershed of Oued El-Aneb is due to the dense vegetation cover characterizing this last.

Tab.5.2. The Vegetation factor **(**C)

Watershed	C_{min}	C_{max}	C_{mean}
Ain Berda	0.008	0.98	0.33
Oued Fregha	0.082	1	0.26
Oued El-Aneb	0.019	0.97	0.14

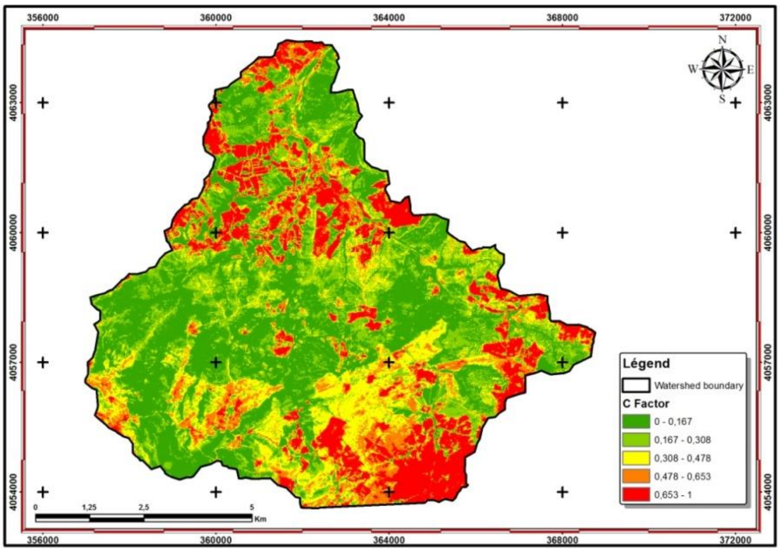

Fig.5.7. Distribution map of C-factor in the Ain Berda watershed.

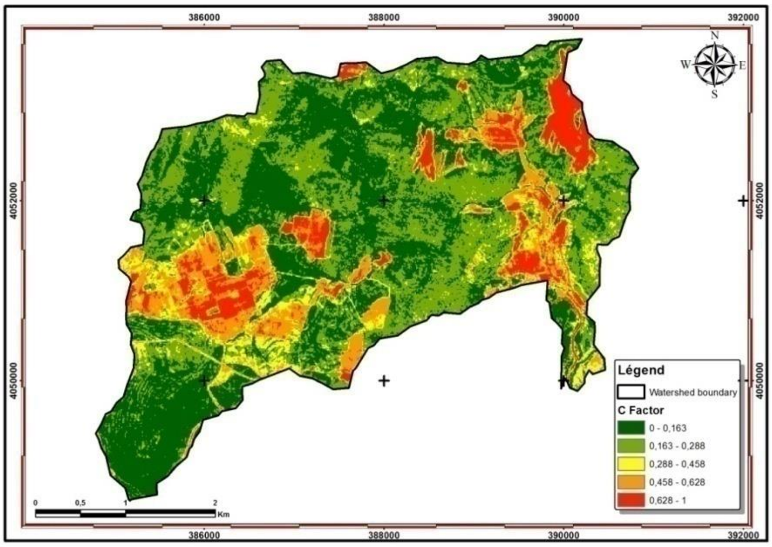

Fig.5.8. Distribution map of C-factor in the Oued Fregha watershed

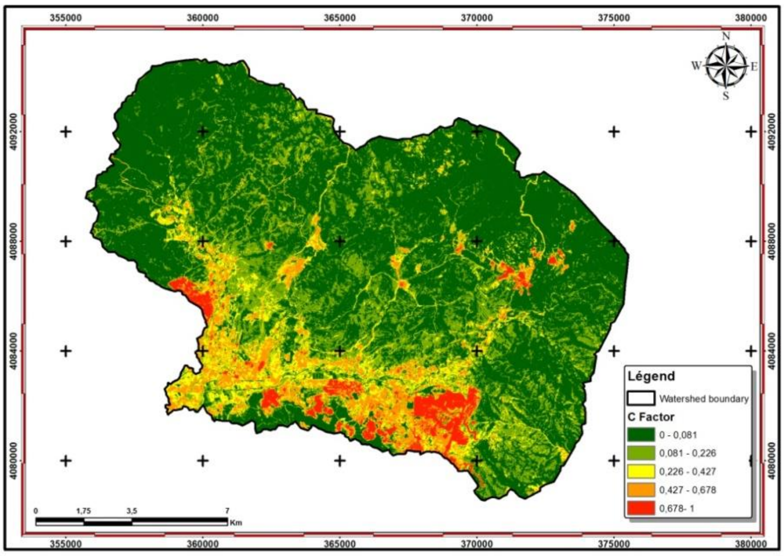

Fig.5.9. Distribution map of C-factor in the Oued El-Aneb watershed

5.1.4 K factor:

In present study we extract the k-factor value was calculated using the formula (4.12), and depending on the data downloaded from (**https://www.isric.org/explore/soilgrids**) website. The result presented in the figure (5.10), figure (5.11), and figure (5.12) showed that the K-factor values at the three watersheds are very close with values ranging from 0.015 to 0,017 [t.ha.h/ha.Mj.mm], and an average of 0.016 [t.ha.h / ha.Mj.mm] which is relatively moderate.

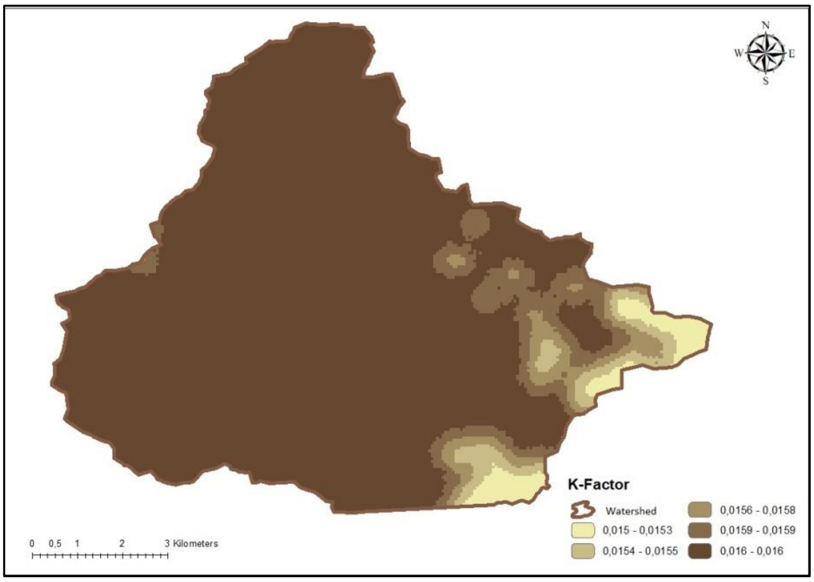

Fig.5.10. Distribution map of the K-factor in the Ain Berda watershed.

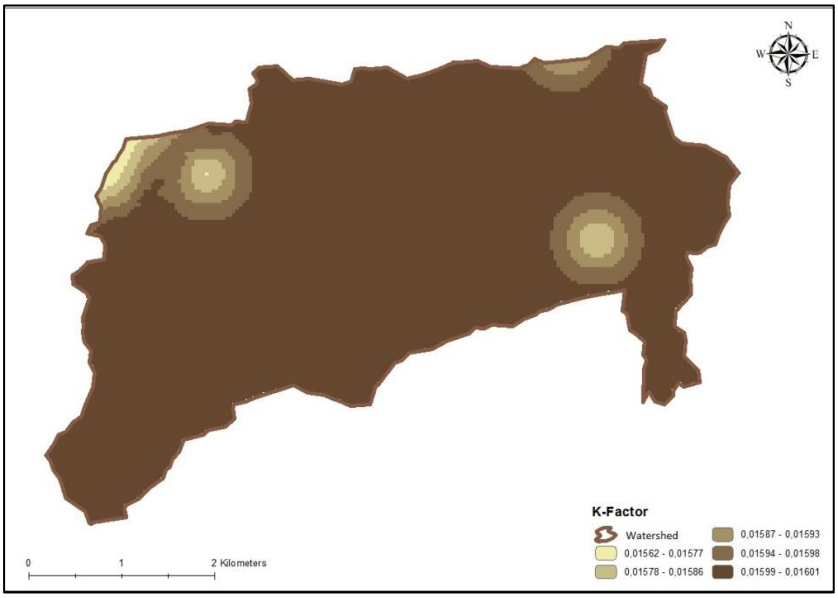

Fig.5.11. Distribution map of the K-factor in the Oued Fregha watershed.

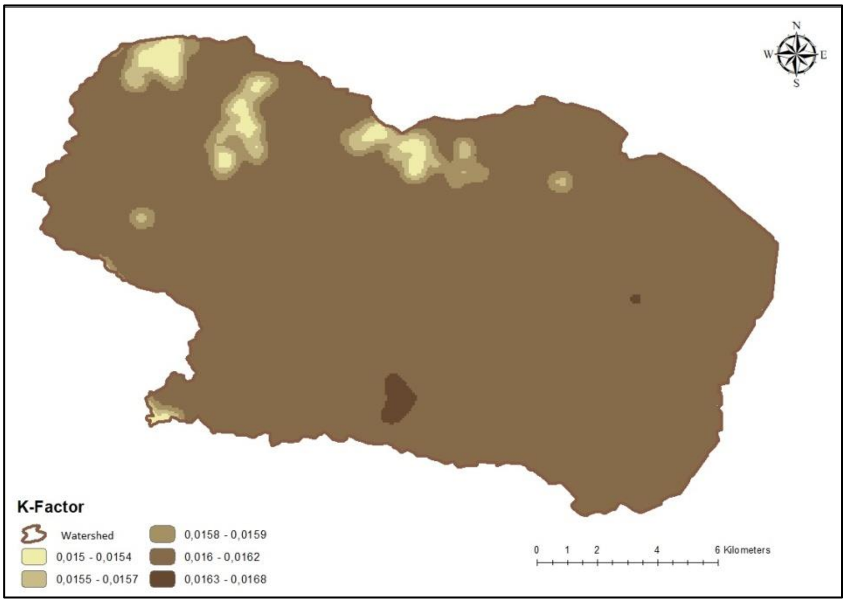

Fig.5.12. Distribution map of the K-factor in the Oued El-Aneb watershed.

5.1.5 P factor:

The P-factor was determined in the watersheds according to the existing agricultural developments, which were identified using google earth satellite images. The main techniques were observed in the watersheds are Terracing, Strip cropping, and Agroforestry in some parts, and the rest are undeveloped areas, where it was expressed at the value of 1. In addition, we have assigned each control technique (areas under cultivation) by its specific P-value, based on the previous works. The presence of the three above mentioned have been verified through field visits.

Tab.5.3. P-value

Control techniques	P-value	Reference
Terracing	0.42	(Debie et al., 2019)
Strip cropping	0.20	(Didoné et al., 2021)
Agroforestry	0.25	(Young, 1989)
undeveloped	1	(Wischmeier, W. H. & Smith, D. D. (1978))

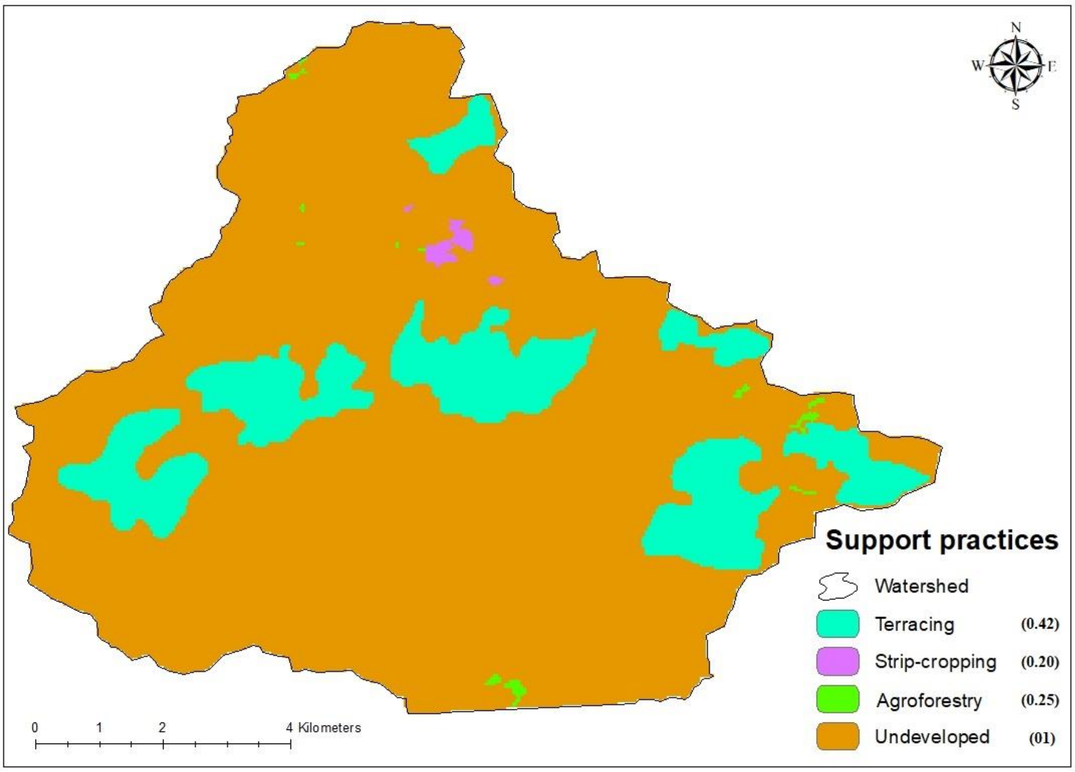

Fig.5.13. Suppot practices in Ain Berda

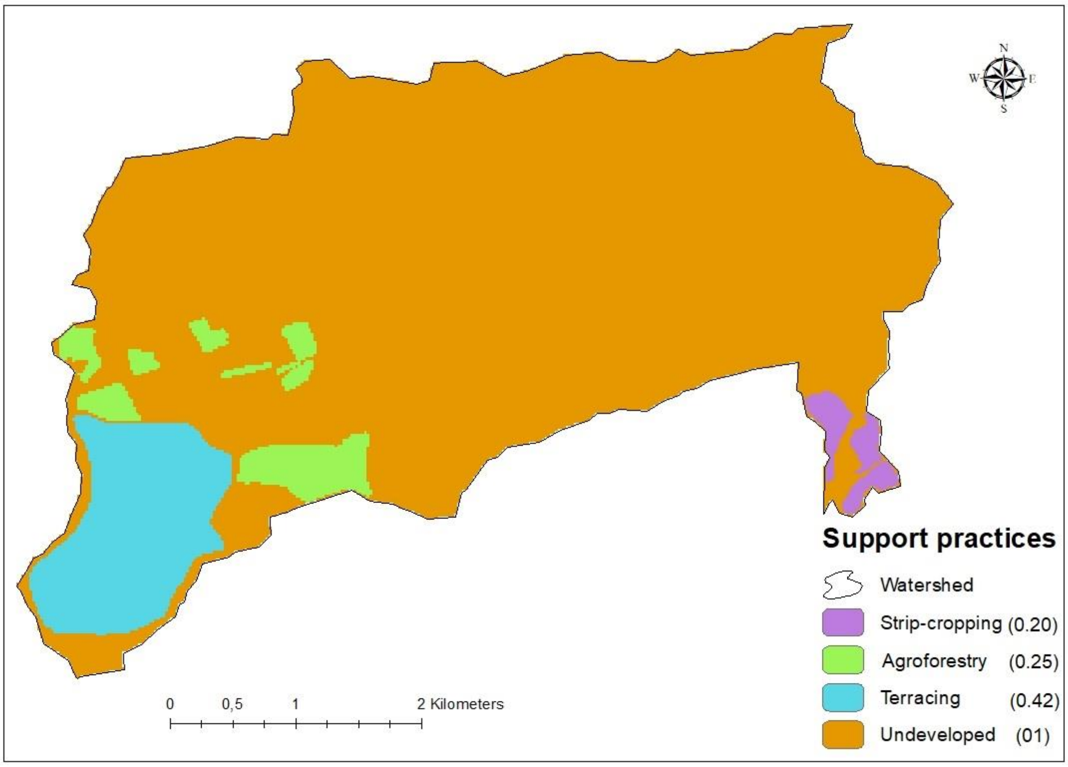

Fig.5.14. Suppot practices in Oued Fregha

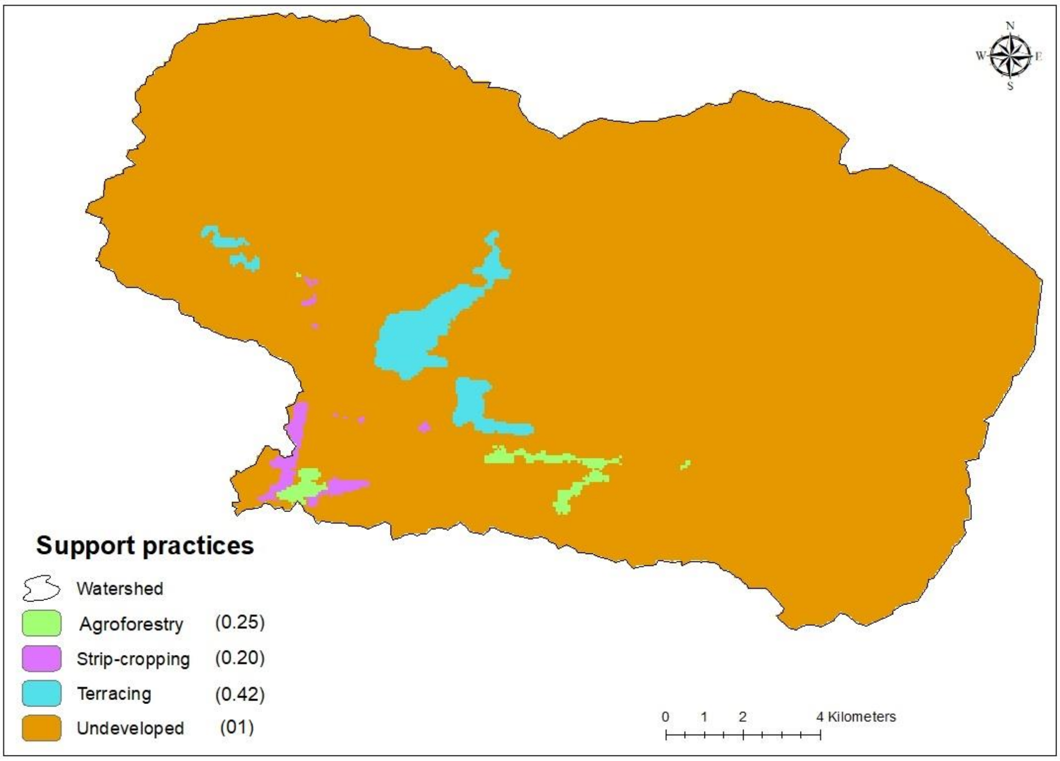

Fig.5.15. Suppot practices in Oued El-Aneb

5.1.6 Annual soil loss:

In order to highlight the role of different support practices in reducing soil loss due to water erosion, the modelling of soil erosion via the RUSLE model was conducted on two phases:

Firstly, without considering the P-factor which reflects the effect of support practices: This means that annual soil loss will result from the multiplication of R, LS, C and K factors. The average annual soil loss at the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha are illustrated in (Tab.5.4).

In the second phase, the P-factor is reintegrated to the RUSLE equation, which enables assessing the effects of the identified practices (Terracing, Agro-forestry, and Strip-cropping) on soil erosion over the three studied watersheds. Each technique was defined by its own coefficient (Tab.5.3). The average annual soil loss at the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha are illustrated in table (5.4). The results showed that in the total area there is an important reduction in the annual soil loss amounts after applying the P-factor.

Tab.5.4. Annual soil erosion rates

Watershed	Without P	Terracing		Agroforestry		Strip-cropping		With P	
	A_{avr}	A_{avr}	$A_{\%}$	A_{avr}	$A_{\%}$	A_{avr}	$A_{\%}$	A_{avr}	$A_{\%}$
Ain Berda	8.6	7.61	12.96	8.48	1.45	8.57	0.38	7.95	14.79
Oued El-Aneb	2.98	2.81	5.86	2.95	1.05	2.95	0.81	2.91	7.72
Oued Fregha	3.98	3.92	1.42	9.35	0.68	3.97	0.14	3.69	2.42

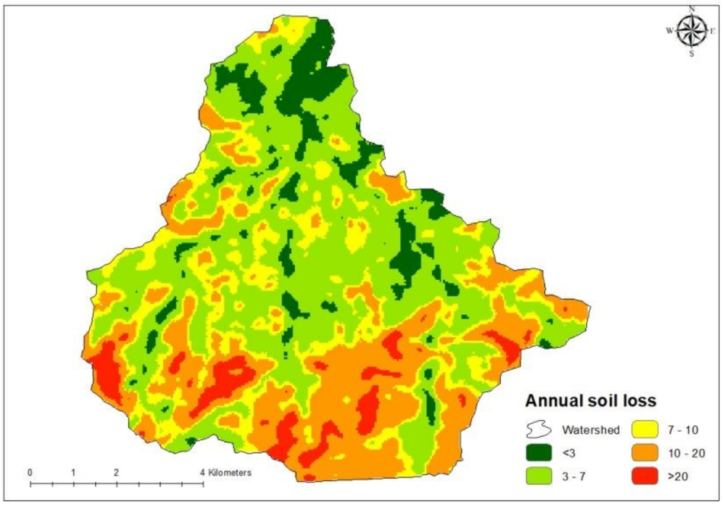

Fig.5.16. Annual soil erosion in Ain Berda watershed (without P-factor)

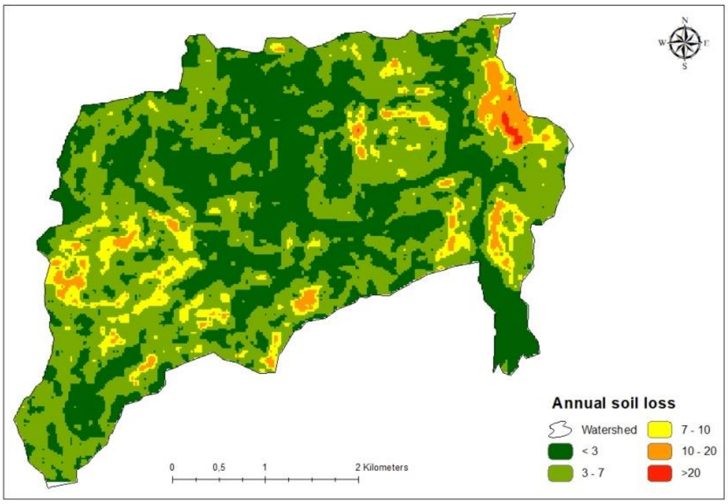

Fig.5.17. Annual soil erosion in Oued Fregha watershed (Without P-factor)

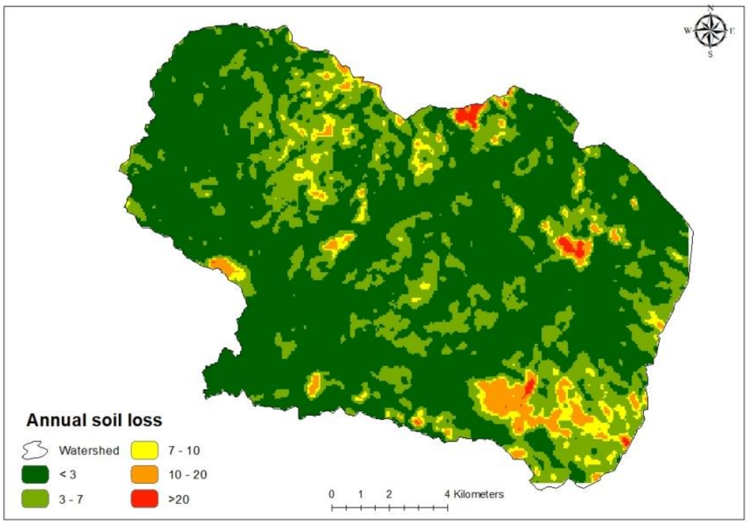

Fig.5.18. Annual soil erosion in Oued El-Aneb watershed (Without P-factor)

Annual soil loss amounts estimated by RUSLE without considering the existing support practices showed that the watershed of high Ain Berda is subject to a high erosion rate with an average of 8.6 [ton.ha^{-1}.year^{-1}], which exceeds the tolerance threshold in Algeria fixed by Demmak, (1982) at 7 [ton.ha^{-1}.year^{-1}]. In contrast, low soil loss amounts were found at the two other watersheds with an average value of 3.98 [ton.ha^{-1}.year^{-1}] at the watershed of Oued El-Aneb and of 2.98 [ton.ha^{-1}.year^{-1}] at the watershed of Oued Fregha.

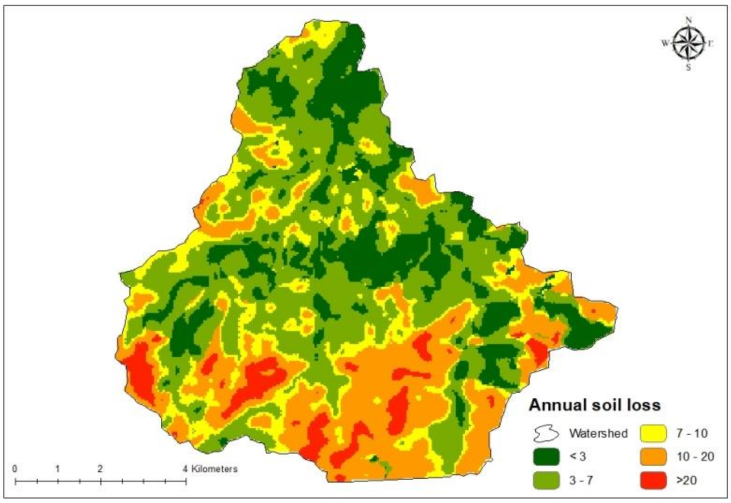

Fig.5.19. Annual soil erosion in Ain Berda watershed (with P-factor)

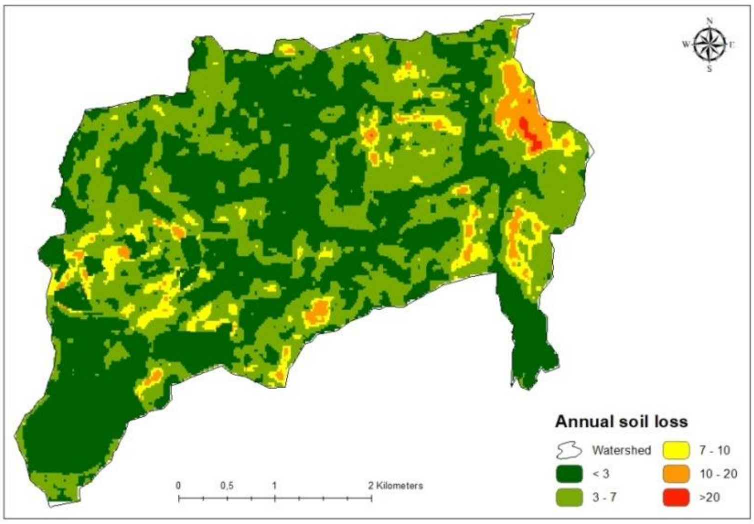

Fig.5.20. Annual soil erosion in Oued Fregha watershed (With P-factor)

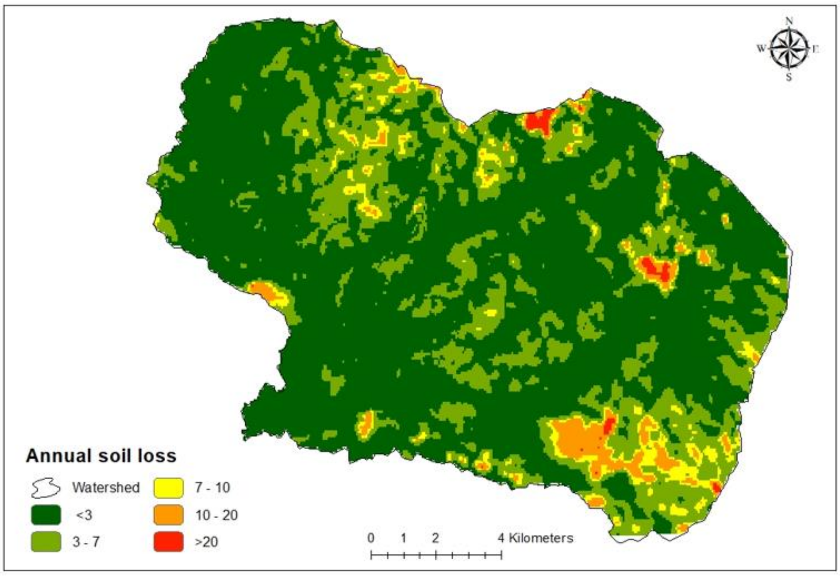

Fig.5.21. Annual soil erosion in Oued El-Aneb watershed (With P-factor)

After applying the support practices, the results of RUSLE show divergent reduction rates over the three watersheds evaluated at 14.79% in the watershed of Ain Berda, 7.72% in the watershed of Oued el-Aneb and 2.42% in the watershed of Oued Fregha. This may be due to the difference in the areas in which these techniques are applied. It is important to mention that the watershed of Ain Berda, even after applying the support practices, gave an amount of soil loss of 7.95 [$ton.ha^{-1}.year^{-1}$], which remains exceeding the tolerance rate of 7 [$ton.ha^{-1}.year^{-1}$].

By comparing the techniques between them, the terracing technique gives the highest rates of soil loss reduction in the three basins (Fig.5.22): 12.96% at Ain berda, 1.42% at Oued Fregha, and 5.86% at Oued El-Aneb. The stripe-cropping techniques gave lesser reduction rates of 0.38%, 0.14 %, and 0.81% in Ain Berda, Oued Fregha, and Oued El-Aneb respectively. Regarding, Agroforestry, its contribution in the annual soil loss reduction were estimated at 1.45% in Ain berda, 0.68% in Oued Fregha, and 1.05% in Oued El-Aneb.

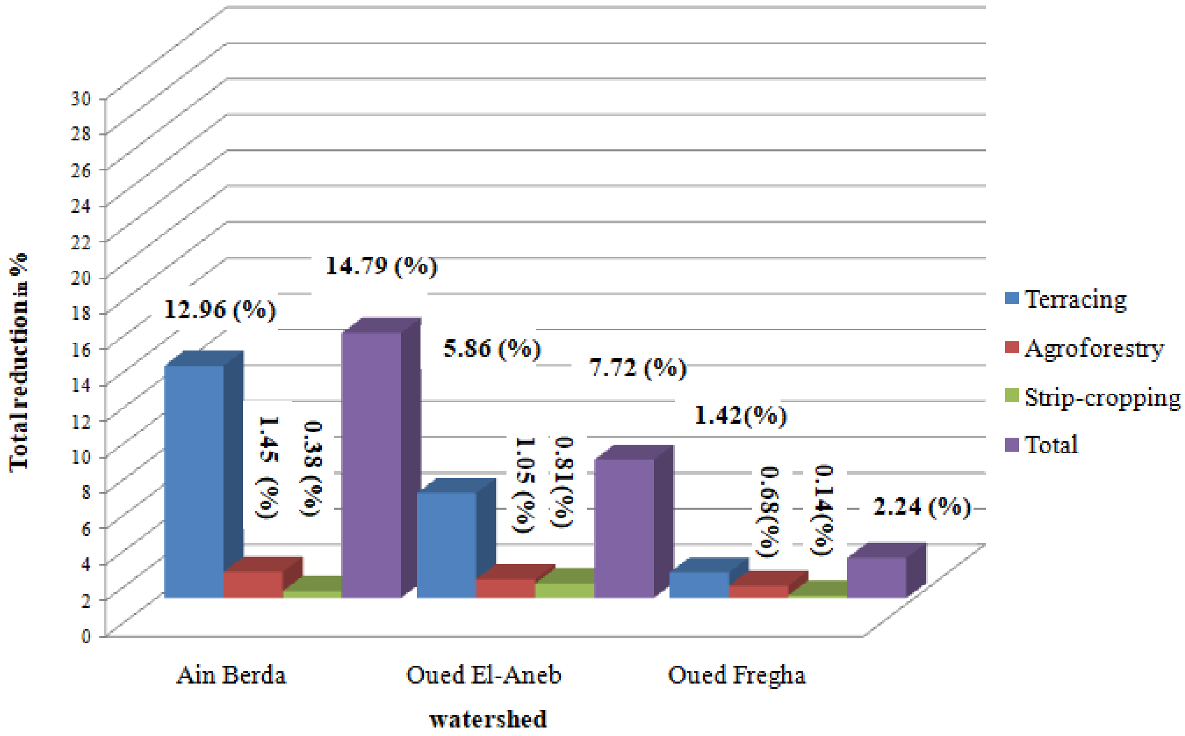

Fig.5.22. Soil loss reduction in watersheds

PART2: Patience of opinions:

During our visit to the studied watersheds, we met some farmers; where some questions were asked in order to obtain information on their views of erosion problems and their conservation knowledge and practices.

Q01: Are your land vulnerable to soil erosion?

The majority said that they yes specially during rainstorms at the beginning of the autumn, in this period all the cultivate land is free of any vegetation cover after the harvester or it is ploughed in preparation for the planting season, so the surface crust in unstable.

Some of the lands on the edge of the rivers are also affected by land movement erosion and the continuing accidental expanding of the waterway, especially with the flood season.

Q02: What kinds of techniques you applied to control this problem?

All the farmers had the same answer that they had no specific way or method to deal with this issue, they only depend on the chemical fertilizer to strengthen the exhausting land fertility because water erosion.

The majority of field labours and farmers are not educated. When we asked them about the existing techniques such as strip cropping and agroforestry they said that, basically they applied these methods for economic reason, and they don't know that are effective in controlling soil erosion.

The common way used in these watersheds is the method of tillage where they do it twice in the year with different directions, one lengthwise and the second transversal, for soil ventilation and to allow the water enforcement and the organic matter to the roots of plants and trees.

Q03: What is the role of authorities in the agriculture sector?

The role of the authorities through the minister of agriculture and marine fishing is in supporting farmers with raw materials such as fertilizers and provides seeds that are good for growing. Also provides important financial loans, land preparation and grants in long-term concession contracts, water supply and supporting its prices, the provision of the modern farming machines.

Q04: Do you see that the government do her part to protect soil?

Some time yes, especially in the mountain and the steep slopes like terracing it was applied by the forest protection and they also applied many techniques to control gully erosion such as structural measures: dams built and gabions, geo textures in the edge of the roads, Contour Ridging, artificial water way.etc, or by vegetation measures like planting trees.

After having some interviews with the number of farmers, we found that some of them lack awareness, as they are not taking this issue seriously. During our field investigation, we remarked that most of encountered farmers have a low educational level, this fact can be confirmed with the statistics published by the food and agriculture organization (FAO) in its report about agriculture in Algeria, where it is mentioned that about 65% of Algerian farm holders are uneducated.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion:

Soil erosion is the most important soil degradation process in Algeria as everywhere in the world. Mitigating its effects on environmental and socio-economical scales constitutes a real challenge for researchers and policy-makers during these last years. In this framework, this study came to assess the role of management strategies in controlling water erosion over three watersheds located in the north-east of Algeria namely the watersheds of Ain Berda, Oued El-Aneb, and Oued Fregha.

For this purpose, an integrated approach based on the implementation of the universal soil loss equation (RUSLE) through a geographical information system environment (GIS), and depending on the freely available geospatial datasets (Rainfall grids, Soil profile grids, Digital Elevation Model, Land-Sat and Google Satellite imagery). Inspections carried out through Satellite imagery and field visits allowed the identification of three support practices namely terracing, strip cropping, and agro-forestry in all the considered watersheds. According to RUSLE modeling results, the application of these techniques are efficient, as they gave significant soil loss reduction rates of 14.79%, 7.72 %, and 2.42% at the watersheds Ain Berda, Oued El-Aneb, and Oued Fregha respectively.

In a second step, the performances of three support techniques in reducing soil loss were separately evaluated and compared. The results showed considerable differences in the performance of these techniques in reducing soil loss. Where the terracing technique was more efficient in the three watersheds, it provides a reduction in the susceptibility of erosion about: 12. 96%, 5.86%, and 1.42% in Ain Berda, Oued El-Aneb, and Oued Fregha respectively. In return, the participations of strip cropping and agroforestry techniques in reducing soil erosion rates were relatively low, but it remains important especially that the implementation of these techniques are not expensive.

The study comprised, also a patience of the farmers' opinions about their understandings of soil erosion phenomena and whether they are using specific techniques to reduce soil erosion effects. The patience of opinions revealed a lack of awareness, and a large ignorance of the role that different support practices can play in reducing soil erosion.

In general, this study showed that the general land-use policies of the country are premised on fundamental concern for soil conservation. However, its implementation remains not comprehensive and confined only to some watersheds. Overall, taking into account the existence of certain support practices and using effective models may give reassuring predictions about the efficiency of their use. Thus, this study suggested subsidizing the existing support practices, and putting the necessary policy to expand their applications in different watersheds.

6.2 Recommendations:

This study recommends:

1) Raising awareness of farmers and livestock herders about the risk of soil erosion.
2) Improving the level of education of farmers.
3) Providing free datasets for the data science community.
4) Supporting institutional and research projects in the environmental sector.
5) Evaluate the applicability and effectiveness of different erosion control techniques before implementing them, because some of them are expensive and need certain conditions.
6) Encouraging reforestation campaigns which should ameliorate soil quality and reduce soil erosion,
7) Enhance the cooperation between relevant authorities; stockholders, and social public, to draft a national program for sustainable soil and water conservation.

6.3 Further Research:

This study was limited by several conditions that’s why further research should focus on larger areas including more support practices

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APPENDIX:

Tab.6.1 Hypsometric distribution of the Ain Berda watershed

Class N°	Altitude classes		Average Alt.	Surfaces		
	Min.	Max.	H_i[m]	S_i[km^2]	S_i[%]	$\sum S_i$[%]
1	716	788	752	3.470	4.919	4.919
2	665	715	690	5.657	8.019	12.938
3	620	664	642	6.445	9.135	22.072
4	580	619	599.5	6.891	9.768	31.840
5	543	579	561	6.579	9.266	41.106
6	507	542	524.5	7.596	10.698	51.805
7	471	506	488.5	6.660	9.380	61.185
8	435	470	452.5	5.696	8.022	69.207
9	400	434	417	4.835	6.809	76.017
10	368	399	383.5	4.249	5.984	82.001
11	339	367	353	3.105	4.373	86.374
12	310	338	324	2.207	3.108	89.482
13	281	309	295	1.719	2.421	91.902
14	253	280	266.5	1.501	2.115	94.017
15	224	252	238	1.178	1.660	95.677
16	195	223	209	0.926	1.304	96.980
17	164	194	179	0.748	1.053	98.033
18	132	163	147.5	0.582	0.820	98.853
19	99	131	115	0.326	0.460	99.313
20	43	98	705	0.184	0.260	100

Tab.6.2 Hypsometric distribution of the Oued Fregha watershed

Class N°	Altitude classes		Average Alt.	Surfaces		
	Min.	Max.	H_i[m]	S_i[km^2]	S_i[%]	$\sum S_i$[%]
1	333	356	344.5	0.533	3.142	3.142
2	315	332	323.5	0.570	3.355	6.497
3	297	314	305.5	0.740	4.357	10.854
4	278	296	287	0.883	5.198	16.053
5	262	277	269.5	1.000	5.891	21.943
6	251	261	256	1.527	8.997	30.940
7	239	250	244.5	1.724	10.197	41.097
8	226	238	232	1.689	9.792	51.046
9	212	225	218.5	1.857	10.924	61.969
10	197	211	204	1.662	9.792	71.761
11	182	196	189	1.222	7.199	78.960
12	168	181	174.5	0.935	5.508	84.468
13	154	167	160.5	0.675	3.974	88.442
14	140	153	146.5	0.530	3.124	91.566
15	125	139	132	0.484	2.851	94.417
16	110	124	117	0.449	2.648	97.065
17	94	109	101.5	0.111	0.652	97.716
18	78	93	85.5	0.102	0.601	98.317
19	60	77	68.5	0.103	0.605	98.922
20	48	59	53.5	0.035	0.203	100

Tab.6.3 Hypsometric distribution of the Oued El-Aneb watershed

Class N°	Altitude classes		Average Alt.	Surfaces		
	Min.	Max.	H_i[m]	S_i[km^2]	S_i[%]	$\sum S_i$[%]
1	776	816	796	8.38	4.21	4.21
2	754	775	764.5	19.98	10.03	14.24
3	729	753	741	16.23	8.15	22.39
4	703	728	715.5	16.93	8.50	30.89
5	675	702	688.5	18.21	9.14	40.04
6	650	674	662	18.23	9.16	49.19
7	622	649	635.5	14.81	7.44	56.63
8	597	621	609	14.83	7.45	64.07
9	568	596	582	12.96	6.50	70.58
10	543	567	555	11.53	5.79	76.36
11	515	542	528.5	9.51	4.78	81.14
12	490	514	502	8.67	4.35	85.49
13	465	489	477	5.70	2.86	88.36
14	436	464	450	4.59	2.30	90.66
15	408	435	421.5	3.75	1.88	92.54
16	380	407	393.5	2.68	1.34	93.89
17	355	379	367	1.20	1.10	94.99
18	330	354	342	1.78	0.89	95.89
19	301	329	315	1.60	0.80	96.69
20	276	300	288	1.35	0.68	97.37
21	251	275	263	0.96	0.48	97.85
22	226	250	238	0.93	0.47	98.31
23	201	225	213	0.63	0.31	98.63
24	176	200	188	0.60	0.30	98.93
25	147	175	161	0.48	0.24	99.17
26	119	146	132.5	0.47	0.23	99.41
27	91	118	104.5	0.37	0.19	99.60
28	66	90	78	0.34	0.17	99.77
29	41	65	53	0.29	0.14	99.91

30	15	40	27.5	0.18	0.09	100

THANK YOU