Pan African University
PAU Institute of Water and Energy Sciences

PAN-AFRICAN UNIVERSITY

INSTITUTE FOR WATER AND ENERGY SCIENCES

(Including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree in

WATER ENGINEERING

Presented by

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Simulation of the spatial distribution of soil erosion risk in Mellah Watershed, North-eastern Algeria

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DECLARATION

STUDENT'S DECLARATION

I, Asma Bouamrane, hereby declare that this thesis titled "Simulation of the spatial distribution of soil erosion risk in Mellah Watershed, North-eastern Algeria" is my original work to the best of my knowledge and has not been submitted to a University or any other institute or published earlier for the award of any degree or diploma. I also declare that all the information, materials and results from other works presented in this thesis have been duly cited and recognized as required of academic rules and ethics.

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SUPERVISOR'S DECLARATION

I, Professor Habib Abida , hereby declare that I supervised the preparation of this Master thesis submitted therein in accordance with the guidelines on supervision of Master thesis laid down by the Pan African University Institute of Water and Energy Sciences, Algeria.

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ACKNOWLEDGEMENT

First and foremost, I would like to thank God Almighty for giving me the strength and knowledge to finalize this work.

I am profoundly grateful to my supervisor, Professor Habib Abida from the University of Sfax Tunisia, for his helpful support, encouragement, valuable guidance, patience, suggestions and professional advices throughout the realization of the master thesis.. I greatly appreciate his deep knowledge in various disciplines, which contributed a lot to this project. I am privileged to have been under his supervision.

My special thanks go to Professor Yassine Djebbar from the University of Souk-Ahras, Algeria for his professional advices, help and encouragement.

My sincere gratitude goes to the African Union Commission (AUC) for awarding me a full scholarship for my master studies at the Pan African University Institute of Water and Energy Sciences (PAUWES) as well as a research grant for conducting this study. I would also thank the government of my country Algeria for all welfare provided during our study period and for presenting a pleasant schooling environment for us. In addition, I thank all PAUWES staff members (Professor Abdellatif Zerga, the director and deputy director Professor Ziani-Cherif and the water coordinator ABDELBAKI Chérifa, Fatima Chaib and Khadija Bousmaha, Prof Amazigh Diab andFouad Hadj-Amara) for all their help during the two passed years and all the other staff members of PAUWES.

I would like to express my appreciation and sincere thanks to all students of Pauwes specially water engineering class for the wonderful time we passed together.

I would also like to thank the University of Tlemcen, Algeria for their support throughout my studies. My appreciation also goes to John Mwangi Gathenya, Associate Professor of Jomo Kenyatta University of Agriculture and Technology, Nairobi (JKUAT) Kenya for helping me to get an internship in his university but it was canceled because of the pandemic (Covid 19).

I want to express my heddle thanks to my whole family, especially my best dad and beautiful mom without forgetting my sister and my brothers, especially Ali Bouamrane for his helpful support, encouragement, and valuable guidance throughout my thesis work. This accomplishment would not have been possible without them. Thank you very much from the bottom of my heart.

ABBREVIATIONS AND ACRONYMS

AHP: Analytic Hierarchy Process

ANRH: National Agency for Hydraulic Resources

ANSWERS: Areal Non-point Source Watershed Environment Response Simulation

ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer

CES : Conservation des eaux et des sols

CI: consistency index,

CR: Consistency Ratio

CREAMS: Chemical Runoff, Erosion from Agricultural Management Systems

CTI: Compound Topographic Index

DBMF: Dendy-Boltan Method Flaxman

DDM: Discrete Dynamic Models

DEM: Digital Elevation Model

DFR: Distance from river

DFRO: Distance from road

DPM: Discrete phase model

DRD: Distance from roads

DRI: Distance from river

EPIC: erosion productivity impact calculator

ERM: Ediment Routing Model

ESRI: Environmental System Research Institute

EUROSEM: The European Soil Erosion Model

FAO: Food and Agriculture Organization

Fr: frequency ratio

GIS: Geographic Information System

HSPF: Hydrologic Simulation Program, Fortran

IDW: Inverse Distance Weighting

KWM: Kinematic Wave Model

Lar: Length Area Relation

Lg : Length of Overland Flow

LISEM: Limburg Soil Erosion Model

Lu: Stream Length

LUC: Land cover

MPSIAC: MPSIAC model

Musgrave: Musgrave Equation

MUSLE: Modified Universal Soil Loss Equation

NASA: National Aeronautics and Space Administration

NDVI: Normalized difference vegetation index

R-L M: Renard-Laursen Model

ROC: Receiver Operating Characteristic

RUSLE: Revised Universal Soil Loss Equation

SLEMSA: Soil Loss Estimation Model of Southern Africa

SPI: Stream Power Index

SRTM: Shuttle Radar Topography Mission

STI: Stream Transport Index

SWAT: The Soil Water and Assessment Tool

TWI: Topographic Wetness Index

U.S: United State of America

USGS: U.S. Geological Survey

USLE: Universal Soil Loss Equation

WEPP: Water Erosion Prediction Project

TABLE OF CONTAIN

LIST OF TABLES
Literature Review

Material and methods

Results and discussions

Appendix

LIST OF FIGURES

Literature Review

Material and methods

Results and discussions

ABSTRACT/ RESUME

Abstract:

Mellah watershed is one of the semi-arid regions in Eastern Algeria confronted with the problem of erosion due to the effects of climate change, population growth and rapid expansion of urbanization. The aim of this study is to identify and map soil erosion sensitivity areas in Mellah Watershed, using an empirical model (RUSLE: Revised Universal Soil Loss Equation), a semi quantitative model (AHP: Analytic Hierarchy Process) and a statistical model (FR: Frequency Ratio). Geographic Information System (GIS) and Remote Sensing (RS) techniques were used to identify and characterize a set of factors influencing water erosion in the watershed, including rainfall, ground elevation, slope, land cover, soil type, Normalized difference vegetation index (NDVI), Stream Power Index (SPI), Topographic Wetness Index TWI and distances from road and stream. The results of soil erosion susceptibility, obtained on a GIS platform, were categorized into five classes, including very low, low, moderate, high and very high erosion risk. Based on this analysis, the area distribution and the percentage of sensitivity levels were calculated. The corresponding results showed that the region characterized by very high sensitivity represent 4.2%, 9.8% and 10.1% using RUSLE, FR and AHP models respectively. The results obtained were validated by comparing the generated maps to a soil erosion inventory map, which was prepared based on 200 field observations of rill erosion. In this context, ROC (Receiver Operating Characteristics) curve was adopted. The values for the Area Under the Curve (AUC) were 93.6%, 93.1%, and 95.7% for RUSLE, AHP and FR models respectively, implying reasonably good performances for the three adopted models. Finally, it is important to note that the soil erosion susceptibility maps developed in this study may be considered as a decision support tool for watershed management strategies to alleviate water erosion in El Mellah Watershed.

Key words: Mellah Watershed, erosion, RUSLE, AHP, FR, ROC, GIS

Résume :

Le bassin versant El Mellah est l'un des bassins versants semi-arides du Nord-est Algérien les plus vulnérables au risque d'érosion à cause des effets du changement climatique, de la croissance démographique et l'urbanisation rapide qui se manifestent souvent de manière catastrophique, constituant une contrainte majeure au développement économique et social .

L'objectif de cette étude est d'identifier et de cartographier les zones de sensibilité à l'érosion des sols dans le bassin versant de Mellah, en utilisant le modèle empirique RUSLE (Revised Universal Soil Loss Equation), le modèle semi-quantitatif Analyse Hiérarchique des Procédés (AHP) et le modèle statistique Rapport de Fréquence (FR). Le système d'information géographique et les techniques de télédétection ont été adoptés pour identifier et caractériser l’ensemble des facteurs influençant l'érosion tels que: précipitations, élévation, pente, couverture végétal, type de sol, NDVI, SPI, TWI et les distances par rapport à la route et le cours d’eau. Les résultats obtenus sur une plate-forme SIG ont été arrangés en cinq classes : très faible, faible, modéré, élevé et très élevé. Sur la base de cette analyse, la distribution des zones et le pourcentage des niveaux de sensibilité ont été calculés. Ces résultats montrent que la région caractérisée par une sensibilité très élevée représente 4,2%, 9,79% et 10,07% pour les modèles RUSLE FR et l'AHP respectivement. Les résultats obtenus ont été validés suite à la comparaison des performances des cartes générées à une carte d'inventaire de l'érosion du sol, préparée à partir de 200 observations d'érosion en rigoles. Pour cette recherche, les résultats des modèles appliqués ont été validés à l'aide de la courbe ROC (Receiver Operating Characteristics), où les valeurs AUC étaient 93,6%, 93,1% et 95,7% pour les modèles RUSLE, AHP et FR t respectivement. Les résultats ont montré que le modèle RUSLE avait la valeur AUC la plus élevée par rapport aux modèles AHP et FR, alors que tous ont montré une bonne performance. Sur la base des résultats de ces travaux, certaines stratégies de gestion peuvent être proposées pour contrôler et réduire l'érosion des sols.

Mots clés : Bassin versant Mellah, Erosion, RUSLE, AHP, FR, ROC, SIG

INTRODUCTION

1.1 Introduction:

Soil erosion is considered as one of the most natural hazards in recent decades which threatened human societies and environments(Gomiero, 2016). According to statistics, nearly 75 billion tons of soils are eroded each year around the world, which leads to exacerbating the economic losses with equivalent to $400 billion financial loss (Borrelli et al,2017). The Mediterranean regions, especially under semi-arid climates do not escape to this challenge, due not only to climate condition, but also to morphological and anthropogenic factors. Algeria, for instance, recorded some of the highest erosion rates in the world and this, despite the efforts of erosion control (Roose et all , 2004). According to the Algerian Ministry of Agriculture and Rural Development, 50 million hectares were estimated to be eroded.

The assessment and the quantification of soil erosion are important because the corresponding results allow the proposition of the appropriate soil conservation strategies, and management practices to mitigate erosion impact. Conventional methods of erosion risk mapping and estimation of sediment yield based on hydrological and hydraulic models exist in the literature. Nevertheless, these approaches require observed and simulated data, such as meteorological time series, topographic data and observed flows, which are not usually available.

Nowadays, the development of computer hardware and the rapid access to satellite remote sensing data led to the development of mapping applications of soil erosion susceptibility .In this context, several researchers were directed towards the development of models that aim to better understand the causes, mechanisms and impacts of soil erosion. These models are categorized as empirical, semi-empirical and physically process-based models. For better spatial planning and soil conservation, mapping the sensitivity of soil erosion is an essential decision-making tool that makes it possible to fight effectively against this phenomenon and to locate the most vulnerable areas. The main purpose of this research is to combine geographic information system (GIS) and remote sensing data with a set of methods and techniques, such as the empirical model RUSLE

(Revised Universal Soil Loss Equation), the analytic hierarchic method (AHP) and Frequency Ratio (FR) in order to assess soil erosion in Mellah Watershed (Eastern Algeria).

1.2 Problem statement:

Soil erosion is widespread in Mellah Watershed (Eastern Algeria). It negatively affects agricultural productivity, reduces water infiltration, groundwater resources and water availability. There is therefore a need to evaluate the importance and extent of this natural hazard in order to propose solutions and measures for its control. In this context, water erosion in this basin is assessed using different sources of data and different simulation methods.

1.3 Research questions:

1. What is the major source of erosion in the catchment?
2. How can erosion affect the agricultural sector?
3. What is the data required to evaluate soil erosion in the study watershed?
4. What are the most exposed areas to erosion risk?
5. What are the necessary strategies to mitigate this natural hazard?

1.4 Main objective

The aim of this study is to evaluate soil erosion in Mellah Watershed using RUSLE, FR and AHP methods to assess the severity and extent of the phenomenon. Expected results shall serve as a decision-making tool to propose solutions mitigating erosion effects.

1.5 Specific objectives :

- Collect climatic data, especially rainfall and spatial data including geology, soil type, topography, land use, etc.

- Assess and predict the spatial distribution of soil erosion in Mellah Watershed.
- Develop soil erosion risk map using remote sensing and geographic information systems.
- Simulate soil erosion risk maps using RUSLE, FR and AHP methods.
- Compare the simulated risk maps to field observations and remote sensing data.
- Propose solutions to mitigate the effects of water erosion in the study basin

- Delineation of the study watershed and evaluation of its physical characteristics.
- Development of thematic maps (topography, soil type, stream network, land cover, etc.)

1.6 Thesis organization

The work presented in this thesis consists of seven chapters:

- ✓ The thesis starts by an introduction presenting the scientific problem statement and the aim of the study.
- ✓ The second chapter is devoted to a literature review about soil erosion and its different processes as well as the different interacting factors responsible for this phenomenon. This chapter also outlines the different tools and methods generally used in modeling and predicting soil erosion and its spatial variation. Finally, it presents a brief summary of the impacts of erosion and the methods of its mitigation.
- ✓ Chapter three presents the material and methods adopted in the study. Moreover, it describes the study watershed, including physical characteristics (Topography, soil type, land use, etc.) and climatic factors (rainfall, temperature, humidity, wind speed, etc.)
- ✓ The fourth chapter shows the factors affecting soil erosion. It also presents the procedures used to develop spatial Data bases for modelling soil erosion in a GIS environment.
- ✓ Chapter five displays the main conclusions of the study as well as recommendations of practical interest that may be adopted in order to alleviate the impacts of soil erosion in Mellah Watershed. Future research activities are also proposed.

LITERATURE REVIEW

2.1 Introduction:

This chapter presents an overview for soil erosion. In the first section, the concept of soil erosion and its different processes are explained. Next, the factors controlling this phenomenon are outlined. Section three is devoted to the presentation of the different models generally used for the simulation of soil erosion and sediment transport. Finally, a summary of the impacts of erosion and the techniques generally used for soil conservation are presented.

2.2 concept of soil erosion:

Soil erosion is one of the most serious and complex environmental problems which affect hydrological systems and human societies (Gomiero, 2016). It is defined as a set of external phenomena that remove all or part of the existing terrain and modify the relief. Erosion is defined as detachment and transport of soil particles from its original location under different agents and their deposition downstream (liu, 2016). According to the movement of the particles, two types of erosion are distinguished: mass or superficial. The first type includes all forms of erosion where particles tend to move in mass, mainly under the effect of gravity. It generally includes various types of landslides, as well as forms of erosion not related to rainfall. The second type represents the movement of soil particles by forces other than gravity, such as surface runoff.

2.2.1Water erosion:

Water erosion can be defined as the phenomenon of soil degradation under the action of water. This degradation develops when the ability of a soil to infiltrate rainwater is low. This refusal of the soil to absorb the excess water appears when rainfall intensity is higher than the infiltration capacity of the soil surface. water erosion is the result of dissociation of rocky or earthy material, which is then transported and deposited downstream. The dissociation can be chemical (chemical alteration and dissolution) or physical (disaggregation mechanical and debris removal). Water erosion depends simultaneously on topography, soil type, vegetation cover, climate aggressiveness and anthropogenic action.

2.3 Mechanism of soil erosion:

Soil erosion is a natural phenomenon characterized by three actions (Issaka et all 2017) which correspond to detach, transport and deposit soil particles from their original location under the effect of different agents, such as wind, water and glaciers. The first stage of water erosion starts when there is detachment of particles eroded from the surface due to the bombardment of the soil surface by rain drops (figure 2.1) which affect the soil composition, such as minerals and organic particle. This represents the splash erosion process. During rainfall, rainfall intensity exceeds the infiltration capacity of the soil, resulting thereby in runoff that spreads throughout the soil surface.

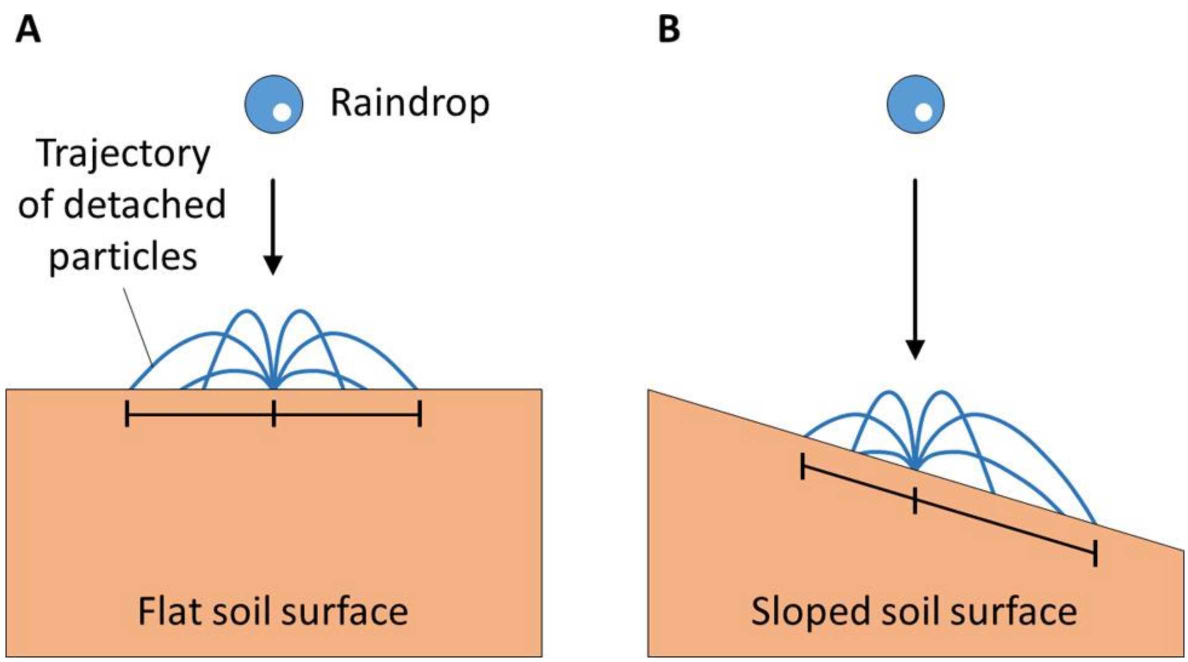


Figure 2.1 : The raindrops break the aggregates (effect of splashes) (Fernández et al., 2017)

Soil particles are detached and transported by overland flow (sheet or inter-rill erosion) as presented in figure 2.2. Under the effect of slope, water runoff may cause notches accompanied by scratching in soil surface, bare and unprotected, which is classified as rill erosion. This action is known as the transition stage between sheet and gully erosion, which is a dramatic form of soil erosion resulting from the development of enlarged rill under the effect of runoff erosive power (Rahma et all 2020).

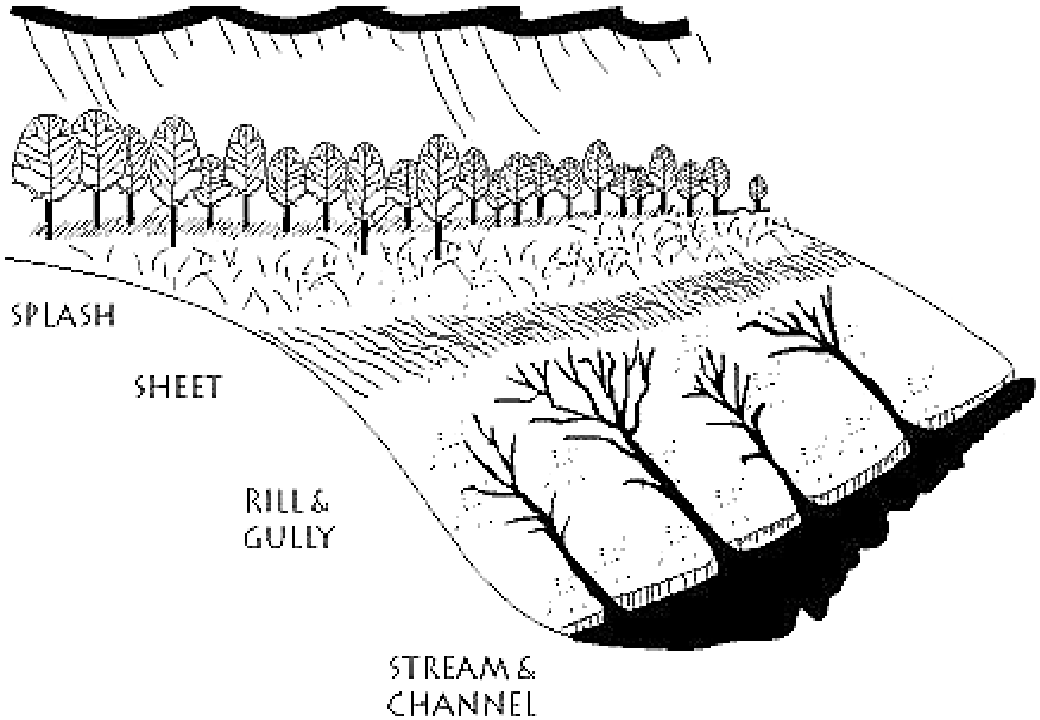


Figure 2.2 : Different mechanisms of soil erosion (Pierre Y, 2015)

2.4. Different form of soil erosion:

2.4.1. Splash erosion:

Also known as raindrops erosion, this process represents the first stage of soil erosion. This type of erosion occurs when raindrops splash on the soil and beat the bare soil into flowing mud (Figure 2.3).

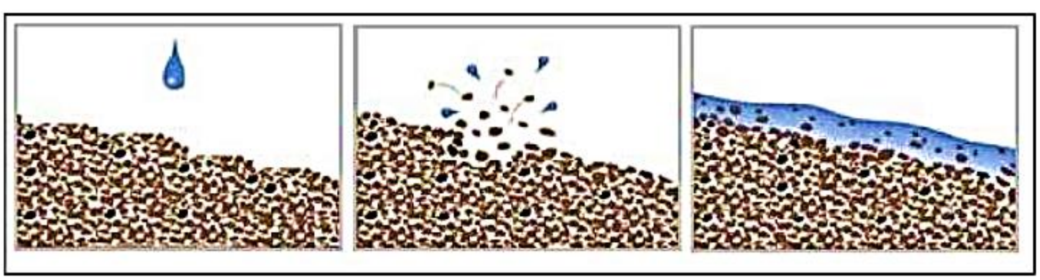


Figure 2.3: Splash erosion (Cheggour, 2008)

2.4.2. Sheet erosion:

This type of erosion occurs when soil is removed uniformly in a thin layer from the entire surface area (Figure 2.4). Movement of soil by splash erosion is the primary cause of sheet erosion (Hagen, 1991). It can be serious on soils that have a slope gradient of only 1 or 2 percent, but it generally becomes more serious when the slope gradient increases.

Figure 2.4: Sheet erosion

2.4.3. Rill erosion:

If the overland flow process continues its erosive action, the result is the formation of sallow channels, known as rill erosion, which represents the second stage of soil erosion (Figure 2.5). This type of erosion takes place when runoff water land with soil flowing along the slopes, from finger like channels. Rill erosion is an intermediate stage between sheet erosion and Gully erosion. It is common in bare agricultural land, overgrazed land in freshly cultivated soil. Rrill erosion can usually be removed with primary tillage implements.

Figure 2.5 : rill erosion

2.4.4. Gully erosion:

Ii is an advance stage of rill erosion and represents the last stage of erosion (figure 2.6). This happens when rills are not destroyed and the detachment continues deeper and wider. As the volume of concentrated runoff increases and reaches high velocities on slopes, it enlarges the rill into gullies. Advanced stage gullies result in ravines which are sometimes 50 to 100 feet deep. Gully erosion may be classified into different types:

Figure 2.6.: Gully erosion

2.4.4.1 Waterfall erosion:

The overland flow falling into gully at the head end undercuts it and results in upslope extension of the Gully (Figure 2.7).

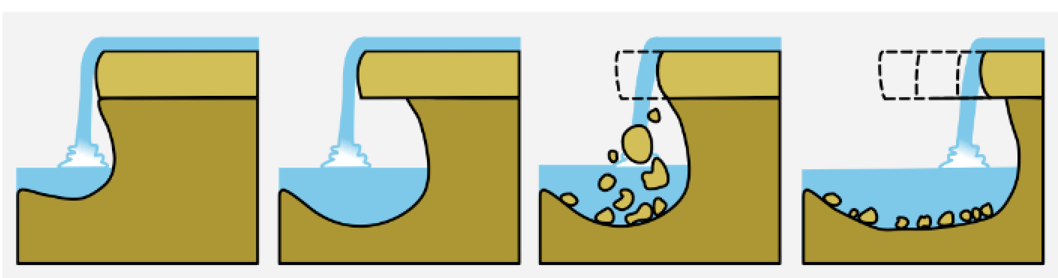


Figure 2.7: waterfall erosion

2.4.4.2. Chanel erosion:

Water flowing thought gully erodes the bed and the sides, causing wall collapse and sampling of the sidewalls (Figure 2.8).

Figure 2.8: represent channels erosion

2.4.5. Stream bank erosion

This type of erosion (Figure 2.9) is caused by water flowing over the side of the stream. It is a natural process but the rate which occurs may be influenced by human activities. Streams and rivers change their courses by cutting one bank and depositing the silt load on the other. During flash floods the damage is much accelerated. it gets aggravated due to removal of vegetation, overgrazing or cultivation on the area close to stream bank.

Figure 2.9: stream bank erosion

2.5. Factors controlling Soil Erosion:

Soil erosion is a global environmental problem, explained by different natural and anthropogenic factors. In erosion modelling, several parameters are usually taken into consideration and each model requires its input data set because it is designed for specific purposes. However, the most commonly used parameters are climate characteristic (rainfall, temperature), soil texture, vegetation cover, topography and human activity. The different factors controlling soil erosion are listed by Pimentel et al. (2013).

2.5.1. Topographic factors:

The Topography or slope land is the factor that most directly affects soil erosion. According to Stone (2000), the risk of erosion is increased on a steeper slope than the flat earth due to increased runoff velocity and a decrease in the infiltration rate. The physical features of the land also contribute to soil erosion. Land with a high slope facilitates the process of rainwater flow or runoff saturation in the area, particularly due to the faster movement of the water downhill (Issaka,2017).

2.5.2. Climatic factors:

The climatic variables influencing erosion processes in a given territory are mainly air temperature, atmospheric precipitation, solar radiation, wind, and air humidity. For instance, raindrops may break up aggregates and disperse soil particles. In addition, the runoff rate is often increased if, during rain events, infiltration is reduced by compaction, the formation of a crust or gel .Precipitation is the lifeblood of erosion. Fournier (1960) studied the relation between soil loss, water and weather condition and found that the rain has a significant impact on soil loss.

2.5.3. Soil factors:

Soil is one of the main factors influencing the susceptibility to erosion. Elements, such as structure, organic matter content and soil permeability also play an important role (Khanchoul, 2020) According to coarse sands, and compact clays tend to erode less than silts, very fine sands, and clay loams. On the other hand, according to (Poesen et al 2003), the contribution of gullying to the total loss of soil is more important where the soil is clay and where the texture of the soil is coarser.

2.5.4. Vegetation covers:

According to (DeVente et al. 2005), the type and density of vegetation cover play an important role in protecting the soil and erosion process (influencing the structure and infiltration capacity of the soil). From(CHERHABIL, M et all .2019) The risk of erosion increases with decreasing plant cover and the percentage of crop residues on agricultural land .

2.5.5. Anthropogenic factors:

Anthropogenic action is considered a key factor of soil erosion. This is mainly explained by agricultural practices, soil use and urbanization (Borrelli, 2017). According to FAO, in the last decades the rate of deforestation was estimated at 10 million hectares per year down from 16 million hectares per year in the 1990s. Practices that promote erosion are mainly: population growth and urbanization. Increasing the factor of impermeability of surface area exacerbates floods, promotes runoff and is therefore a ground drive factor. Overgrazing causes soil to settle, reduces permeability and promotes runoff from the water. Deforestation promotes water flow, resulting in enhanced water erosion.

2.6. The impact of soil erosion:

The consequences of erosion are various and can be seen in the loss of soil depth, land productivity and environmental quality .This damage has important environmental impacts and high economic costs (Shrestha et all 2015). According to the United Nations (2015), the loss production of cereals due to erosion were estimated at 7.6 million tons per year and will be in 2050 over 253 million tons, which corresponds to 15 billion hectares of land from an agricultural activity point of view if nothing is done to mitigate erosion (FAO, 2017). In addition, the volume of water stored in dams and the quality of water does not escape to this problem due to siltation and the concentration of fine materials in the water that affect also the respiratory capacities of aquatic animals. Moreover, the degradation of water quality has a huge damage agricultural.

2.6.1. Degradation of water quality:

Soil erosion by rain leads to an influx of particles into the environment during rainy episodes. These soil particles, known as "suspended solids", can affect the biodiversity of environments and water quality when they are present in too large a quantity in the aquatic environment. From (CHERHABIL, M et all .2019)The latter also reduces the penetration of light and its transparency, which affects the photosynthesis of submerged plants. Furthermore, the respiratory capacities of aquatic animals are also impaired by an excess of fine materials, resulting in eutrophication of surface water bodies and loss of aquatic biodiversity.

2.6.2. Siltation’s of dams:

The siltation process affects the volume of useful water stored in dams, leading to reduced storage capacity (Figure 2.10). This problem of sedimentation is related to the phenomena of water erosion in the watershed which itself is conditioned by certain parameters such as, soil type, plant cover, slope, and the amount of precipitation and its intensity.

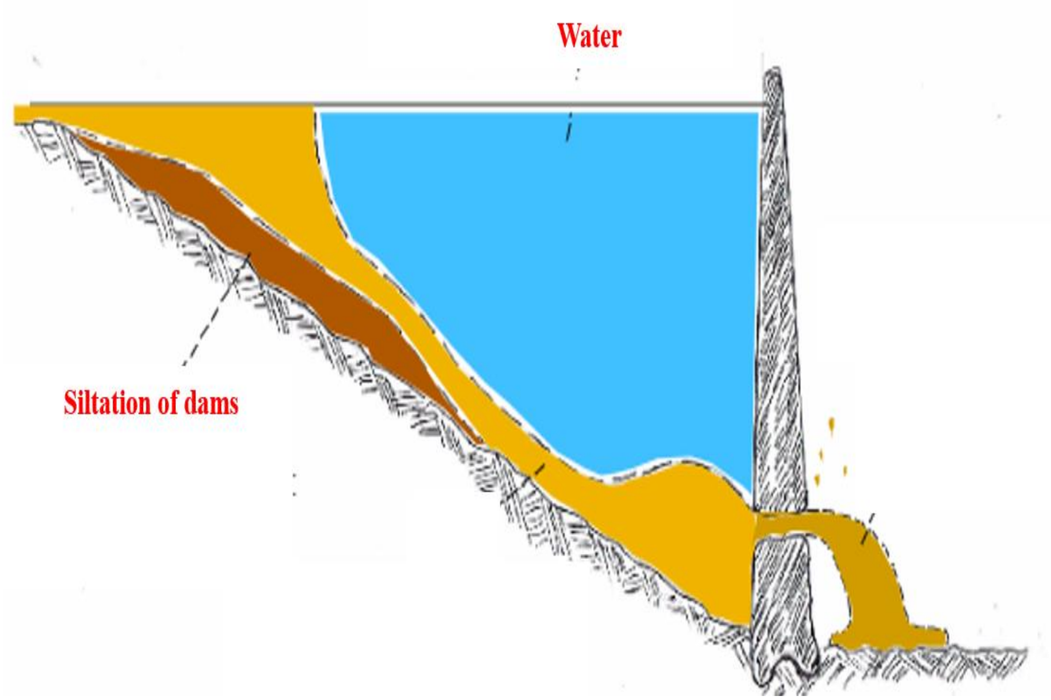


Figure 1.10: Dam siltation *(HAROUN, B. 2019)*

2.6.3. Soil degradation

In addition to the degradation of water quality, loss of soil by water erosion damages agricultural crop (loss of fertile topsoil for agriculture). The natural renewal of the soil is very slow. The annual loss of several tons of soil in a plot threatens its productivity, sometimes even in the short term. According to statistics, around 6 million hectares are exposed to active erosion, and on average 120 million tonnes of sediment are washed away annually by water. Annual losses in water storage capacity in Algerian dams are estimated at around 20 million m^3.

2.6.4. Landslides :

The phenomenon of erosion is sometimes manifested by ground movements (Figure 2.11). These can appear in rock ruptures, landslides, mudslides, or debris. These natural events can be accentuated or triggered by human activities - causing local and more or less lasting destruction of living species and natural habitats.

Figure 2.11 : Landslide at Beni Amrane , Department of Boumerdes, causing damage to retaining wall, January 2003(Salah-Mars et al.2004).

2.7 Review of Soil Erosion Modeling:

For a better assessment of impacts, control mechanisms, and in order to understand the phenomenon of soil erosion, it is very important to develop different models to predict soil loss and plan land use. Over the years, many researchers moved towards finding solutions and models to reach these objectives. Three types of erosion models are generally distinguished: empirical, conceptual and physical-based models. These models are based on several factors, including: climate, topography, soil type and vegetation cover. Different models describe erosion processes altering soil surface differently. Another difference is whether these models describe the process continuously or for a single erosion event .

2.7.1Empirical models:

Empirical models are based primarily on observation and are usually statistical in nature. Empirical relationships are considered a good solution to identify the source areas of soil erosion

(Cama, 2020).These models are based on inductive logic and are usually applicable to the conditions for which the parameters are calibrated. The key focus of empirical model process is prediction of average soil loss, although some extensions are designed and developed for sediment yield estimation. Empirical models generally require less data than conceptual and physically based models.

2.7.2 Conceptual models:

This type of models is based on combination of physically-based and empirical model. It offers an indication of the qualitative and quantitative effects of land use dynamic devoid of requiring large amount of spatially and temporally dispersed input statistics/data. In this model, sediment yield is estimated based on spatially lumped forms of water and sediment continuity equations Conceptual models lie somewhere between physically-based and empirical models (Cama,2020).

2.7.3 Physically-Based Models:

These models provide the mechanisms needed to control erosion. In the 1970s, initiatives were made to change the methodology of soil erosion used in classical approaches. Generally, these models take into account various parameters, such as land use, landforms, soil type, vegetation cover, climate, and topography to estimate soil loss (Flanagan et all 2013). The Physically-based models rely on the solution of fundamental physical equations describing stream flows, sediment fluxes, and associated nutrient fluxes in a catchment (Cama, 2020).

Table 2.1 comments on some soil erosion models

Models	Comment	Scale
USLE	The model for assessment and determination of the sensitivity to the soil loss by (ta/ha/yr). It is determined by the different soil, climate and climate conditions Vegetation cover and topography.	Hillslope/Catchment
MUSLE	This model was produced for specific conditions, its application without calibration has resulted in huge errors. Rill and sheet erosion purposes of sediment yield estimation	Sheet and rill erosion
SLEMSA	were developed for «East and South Africa» and «West Africa» region LPM, measures long term annual soil loss (kg/ha/yr) resulting from rill and inter rill erosion on slope and agricultural fields in the tropics.	Catchment
RUSLE	Were developed For soil losses prediction in (Ta/ha/Yr) Need to input five data set (R,Ls,K,C,P)	Sheet and rill erosion
HSPF	was employed for simulating runoff and sediment yield during the monsoon months data requirements are rainfall records and other meteorological data such as air temperature, wind, solar radiation, cloud cover, snowmelt, groundwater recharge	Catchment large scale and small scale regions
ANSWERS	It is designed to estimate soil erosion inside a watershed by subdividing the watershed into a uniform grid of square cells Can be run on an event or continuous basis. Has the capability to be linked to a GIS. Developed in the USA.	Small Catchment
CREAMS	has been used to estimate sediment yield, particle size, soil moisture, infiltration, percolation, evapotranspiration, peak runoff and runoff volume. it is not suitable for regions with un-uniform cropping and soil developed by the U.S	Field 40-400 ha
WEPP	This weep used in soil and water conservation planning and assessment. it is a process-based, distributed parameters, capable of doing both single-event and continuous simulation erosion prediction The data required are soil characteristics, slope, climate, land use Developed in US to replace USLE model	Hill slope/ Catchment
SWAT	, continuous-time model, predicts the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. required data are temperature, soil temperature, land management, hydrology, weather, vegetation cover, nutrients, and pathogens Developed in US	Catchment
LISEM	is a powerful physically based model used to simulate the sediment transport and hydrological processes during and after a single rainfall event developed between 1991 and 1994 Developed in Europe.	Small Catchment 10 to 300 ha.
EUROSEM	For the simulates of erosion on event basis. Requires intensive data. Can be linked to GIS. Developed in Europe	Catchment

2.8 Choosing models and application:

There is a large range of models available for modeling the detachment and transport of sediment (and associated pollutants). These models are different in terms of complexity, objectives basic process description, and input data required. Typically, there is no one optimal model for all applications. The most appropriate model will depend on the intended use and the characteristics of the environmental modeling. Other factors influencing the choice of a model for an application include:

- ✓ Nature of input data (including temporal variations in inputs and outputs)
- ✓ Accuracy and validity (including underlying assumptions)
- ✓ Model components, which reflect its capabilities
- ✓ The user's goals (including their ability to take charge of the model, nature and scale of expected results)
- ✓ Quality of computer hardware

2.9 The integration of GIS in erosion models:

Geographic Information System (GIS) is a powerful set of tools for creating, transforming, and displaying, analyzing and storing geographic information. It is used to organize and present spatially referenced alphanumeric data .In the last decades, GIS has been used to integrate and visualize the results of soil erosion models in order to build spatial distribution of soil erosion. Currently, satellite data are easily accessible and can help to map erosion hazards. Yjjou (2014) argued that remote sensing techniques associated with GIS make it possible to estimate quantitative and qualitative soil losses. Moreover, the evaluation and quantification of soil losses it is helpful tools a decision support tool to develop a conservation plan in order to control erosion under different land-cover scenarios.

2.10 Methods for Soil Erosion Control:

There are different ways to alleviate soil erosion. Most of them are straightforward and are adopted to decrease the effects of natural and anthropogenic processes, such as rainfall, slope and deforestation, via the implementation of different strategies of soil conservation. The corresponding technologies can be differentiated either by their main purpose or by type. As many among them fulfill several functions simultaneously, these are classified here by type (see figure 2.12).

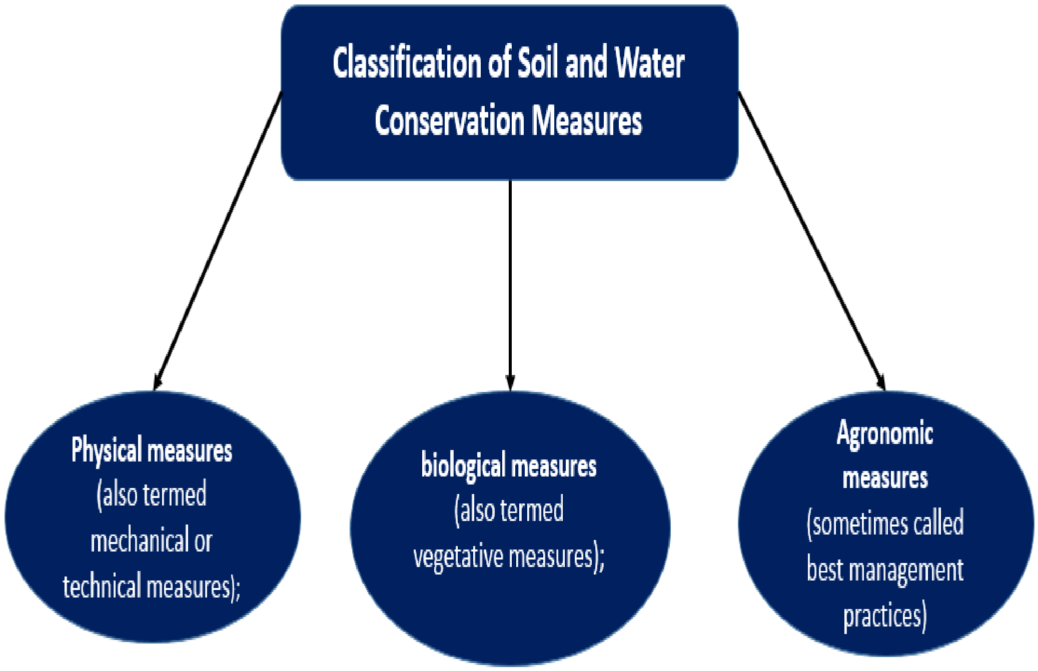


Figure 2.12: Classification of soil and water conservation measures (Krüger et al. 1997)

Table 2.2: Classification of soil and water conservation measures

Soil and Water Conservation Measures	Aims
Physical conservation measures	• Increase the necessary time to concentrate surface runoff, to allow the runoff infiltration more into the soil. • divide a long slope into several short ones and thereby reducing amount and velocity of surface runoff; • reducing the velocity of the surface runoff it s necessary • protect against damage due to excessive runoff (Tidemann 1996).
Agronomic conservation measures	• reducing the impact of raindrops through interception and thus reducing soil erosion and • Increasing infiltration rates and thereby reducing surface runoff and soil erosion
Biological measures	• This way can avoids splash erosion; • the velocity of surface runoff reduces due to biological measure • the organic matter has an several influence on soil aggregates and can increase infiltration (Morgan 1999; Richter 1998; Hurni et al. 2003).

2.10.1. Bench Terraces:

This type of terracing is generally found on areas of medium to steep slopes. As shown in figure (2.13) .they consist of beds which are more or less level, and risers (walls or bunds). Bench terraces are a series of level or virtually level strips running across the slope at vertical intervals, supported by steep banks or risers (FAO, 2009).

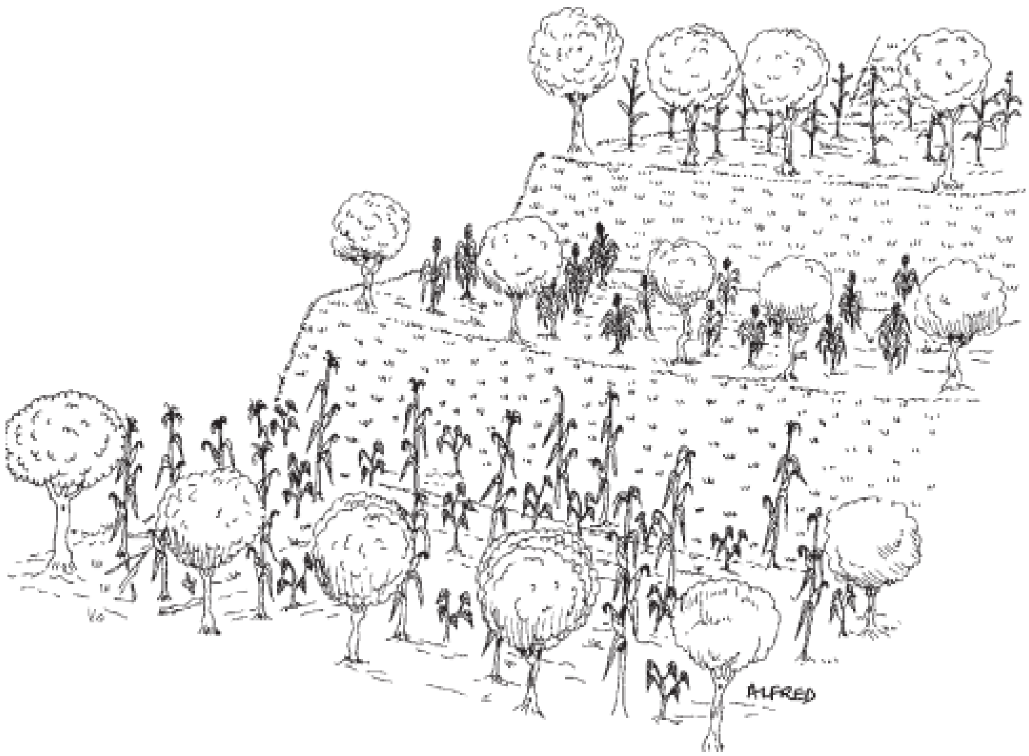


Figure 2.13: bench terraces

2.10.2. Stone band:

Its purpose is to control and diminish ongoing land degradation. Technically speaking, stones are laid out along contour lines on both barren and cultivated lands (Figure 2.14). With the water and sediment harvested, this shall result not only in improved crop performance, but also local groundwater recharge.

Figure 2.14: Stone band

2.10.3. Terraces:

A terrace is an earthen embankment that follows the contour of a hillside, breaking a long slope into shorter segments and intercepting the flow of water (Figure 2.15). It is designed to intercept runoff on a slope, and reduce its erosive action on the soil down the slope. Water is channeled at a slower speed, along the vegetated channel to a safe, stable outlet such as a grassed waterway or standpipe or drop inlet.

Figure 2.15: Terrace for soil conservation

2.10.4. Rock chute:

It is a pile of rocks designed to move concentrated water flows over steep slopes (Figure 2.16). Drop inlets and rock chutes are often used to "step" water down where there are rapid changes in elevation, and thereby protect soil from erosion.

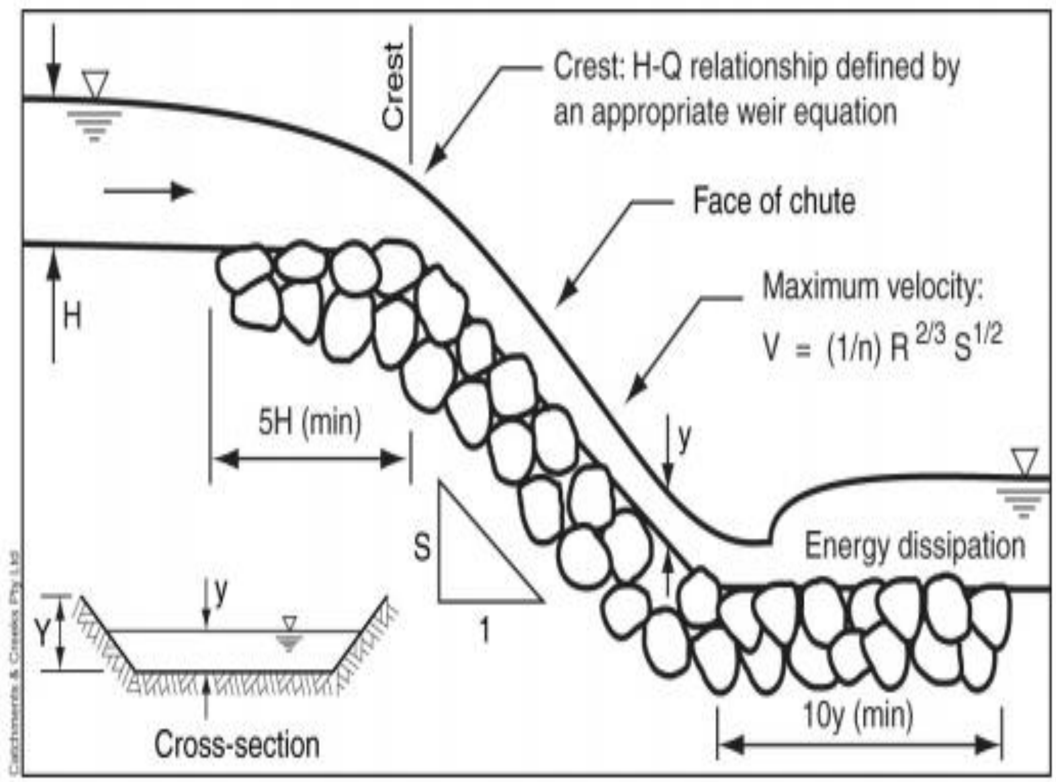


Figure 2.16: Rock chute (Dorren, 2004)

2.10.5. Contour farming:

Contour farming (Figure 2.17) is farming with row patterns that run nearly level around the hill rather than up and down the slope. The furrows and rows of plants act as dams which slow down the flow of water moving down the slope. This practice can also increase crop yield through the soil moisture retention in arid and semi-arid regions (Farahani, 2016).

Figure 2.17: Contour farming

MATERIAL AND METHODS

3.1 Introduction:

The soil erosion status is influenced by a variety of factors related to the regional conditions of the area such as climate, soil type, land cover, topography, lithology, etc. The aim of this chapter is to present the study area of the basin and the dataset used to achieve the aim of this work. This chapter first presents the geographic location of the study basin, its geological, morphological and meteorological characteristics. In addition, this chapter presents the tools and the techniques adopted in the study.

3.2 Geographic location:

The study was conducted in Mellah Watershed (Figure 3.1), which is represent a part in the northeast of Algeria, is characterized by an area of 550 Km^2. This area share a national boundary with Medjerda Mellegue Watershed in the southeast and the Constantinois Basin in north east It constitutes the fourth sub-basin in terms of surface in the large Seybouse Basin following Cherf, Bouhamdene and Guelma. It drains a mountainous area from the northern Tell (Medjerdah Mountains). It lies between the latitudes 36.216°N and 36.512°N and longitudes 07.487° E and 07.983° E. The Mellah Wadi is the principal right bank affluent of Seybouse River which it joins with the outlet of the valley of Guelma. It owes its name to the high salinity of the waters of the downstream catchment. This basin has a highest altitude of 1180 m in the southwestern part of Djbel Bardo.

3.3. Geology of the basin:

From the literature, Mellah Watershed belongs to the structural-sedimentary complex of the Tellian Atlas. From the geological point of view, the exposed rocks in the study area are limestone, sandstone and fragile rocks (Bouzeria, 2018). According to Khanchoul (2006) the weathered the un-consolidated geologic formations represent the highest percentage in this area, this formation contain compson that very senstivtie to erosion such as glyphic clay of Trias, limestone and marl of Senonian, sandy and conglomeratic clay of Miocene and clay of Oligocene which generate very erodible soils.

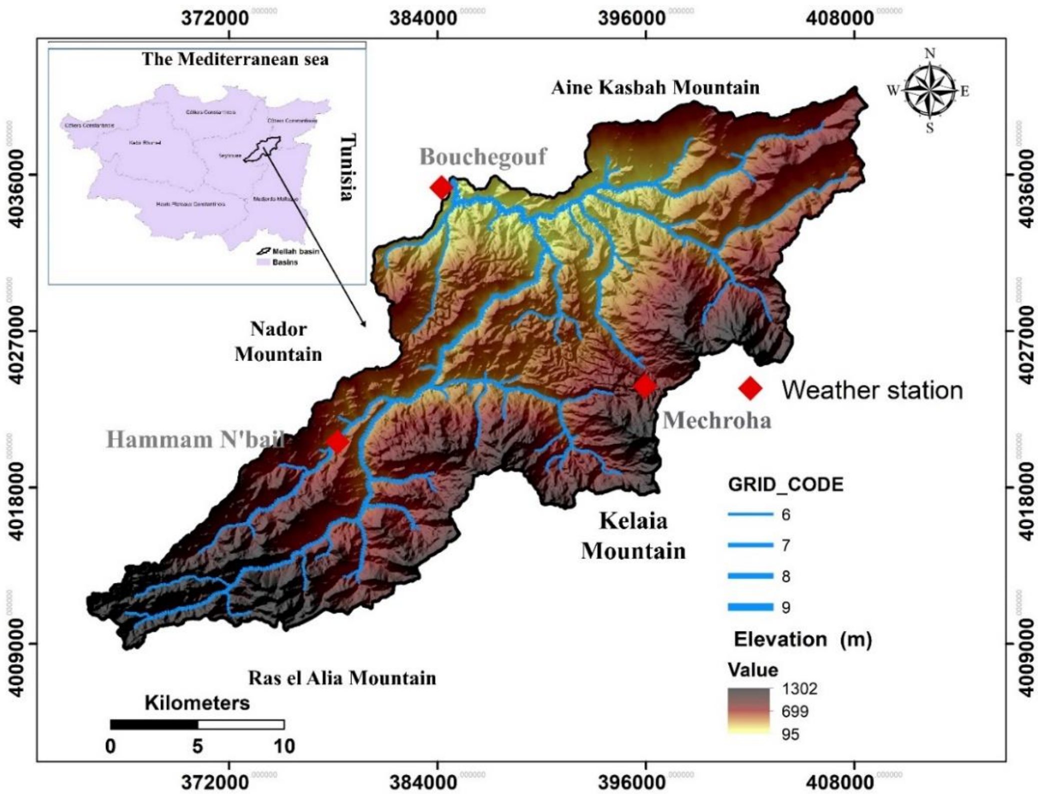


Figure 3.1: Geographic location of study watershed

3.4. Topography and slope:

3.4.1. Topography: Topography is a term used to describe the elevation and relief of the land surface. It includes a variety of different features, referred to landforms. The Differences between high and low elevation are referred to as changes in relief. The average, maximum and minimum elevations of Mellah Basin are 698.5m, 1302m (south eastern part of the basin) and 95 m respectively (in the western part of the basin).

3.4.2. slope :

Slope is the most important and specific feature of the earth's surface form. Slope angle is regularly used in soil erosion susceptibility studies since soil erosion is directly related to slope angle (Yomralioglu, 2011). Slope can be evaluated as a quantitative parameter. For this reason, the slope degree map (figure 3.2) of the study area is prepared from the digital elevation model

(DEM) and divided into six slope categories. GIS (ArcGIS 10.6) Software was used to calculate the slope degree of the basin. The mean slope was estimated to be 20.2% (Table 3.1).

Table 3.1: Classification of slope (Morgan, 1995)

Description	Slope (%)	Area in km^2	Area in (%)
Flat or almost flat	0-3	115.51	21.4
Gently sloping	3-8	186.17	34.6
Sloping	8-15	137.62	25.6
Moderately steep	15-30	67.02	12.5
Steep	30-40	25.9	4.8
Very Steep	< 50	6.07	1.1

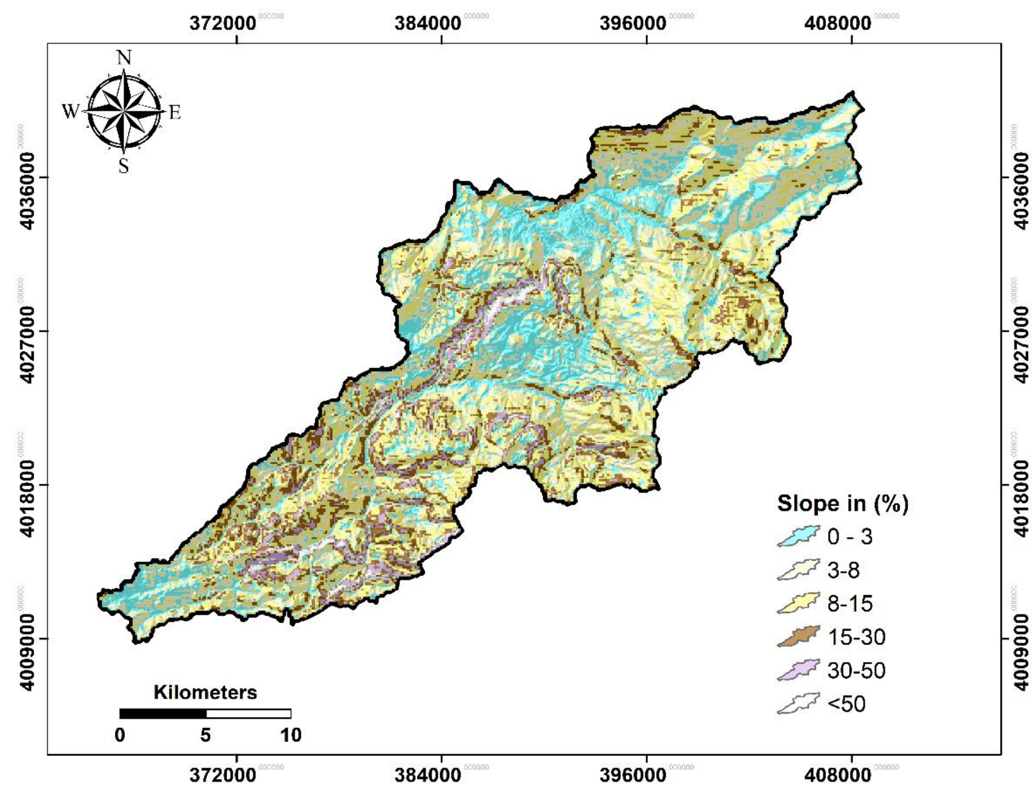


Figure 3.2 : Slope Map of Mellah Watershaed

3.5. Drainage Network:

3.5.1 Stream network:

The middle Seybouse drains two main streams which form the sub-basins of the Oued Bouhamdane and the Oued Mellah.. A hydrological model was built in which hydrographic network was presented by streams in a linear form. This added value to the data model .mellah basin contain different stream network : Maaza Wadi ,Bou Rdine Wadi ,Ranem Wadi ,Rirane Wadi,Mecheroha wadi .Mellah wadi hamman wadi) are presented in figure 3.3

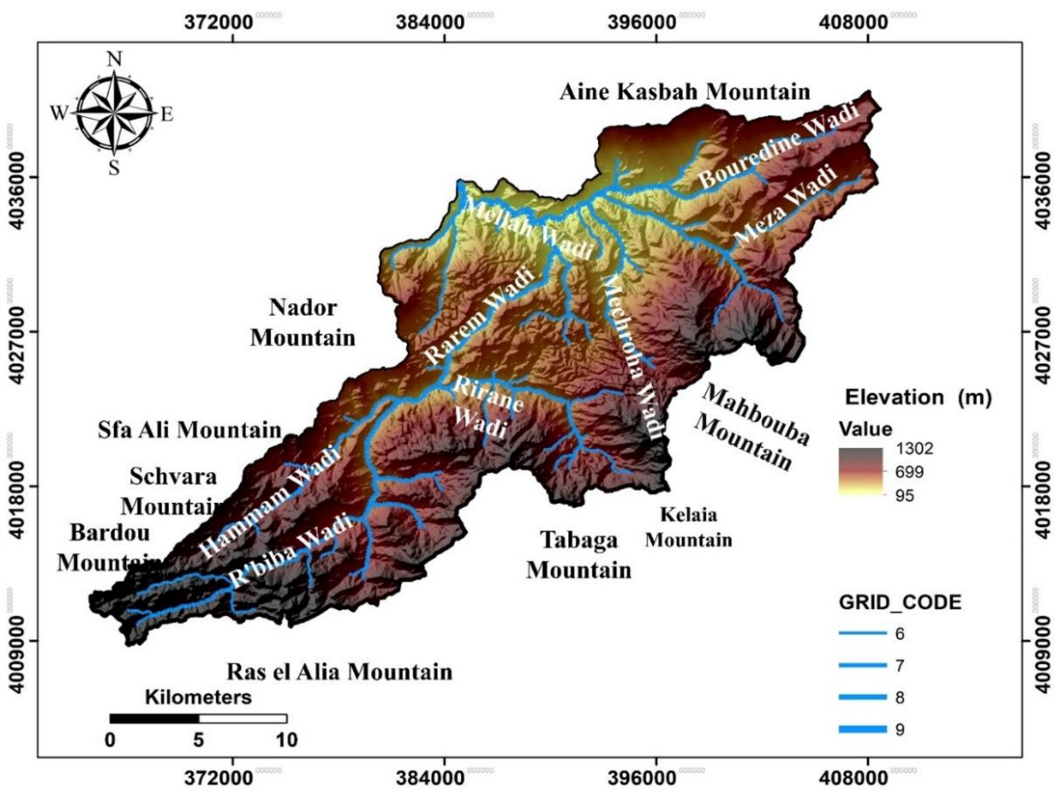


Figure 3.3: The main stream network of Mellah Watershed.

The table bellow presented all the length of river in Mellah watershed

Table 3.2: Lengths of the main streams in Mellah Watershed.

Basin		River	Length	Unit
	Mellah	**Maaza Wadi**	17.83	Km
		Bou Rdine Wadi	17.65	Km
		Ranem Wadi	15.94	Km
		Rirane Wadi	11.14	Km

3.5.2. Stream Length (Lu):

By definition, stream length is represented by its total length of streams of a specific order. As shown in Table 3.14, the total stream length of the basin is approximately 90.km.

3.5.3. Length Area Relation (Lar):

Hack found that for a large number of basins there is relation between the stream length and basin area identified in power function as follows $Lar = 1.4 * A^{0.6}$. In study area the value of Length Area Relation is

$$Lar=1.4*550^{0.6} =61.7km \ldots\ldots (3.1)$$

3.5.4. Length of Overland Flow (Lg):

In this study, the 'Lg' value of the basin is 0.42 km (Table 3.14), which shows low surface runoff in area. Over land area is defined as half of the reciprocal of drainage density. The length of overland flow (Lg) is one of the most important independent variables, affecting both hydrological and physiographical developments of the drainage basin (Horton 1945). In this study, the value 'Lg' is given by the flowing equation

$$Lg =1/2*Dd = 0.41km \ldots\ldots (3.2)$$

3.6. Land use/cover and Socio-economic activities:

In the study catchment, 21% of the basin area is cultivated with wheat and barley. Open forest and shrubs cover 41 % of the Mellah Catchment Forests are found mainly on poorly developed soils on sandstone and gypsic clay of Trias on slopes exceeding generally 12%. Shrubs (Oleo-lentiscus and Erica Europa) with an open canopy covering more than 6% of the basin area are damaged by livestock and fires during the summer season. Overgrazing is observed in pasture and open shrub land that occupy 35% of the catchment area (see table 3.3).

Table 3.3: Lithological composition of Mellah Catchment

surface formation	Area in(Km²)	Area in (%)
lithological formation	75.66	13.76
clay	25.75	4.68
sandstone and conglomerate clay	20.37	3.7
Triassic formation	60.64	11.03
Marl	4.75	0.86
Marley limestone	15.00	2.73
Limestone and marl	114.04	20.74
Conglomerate	59.52	10.82
Numidia sandstone	123.55	22.46
Limestone	50.72	9.22
Total	550	100

3.7. Geometric properties of the study watershed:

3.7.1. Area and perimeter of the basin:

The perimeter and the area are important parameters which may be obtained directly using Arc Map 10.6 software. The area and the perimeter of the study basin were automatically obtained using the tool calculate geometry and DEM. The basin area and perimeter were found to 550 Km² and 158km respectively .see appendix

3.7.2. Shape of the basin:

3.7.2.1 The compactness index (Gravelus index (KG):

Compactness ratio (KG) is the key index developed by Gravelius (1914). It represents the ratio of perimeter of watershed to the circumference of a circle with the same area as the watershed. This ratio, which characterizes the shape of the watershed, is given by the following formula:

$$KG = \frac{P}{2\sqrt{\pi * A}} = 0.28\,\frac{P}{\sqrt{A}} = 1.89 \ldots\ldots\ldots\ldots\ldots \ (3.3)$$

P: perimeter of the basin [km];

P ': equivalent perimeter of the basin [km] ;

A: Area of the basin [km²].

3.7.2.2. Equivalent rectangle length (L):

The equivalent rectangle is a concept introduced to compare the basins from the view point of the influence of their geometrical characteristics on the flow.

The length of the equivalent rectangle is given by the following expression

$$L=\frac{KG*\sqrt{S}}{1.12}*\left(1+\sqrt{1-(\frac{1.12}{KG})^2}\right)\text{................ (3.4)}$$

L=71.45 Km

3.7.2.3. Equivalent rectangle width (l):

$$L=\frac{KG*\sqrt{S}}{1.12}*\left(1-\sqrt{1-(\frac{1.12}{KG})^2}\right)\text{................ (3.5)}$$

l= 7.70 km

3.7.2.4. Equivalent rectangle:

Its perimeter is defined by:

P=2*(L+l)………… (3.6).

P= 2(71.45+7.69) = 158.28 km*

The equivalent rectangle area is define by the flowing equation :

A=L*l…………. (3.7). where A= 71.45*7.69 = 549.45 Km²

L and l are respectively the Length and width of the equivalent rectangle [km].

3.7.2.5. Drainage density:

Horton (1945) defined the drainage density (Dd) as the ratio of total stream lengths divided by the basin area. It is expressed in km/km². Strahler (1964) noted that low Dd is favored where basin relief is low, while high Dd is favored where basin relief is high. Drainage density

$$\boldsymbol{Dd}=\frac{\mathbf{1}}{\boldsymbol{A}}*\sum_{i=1}^{n}\boldsymbol{li} \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.8)}$$

Dd : drainage density [km/km²] ;

l *i*:Length of watershed [km];

A: area of the basin [km²];

i: Flow order from 1 to n

Dd=0.82 Km/Km²

3.8. Biophysical description of the basin:

3.8.1 Climate:

Mellah Catchment is characterized by a continental semi-arid climate, influenced by the Mediterranean Sea. Based on rainfall data recorded in Bouchegouf Station over a period of 30 years (from 1970 to 2000), rainfall varied between 503 and 1143mm/year (Table 3.4). On the other hand, data of Guelma meteorological station showed that the coldest month is February, with an average temperature of about 11.54 °C while the hottest month is July, with an average temperature of about 27.03 °C.

3.8.2 The ombrothermic Diagram:

The ombrothermic Diagram is a climatic diagram, which shows the relation between mean monthly temperature and mean monthly rainfall to determine the length of the dry, wet and extremely wet period. The objective of this diagram is to compare average wetness and dryness for an area of interest, where the data used must be taken as an average over a period of 30 years. The ombrothermic diagram of Bouchegouf station is displayed in Fig. 3.4, which shows a wet period beginning from October to May and a dry period starting from May to the end of September.

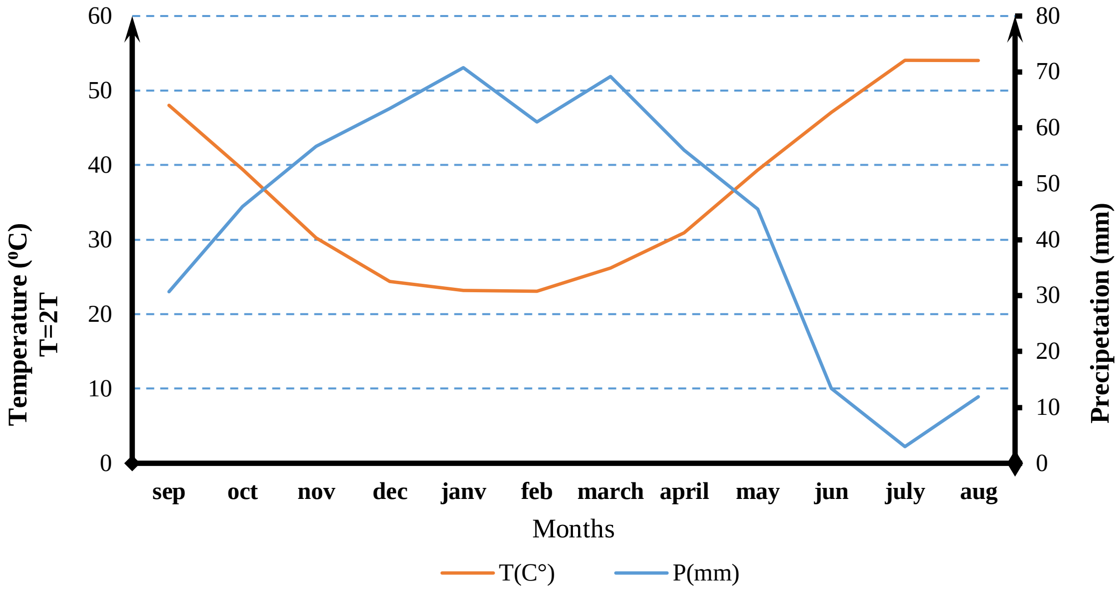


Figure 3.4: The Ombrothermic Diagram of Mellah Basin

3.8.3. Rainfall of the basin:

The Mellah catchment is characterized by irregular precipitation, with a mean annual rainfall of 528 mm Table 3.4 displays average monthly climatic data in Bouchegouf station over the period (1970-2000). The rainiest month is shown to be January (71mm) while the driest is July (3 mm)

3.8.4. Temperature:

The average annual temperature in the watershed is 17.3°C. The highest and the lowest monthly averages are 27.03°C and 11.54°C respectively. According to Table 3.4, February is associated with the lowest temperatures, while august is the warmest month.

Table 3.4: Average monthly Climatic data **of** Bouchegouf Station (1970-2000)

	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Total**
P(mm)	30.71	45.93	56.71	63.43	70.76	61.10	69.19	56.02	45.48	13.43	2.98	11.86	527.55
T(C°)	24.00	19.70	15.11	12.18	11.60	11.54	13.08	15.47	19.69	23.55	27.03	27.00	18.33
ETP(mm)	113.8	73.0	38.6	23.9	23.3	22.6	34.9	51.70	91.00	130.0	173.0	161.8	937.54

3.8.5. Evapotranspiration:

Evapotranspiration of the open surface of the water body was measured by the National Meteorological Office in Annaba (1970-2000) and the corresponding data are displayed in Table 3.4. It had a monthly average of 78 mm, with maximum evaporation of 170 mm in July and a minimum of 23mm in February. Annual evaporation is approximately 938 mm.

3.8.6. Humidity:

Humidity represents the measure of the amount of water in the air. It is usually given as a percentage. The average annual relative humidity in this region is 69.7%, with a maximum value recorded in January (78.25%) and a minimum in July 55.9% (Table 3.5).

3.8.7. Wind:

The Wind is produced by differences in air pressure between one place and another. Average annual wind speed in Mellah Watershed is 1.8m/s (Table 3.5). This speed is rather constant throughout the year, oscillating between 3.0m/s and 3.7m/s. The main directions are North and South-West, but vary from South to North-East clockwise. In general, the wind is calm with a frequency of 18.8%.

Table 3.5 : Guelma station in 2011/2012

Months	janv	feb	mch	aprl	may	Jun	Jul	Aug	sept	oct	nov	dec
Average wind in (m/s)	1.69	2.03	1.96	2.01	1.85	1.87	1.85	1.72	1.61	1.35	1.68	1.8
Average humidity in (%)	78.25	75.5	74.81	73.18	68.8	63.1	55.9	57.88	67.8	70.36	73.88	77.0

3.9 Population:

It is the most densely populated and urbanized catchment in Guelma Region. Approximately, 20% of the global population is aged under 80 to 60 while 60% is aged 59 to 30.and 20 % is under 30. The median age of the Mellah watershed is between 20 and 30 years. The most dense area is in the center and the south part of the basin.

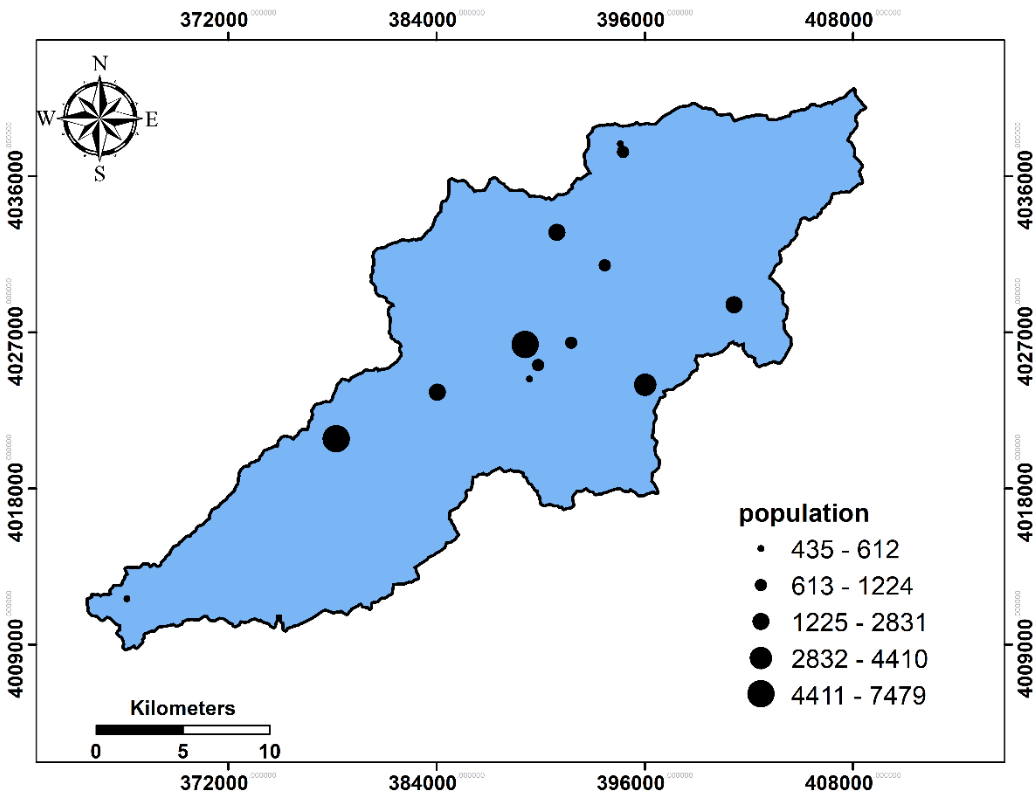


Figure 3.5 Population distributions in Mellah Watershed

3.10. Overview of Methods used for soil prediction

The Soil erosion is effected by various environmental factors Based on that several scholar developed various models for quantify and predict soil loss: Universal Soil Loss Equation (USLE) by Wischmeier and Smith, (1978), Water Erosion Prediction Project (WEPP) by Flanagan and Nearing, (1995), Soil and Water Assessment Tool (SWAT) by Arnold et al, (1998); EuropeanSoil Erosion Model (EUROSEM) by Morgan et al, (1998). Other models subsequently were based on the equation Universal Soil Loss (USLE) from Wischmeier and Smith (1978) and its modified versions (MUSLE) and revised (RUSLE). (Renard et al, 1997) .Some studies were conducted around the world on the aspects using USLE and RUSLE approach combined with GIS (Das et al 2018) for prediction of soil losses while others they have applied the integrated approach of AHP, GIS and RUSLE techniques to determine soil erosion risks(Thomas et al.2018) or they are applying the approach of AHP, GIS, FR (Sar et all ,2016) . The RUSLE is the most commonly used approach and the more convenient than others as it depend on on different parameters like rainfall ,land use , soil texture and practice and conservation sustenance. For sustainable management of soil erosion also the AHP, FR are mostly used for soil prediction (sar et all ; Cerdà et al.2017). based on that the three approaches (RUSLE, AHP, FR) were combined with geospatial technology to predict and quantify soil erosion .

3.10.1 Revised Universal Soil Loss Equation (RUSLE):

RUSLE is a science based tool that has been improved over the last several years by Renard (1997). It represents a revised form of the original Universal Soil Loss Equation (USLE). This equation is especially useful for agricultural watersheds and was applied in many African countries (Bouhadeb et al. 2018). This mathematical equation was implemented in a geographic information system (GIS) with data of remote sensing to estimate the rates of soil loss distributed in space. The superposition of all the physical and anthropogenic factors that control erosion was carried out in raster mode based on the mathematical equation of the model.

RUSLE formula is given as: $A = R \times K \times LS \times C \times P$……….. (3.9)

Where A is the computed average of annual soil loss over a selected period (Ta/ha/Year);

R: Rainfall Erosivity factor;

K: soil erodibility factor;

Ls: slope Length Factor;

C: crop management factor,

P: Conservation practice Factor

The application of this model has the following main objectives:

- Quantification and Derivation of soil loss map based on five factors under GIS .

➢ Identification of sensitive and high erosion risk areas within the study catchment
All the five factors are presented below (3.9)

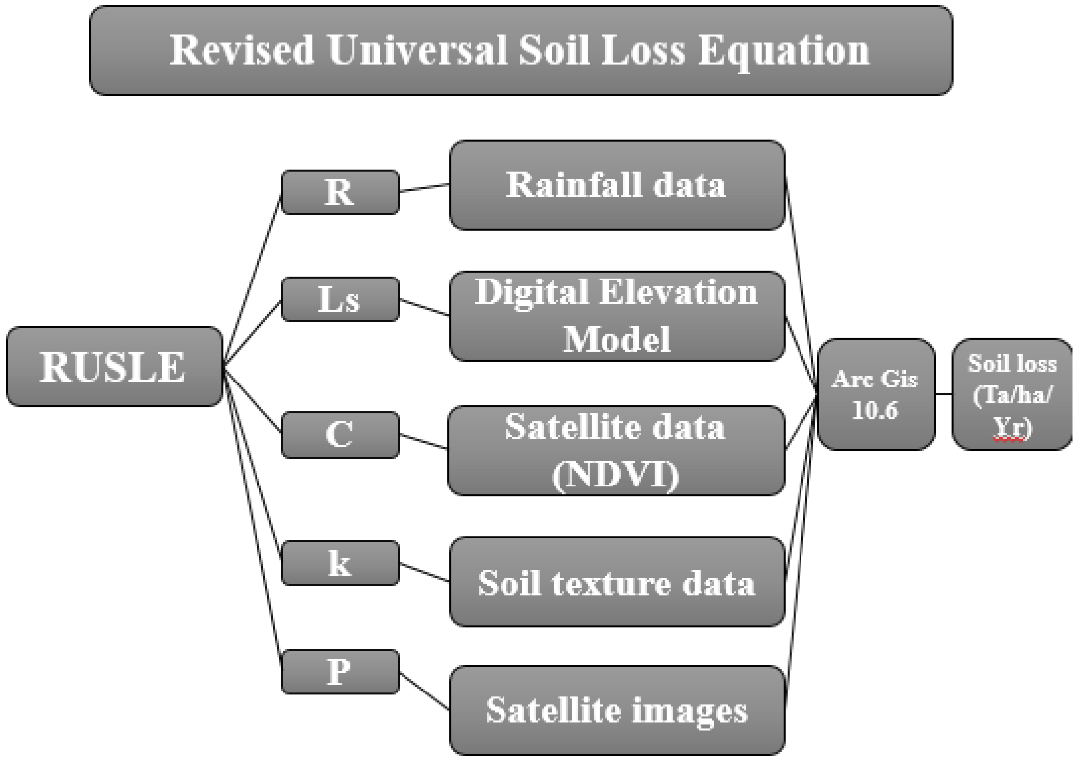


Figure 3.6: Flow chart for steps involved in the soil hazard zonation mapping using RUSLE

3.10.2. Analytical Hierarchy Process:

The Analytic Hierarchy Process (AHP) is semi-quantitative, approach developed by Saaty (1980). It was developed at specific scales by selecting preferences from a set of alternatives (Saaty 1980). It was used to solve various practical problems related to natural hazards (Yasser et al.2013)

The Application of AHP model involves several steps summarized as follows:

1. The first step is to define the problem and the objectives followed.
2. Identify all the variables that influence the problem and rearrange them into hierarchical structure

3. Rank values according to their subjective relevance to determine the relative importance of every factor, and adjust factor ratings based on the priorities determined by decision-makers (Saaty and Vargas 2001).
4. Establish pairwise comparison matrix of the factors through an importance scale. In the construction of a pair-wise comparison matrix, every factor is rated against each of the others by assigning a value of relative dominance (ranging from 1 to 9) to the intersecting cell (Table 3.6). Finally, variables are ranked based on their relative weights from the pair-wise comparison matrix
5. Calculate eigenvalues and eigenvectors to determine the relative weights of the each factor;
6. Compute the consistency ratio to check the consistency of judgement matrixes. The Consistency Ratio CR must be less than 0.1. Otherwise, it is a sign of inconsistency, and the procedure should be reviewed.
7. Finally, the erosion susceptibility map was built by aggregating the weighted decision factors on a GIS platform.

Table 3.6: Scale of preference between two parameters in AHP (Saaty and Vargas 2001)

Scales	**Degree of preference**	**Explanation**
1	Equally	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one activity over another
5	Strongly	Experience and judgment strongly or essentially favor one activity over another
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation
2, 4, 6, 8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7, and 9
Reciprocals	Opposites	Used for inverse comparison

The elements of the matrix is can be expressed as follow

$$A = \begin{pmatrix} x_{11} & x_{12} & \cdots & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & \cdots & x_{nn} \end{pmatrix} where \;\; xji = \begin{cases} 1 & si\ i = j \\ \dfrac{1}{xij} & si\ i \neq j \end{cases}$$

$$aij = \frac{xij}{\sum_{i=1}^{n} xij} \ldots\ldots\ldots\ldots\ldots..(3.10)$$

$$A = \begin{pmatrix} a_{11} & a_{12} & \cdots & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & \cdots & a_{nn} \end{pmatrix}$$

$$W_i = \frac{\sum_{j=1}^{n} aij}{n} \quad and \;\; \sum_{i=1}^{n} Wi = 1 \ldots\ldots\ldots\ldots\ldots.. (3.11)$$

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots. (3.12)$$

Where:

CI is the consistency index, and RI is the consistency index for a random square matrix of the same size. Consistency ratio (CR) should be lower than or equal to 0.1. The commission and omission of a variable in the analysis will depend on the value of CR. When the CR is >0.1, the variable will be omitted and is <0.1, the variable will be incorporated in the analysis. The CI can be calculated using the Eq 3.20

$$IC = \frac{\lambda_{max} - n}{n-1} \ldots\ldots\ldots\ldots..(3.13)$$

$$\lambda_{max} = \frac{\sum_{i=1}^{n} bi}{n} \ldots\ldots\ldots..(3.14)$$

$$where\ is$$

$$bi = \frac{\sum_{j=1}^{n} Wj * aij}{Wi} \quad \ldots\ldots\ldots.(3.15\ )$$

Table 3.7 shows the values of IA

Nombre de critères	3	4	5	6	7	8	9	10
IA	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

(Saaty 1977, 1980): where RI denotes the mean of the resulting consistency index depending on the matrix order provided by Saaty (1980) and CI denotes the consistency index expressed as: where λmax is the largest Eigen value of the matrix, it can be easily calculated from the matrix; ‘n’ represents the matrix order. The CR is a ratio between the random index and matrix consistency index, and its value ranges from 0 to 1. A CR of 0.1 or less is interpreted to be a reasonable level of consistency and more than 0.1 represent indicates that revision is needed due to an inconsistent treatment for individual factor ratings (Malczewski 1999).

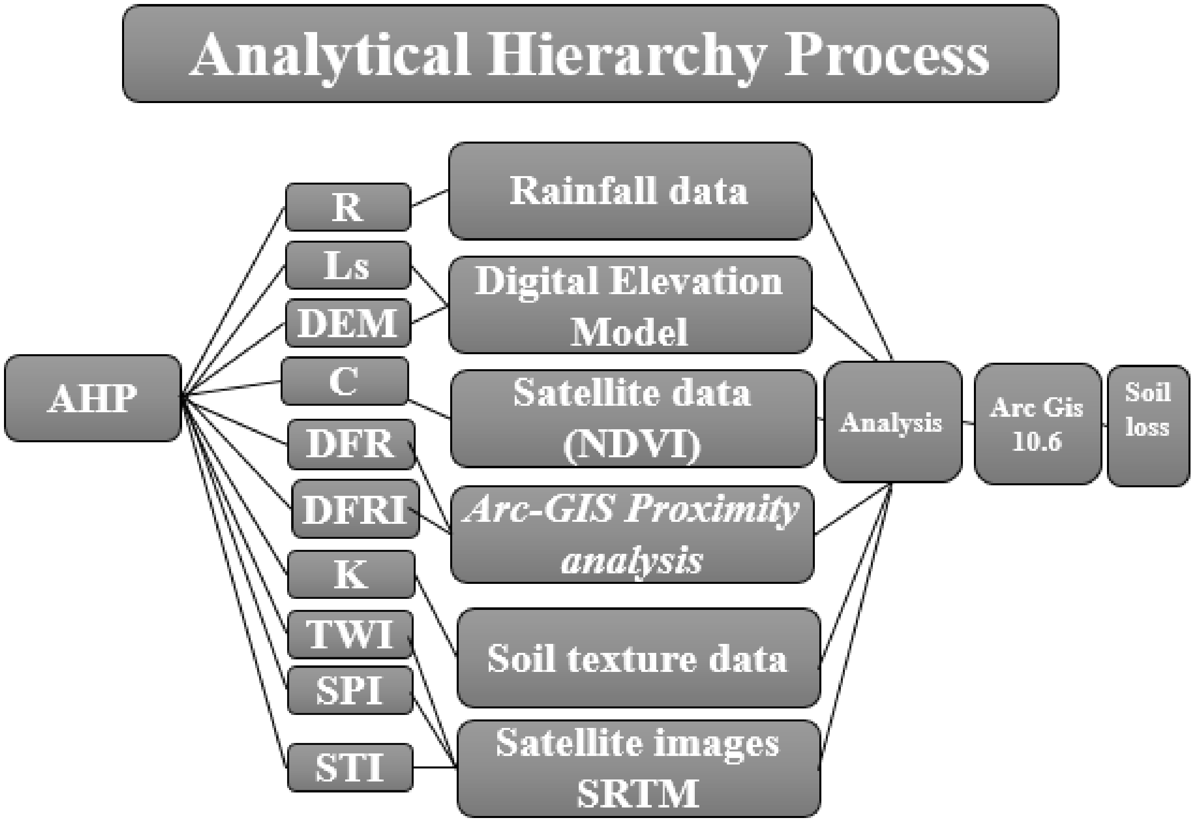


Figure 3.7: Flow chart for steps involved in the soil hazard zonation mapping using AHP model.

For analyzing the soil erosion under the approach AHP ten factor selected namely : (R: Rainfall Erosivity factor; K: soil erodibility factor; LS: slope Length Factor; C: crop management factor,

And distance from rod and river topographic wetness index and stream power index and sediment transport index) all those factors are presented below (section 3.12)

3.10.3. The frequency ratio:

FR, the frequency ratio method, is defined as the ratio of probability of an occurrence to nonoccurrence for a specific event (Mojaddadi et al. 2017). According to Bonham Carter (1994), FR ratio is defined as the degree of correlation between the event location and the class of causative factor. In this study, The FR model is based on the assumption that future soil erosion will occur at similar conditions to those in the past .To calculate the frequency ratio model, the area ratio of soil erosion occurrence to non-occurrence is calculated for each factor, after which an area ratio for the range or type of each factor to the total area is calculated. Hence, the frequency ratio for each factor class is calculated from its relationship with soil erosion occurrence. The larger the ratio is, the stronger is the relationship between soil erosion occurrence and the given factor's attribute (Yalcin et al., 2011). When the ratio exceeds 1, the related conditioning factor shows a greater correlation with the occurrence of soil erosion, while a ratio less than 1 indicates less correlation with an occurrence. FR was calculated using Excel and ArcGIS software. In order to calculate a hazard index for soil erosion, individual conditioning factors were reclassified in terms of acquired weights and the factors were summed. In this case study to predict soil losses under the use of Frequency ratio nine factors were selected **(R:**Rainfall Erosivity factor; **K**: soil erodibility factor; **LS**: slope Length Factor; **DEM:** Digital elevation model and NDVI and topographic wetness index and Sediment transport index and distance from road and river) and analyzed under GIS all the liseted factors are presented in section (3.12)

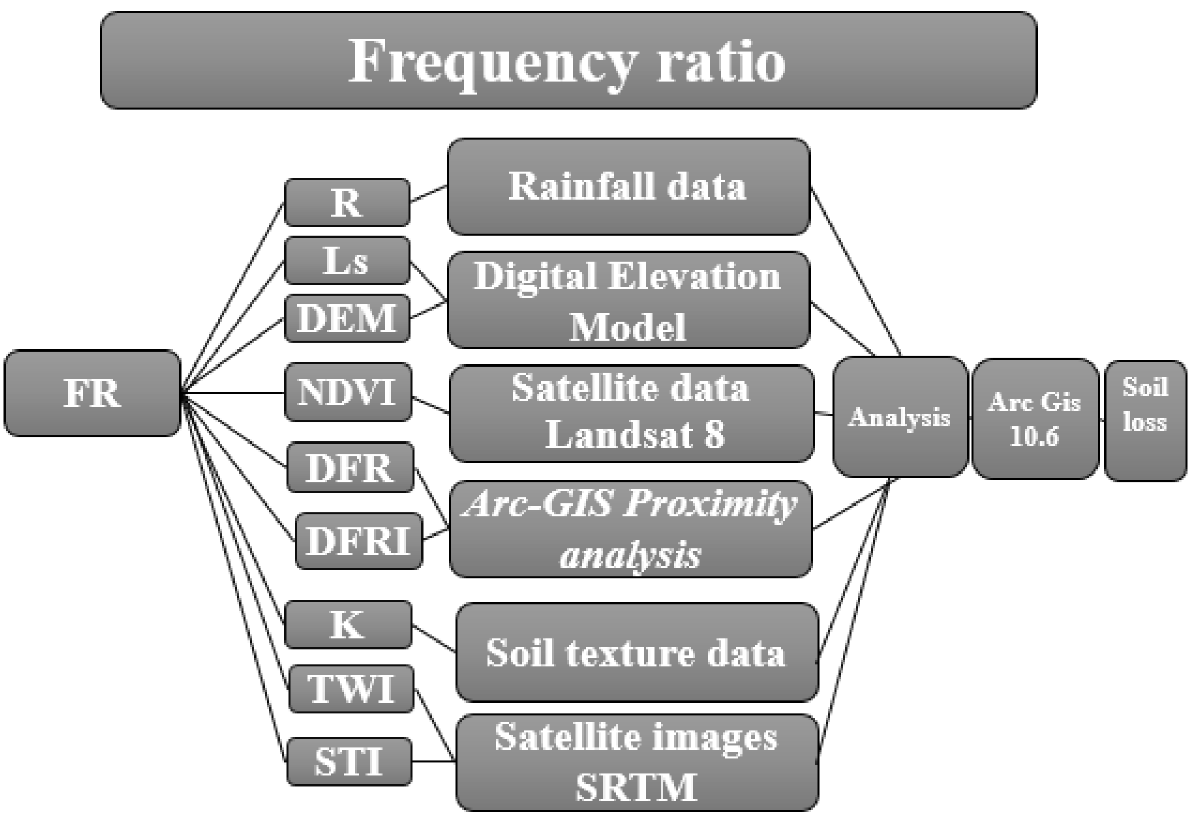


Figure 3.8: Flow chart for steps involved in the soil hazard zonation mapping using FR

3.11. Data set source and their utility:

The data that is utilized in this research work for the achievement of the main objectives are from different sources: data derived from remote sensing (ASTAR ,SRTMLANDSAT 8…...),raster and vector data which analyzed under GIS to identify several factors , metrological data form ANRH (NATIONAL HYDRAULIC RESOURCES AGENCY) for the period (1970-2002) for 15 station tall those data were used to achieve the aim of this study those data are listed and presented in) table 3.8).

Table 3.8: data used in soil loss susceptibility analysis

Data	Utility	Type	Source
Rainfall data	Rainfall Erosivity (R) Calculation	Rainfall data	National agency of water resources (ANRH) For period 1970 -2002
Soil map	Soil erodibility (k) Calculation	Soil texture	Soil grid https://www.isric.org/explore/soilgrids
Digital Elevation Model	slope length (Ls) ,slope (S) calculation	SRTM 1ARC second global With 30 m	USGS earth explorer https://earthexplorer.usgs.gov/
Satellite image	NDVI ,Crop Management (C) factor	Landsat 8 WRS-Path=194	USGS earth explorer https://earthexplorer.usgs.gov/
Satellite image	P factor generation TWI. STI SPT	SRTM 1ARC second global With 30 m	USGS earth explorer https://earthexplorer.usgs.gov/

3.12. Conditioning Factors:

To achieve the main targets of the present work, different condoning factors were selected to quantify the soil erosion including the different factors of RUSLE model(R: Rainfall Erosivity factor; K: soil erodibility factor; LS: slope Length Factor; C: crop management factor, P: Conservation practice Factor). And other selected factors which are (aspect slope ,digital elevation model,distance from road and river land use ….) all those factors are essential elements to analyze the soil erosion under the use of the three approaches (RUSLE,AHP,FR) with the combination of GIS those factors are listed and presented below:

3.12.1 Rainfall Erosivity (R):

The R-factor represents the effects of raindrop that generates the process of aggregate detachment, runoff and transport (Roose and Lelong 1976) and which only involves precipitation. It reflects the amount and rate of runoff likely to be associated with rain (Renard et al. 1997) and given as the product (EI30) of total rain energy (E) and maximum intensity for 30 minutes (I30) (Wischmeier, 1978). However, due to the lack of these data in several regions in the world, including our study area, Arnoldus Formula (1977) is suggested as an alternative for calculation of R factor. This formula, which was used in the present study to compute the rainfall-runoff erosivity factor, uses monthly average precipitation. It is given as follows:

$$R=0.264*F^{1.5} \ldots\ldots\ldots\ldots (3.16)$$

$$F=\sum_{12}^{1} \frac{MRi^2}{AR}$$

With

R: rainfall erosivity factor (MJ.mm/ha.hr.year);

MR: average Monthly precipitation (mm);

AR: Average annual precipitation (mm).

In this study R factor was estimated based on data from twenty-two stations in or near Mellah Watershed for a 30-year series of observations of all the rainfall stations (1970-2000). Values of the R factor were calculated separately for each station and the results are then interpolated using the Inverse Distance Weighting model “IDW”, to produce a map for the erosivity factor. It is important to note at this stage that the IDW method is a local deterministic interpolation technique that calculates the value by averaging the values of the points in the neighborhood weighted by the inverse of the distance to the calculated point: the closer the points, the more important is the weighting factor.

3.12.2. Soil Erodibility factor (K):

The soil erodibility factor (K) represents the resistance of soil particles to detachment and transportability of the sediment by water. This index depends on the basic properties of the soil, such as soil structure, texture, particle size, amount of organic matter and permeability. The K factors are best obtained from direct measurements on natural runoff plots for satisfactory direct measurement of soil erodibility, erosion from field plots needs to be studied for periods generally well in excess of 5 years .The K values reflect the rate of soil loss per rainfall-runoff erosivity (R) index.in this study The model of Stone and Hilborne, (2012) was used to estimate K based on soil contents of organic matter, clay, sand and silt. (Eq 3.17)

$$K=0,1317(0.2+0.3* e^{\left[-0.0256*san\left(1-\frac{sil}{100}\right)\right]} * \left(\frac{sil}{cla+sil}\right)^{0.3} * \left[1-\frac{0.25*toc}{toc+e^{(3.72-2.95+toc)}}\right] * \left[1-\frac{0.7*SN1}{SN1+e^{(22.9*SN1-5.51)}}\right] \quad (3.17)$$

where, :

K: present the soil erodibility factor (t ha h ha−1 MJ−1mm−1)

SAN :is sand weight content (%);

SIL: is silt weight content (%);

CLA :is clay weight content (%);

TOC: is soil organic Matter content (%);

The input data used in the formula were obtained in the form of thematic maps using the Soil Grid web site digital platform (https://soilgrids.org/). From the web site soil grid the percentages of sand, silt, clay, organic matter for each soil have different depths ranging from 5cm to 2m .In our case, there is much more interest in the upper layer of soil that is likely to be eroded and extends over a 30 cm depth of the natural terrain layer (Stone and Hilborne 2012). The assembly of different layers was done using the R-Studio programming tool (appendix b1). The final result is presented in the form of a global thematic map that takes into account all the parameters. R software was adopted for the calculation of the erodibility factor.

3.12.3 Slope Length and Steepness Factor (LS):

The topographic factor is accounted for by the effects of (LS) factor on Soil loss (Renard et al, 1997) because the rate of erosion is increased with an increase of slope length and slope angle due to the progressive accumulation of runoff in the downslope direction. As the slope steepness (S) increases, the velocity and erosivity of runoff increase. Actually, the factor L is the ratio of soil loss from the field of certain slope length. The slope length is the distance from the original point of overland flow of a sediment particle along its flow route to the site where it is deposited. In our case study, the LS factors were calculated using David Formula (1988). The formula used for the calculation of LS in this study is given as:

$$Ls = a + b*(S_L)^{4/5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.18)$$

Where :

a = 0.1, b = 0.21, S_L: Slope (%)

In this study, the DEM and slope were used to calculate and map the LS-factor.

3.12.4. Crop Management Factor (C):

According to Kalman (1967), the most important factor controlling erosion risk is the cover management factor, which represents the ratio of soil erosion from land cultivated under certain conditions to that under the continuous fallow condition. The range is from near zero for well-protected soils to 1 for striated surfaces very sensitive to erosion (Angima et al, 2003). According to the level of data available, C factor can be evaluated in different ways. At present, most of the studies estimate the C factor at large scale. In the case of Mellah Watershed C factor was estimated using the formula of De Jong et al (1998)

$$C = 0.431 - 0.805*NDVI \qquad (3.19)$$

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (3.20)$$

Table 3.9: values of C factor

Land cover	C factor
Dense Forest	0.17
Open forest	0.19
Forested Bushes	0.13
Dense Bushes	0.10
Open Bushes	0.20
Olive groves	0.29
Crops	0.55
Pasture land	0.4
Crops and pasture	0.45
Reforested area	0.18
Rocky Outcrops	0.75
Bare land	1
Water body	0

3.12.5. Conservation Practice Factor (P):

The P factor represents the ratio of soil erosion under a specific practice of soil conservation to that under the increase and decrease of surface slope (Wischmeier and Smith, 1978). It varies from 0 to 1 depending on the cultivation method and on slope class. The conservation practice Factor (P) in RUSLE is defined as the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and downslope tillage. The P factor accounts for control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. In this study to identify the p factor, the slope class percentages used the classification of Shin (1999), as a function of slope and culture (Table. 3.8).

Table 3.10: Conservation support practice P factor (Shin, 1999)

Slope in %	Contouring	Strip cropping	Terracing
0.0-7.0	0.55	0.27	0.10
7.0-11.3	0.60	0.30	0.12
11.3-17.6	0.80	0.40	0.16
17.6-26.8	0.90	0.45	0.18
26.8 >	1.00	0.50	0.20

3.12.6 Digital Elevation Model

Elevation (i.e. height above the sea level) is one of most important factors which have an impact on erosion. It is useful to classify the local relief and locate points of maximum and minimum heights within terrains (Ayalew & Yamagishi 2005). The DEM of the study basin was derived from USGS earth explorer with a spatial resolution of 30 m x 30m. It revealed that elevations range from 95 m to 1302m, with an average of 618 m above mean sea level.

3.12.7. Aspect slope:

Aspect is also considered as an important factor that has an influence on soil erosion susceptibility maps Aspect was defined as the direction of maximum slope of the land surface and has an indirect influence on slope instability (Kanungo et al. 2006). Its associated parameters, such as exposure to sunlight, drying winds, rainfall (degree of saturation), and discontinuities may affect the occurrence of soil erosion .

3.12.8. Distance from river:

Distance to stream is one of the controlling factors for the stability of a slope. The saturation degrees of the materials directly affect slope stability. The proximity of the slopes to the drainage structures is also an important factor in terms of stability. Streams may negatively affect stability by eroding the slopes or by saturating the lower part of material until the water level increases (Dai et al., 2001; Saha et al, 2002). In this respect, the relation between streams and groundwater are also important. Groundwater exchanges directly affect the characteristics of surface water by sustaining stream base flow. Groundwater affects surface water by providing moisture for riparian vegetation, and controlling the shear strength of slope materials, thereby affecting slope stability and erosion processes.

3.12.9. Distance from road:

Similar to the effect of the distance from rivers, soil erosion may occur on the road and on the side of slopes affected by roads (Ayalew and Yamagishi, 2005; Pachauri et al., 1998). Change of slope (over steepening) due to excavation, additional load, and change in hydrology, and drainage may affect the stress state and slope equilibrium. In fact, during the field works, some soil erosion owing to road construction work was detected. For this reason, five different buffer zones are created on the path of the road to determine the effect of the road on slope stability. The soil erosion percentage distribution and its frequency ratio are determined considering the distance classes to the road by comparing the map of the distance to the road and the soil erosion inventory

3.12.10. Land use/land covers

The major land-use types in the study area are road networks, river/ water bodies, built up areas, dense forests, vegetation cover, scrub land, barren land, agricultural cropland and agricultural fallow land These land cover classes are delineated from Landsat 7 satellite data and intense field verification. Around 40% of the total area is under cultivation, forest and barren land are 38% and 22% respectively The study area was represented by five major land cover types, including agriculture, bare land water body soil/rock and urban area. A supervised image classification of NDVI is obtained by the integration of GIS using ArcGIS Software.

3.12.11. Topographic Wetness Index (Twi) :

The topographic wetness index (TWI), also known as the compound topographic index (CTI), is commonly used to quantify topographic control on hydrological processes (Sörensen et al., 2006). TWI was developed by Beven and Kirkby (1979) within the rainfall–runoff model TOPMODEL. The index is a function of both slope and the upstream contributing area per unit width orthogonal to the flow direction. TWI was created from SRTM DEM using the Raster Calculator and ArcHydro tools in ArcMap 10.6 Software. The following equation was applied to create these factors .

$$\mathbf{Twi} = \ln\left(\frac{\alpha}{\tan\beta}\right) \ldots\ldots \qquad (3.21)$$

$\boldsymbol{\alpha}$: flow accumulation, $\boldsymbol{\beta}$: slope

3.12.12. Stream power index:

The stream power index (SPI) is a compound topographic attribute (Moore et al., 1992). It is a measure of the erosive power of running water based on the assumption that discharge is proportional to specific catchment area. It generally predicts net erosion in the areas of profile and tangential convexity (flow acceleration and convergence zones) and net deposition in the areas of profile concavity (zones of decreasing flow velocity). SPI is the product of catchment area and slope and could be used to identify suitable locations for soil conservation measures to reduce the effect of concentrated surface runoff. SPI was created from SRTM DEM using Raster Calculator and ArcHydro tools in ArcMap 10.6 software. The following equation, developed by Moore et al. (1991), was applied to create these factors. SPI $=\alpha * \tan\beta$ …………(3.22)

3.12.13. Sediment transport index:

The sediment transport index characterizes the process of erosion and deposition. It accounts for the effect of topography on erosion. Unlike the length-slope factor in the universal soil loss equation (RUSLE), it is applicable to three-dimensional surfaces (Burrough,1986). The sediment transport index is defined by the upstream area and the slope at a given cell. The upstream area is weighted stronger than the slope. For this reason, the main causes for this phenomenon may be the distributed drainage system and low slope gradient trend on soil erosion surface Therefore, this distinct anomaly can be considered as a good indicator of soil erosion occurrence (Nefeslioglu et al., 2008).

3.12.14. Normalized Difference Vegetation Index (NDVI):

Vegetative cover is one of the most important biophysical indicators of soil erosion, which allows the delineation of the distribution of vegetation and soil based on characteristic reflectance patterns of green vegetation. Normalized difference vegetation index .It is universally accepted that satellite derived normalized difference vegetation index (NDVI) is an important index to assess vegetation condition (Sar et al., 2016). Vegetation condition at any given time during its growth is influenced by complex interactions of weather, soil moisture, and soil and crop types. The NDVI can take values between -1 and + 1. NDVI is calculated on a per-pixel basis as the normalized difference between the red and near-infrared bands from a remotely sensed image. In this study, NDVI values were obtained by the combination of visible bands (red) and near-infrared band of the Landsat ETM + data. Formula (Eq 3.20). Table 3.11 shows the different values of NDVI.

Table 3.11: NDVI factor

Factor	Water	Built-up River sand	Fallow Wasteland	Crop grass	Agroforestry	Dense Forest
NDVI	-0.41379 To -0.10141	-0.10141 To 0.055727	0.055727 To 0.20579	0.20579 To 0.37035	0.37036 To 0.51037	0.51038 To 0.82051

3.13. Inventory Map:

The inventory map figure 3.9 was generated over the entire surface of the study area, using a collection of historical data, previous work, fieldwork and interpretation of processed Landsat 8 satellite images on the GIS environment.

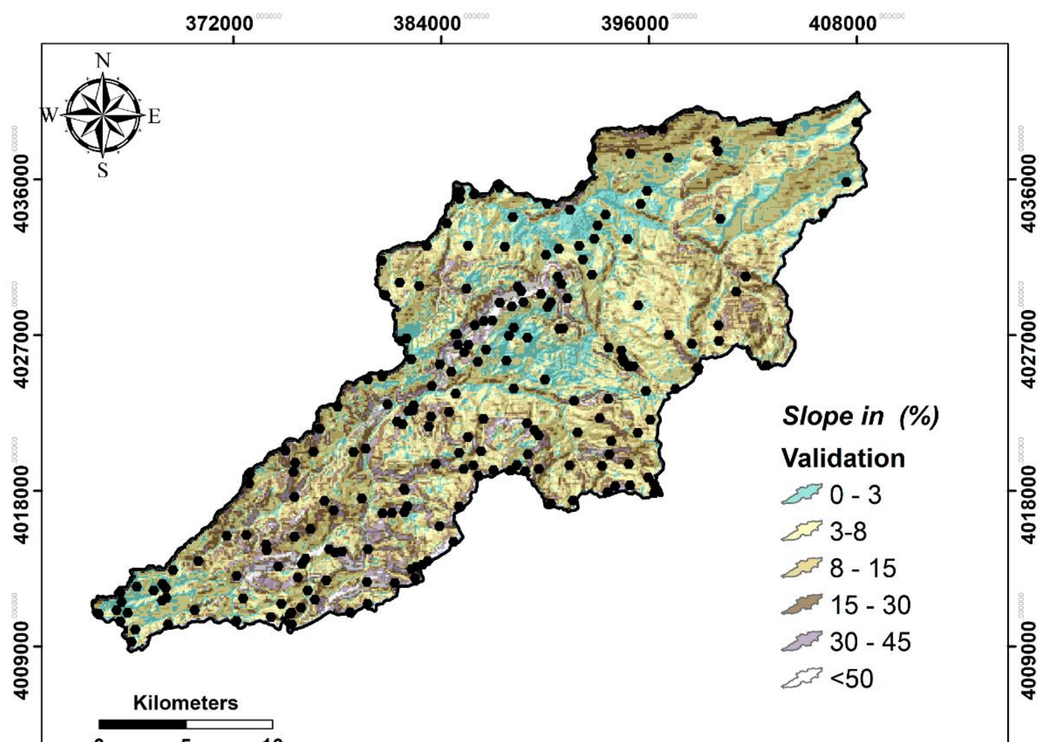
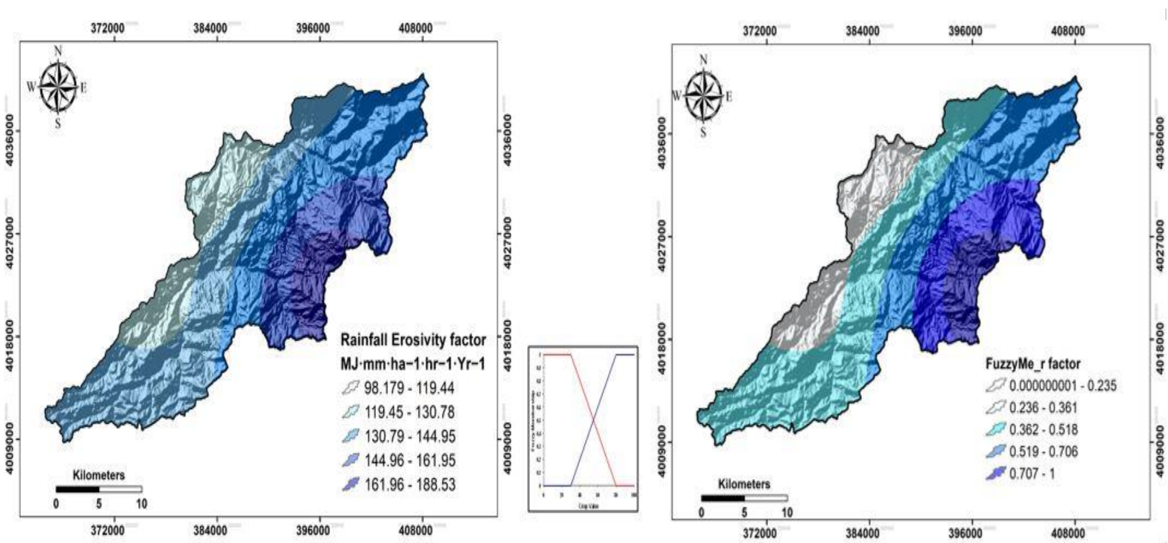


Figure 3.9: Inventory map of Mellah watershed

3.14. The standardization technique :

The standardization technique is used to translate various inputs of a decision problem to a common scale, to allow comparison and overcome the immeasurability of the data (Rahman et al, 2009). The standardization process allows the scaling of all evaluation dimensions between 0 and 1. Standardization of factors was established on the basis of fuzzy logic. New features of Arcgis in the operator (Fuzzy member ship) were introduced in the spatial modeling of erosion risk to standardize the factors on the same scale in order to measure them on one hand and convert the semantic description of the risk of water erosion into a model digital spatial prediction on the other.the (figure 3.10) shows of the processes of the standardization in ArcGis which is represent the rainfall factors before and after standardization .



Figures 3.10: the processes of the standardization in ArcGis

3.15. Assessment the performance of soil erosion map :

Validation represents an important step in the evaluation of the performance of soil erosion map for such prediction model. In this study, the accuracy of the results is checked by ROC (Receiver Operating Characteristics) and AUC (area under the curve). The curve is created by plotting sensitivity (the true positive rate) values, shown on y axis, against the false positive rate (FPR) shown on the x axis. AUC may be used for quantitative comparison of these models. The value of one for AUC represents a perfect model while when AUC equals 0 it indicates a noninformative model (Bouamrane et al., 2020). . Sensitivity is computed as the fraction of cells hosting gullies that were correctly classified as susceptible, while specificity is derived from the fraction of cells free of gullies that were correctly classified as non-susceptible. Table 3.12 shows the levels of accuracy of the AUC values which is produced by Rashid et al. (2016)

Table 3.12: Accuracy of AUC values (Rashid et al. 2016)

levels of accuracy	**excellent**	**good**	**satisfactory**	**poor**	**failing**
Value of AUC	(0.90–1.00)	(0.80–0.90)	(0.70–0.80)	(0.60–0.70)	(0.50–0.60)

RESULTS AND DISCUSSIONS

4.1 Introduction:

This chapter is subdivided into two main parts. The first presents the results and discussion of the annual average soil loss rate distribution of Mellah Watershed. The second part is devoted to the presentation of the soil erosion susceptibility maps produced by the three different models used, namely RUSLE, AHP and FR. The results obtained by the different models were compared and validated using ROC curve by selecting 200 field observations of rill erosion.

4.2. Conditioning factors:

4.2.1. Rainfall Erosivity (R):

Mellah Watershed is affected by a heavy-duty seasonality effect. The R factor values for this chapter need an annual rainfall for the period (1970-2000) ANRH(national agency water resources) for calculation the (Eq 3.16) were used and the results obtained analyzed under ArcGIS (10.6).to identify rainfall erosivity factor maps (Figure 4.1(A)) .A high R-factor value characterizes a region experiencing severe heavy erosive rainfall while a low R value reflects low power erosion of the rains. For Mellah Basin, *R* factor values ranged from 98.18 to 188.53MJ mm ha-1 h-1, with a mean value of 134.03MJ mm ha-1 h-1. The highest value of R factor was observed in Tabaga Mountain and Kelaia Mountain (188.53MJ mm ha-1 h-1), followed by "Rirane Wadi" (144.96 MJ mm ha-1 h-1) (both in the Centre of the watershed) while the lowest value appeared on the north-western side "Nador Mountain" (98.17 MJ mm ha-1 h-1). According to the distribution tendencies of R in Mellah Basin (Fig 4.1), it can be shown that the distribution of R factor in the watershed varies depending on altitude and distance from the sea.

4.2.2. Soil Erodibility (K):

A soil erodibility map (K) was generated using the Soil Grids database of ISRIC–World Soil Information and equation (Eq 3.17) presented in chapter 3. Five categories of lithological formations were distinguished, including silty loam (70%), silt (15.6%), silty clay (8.7%), Loam (5.4%) and sand (0.3%). Figure 4.1(B) shows the spatial distribution of the soil erodibility factor, where five classes were identified based on the natural break classification. The average value of the soil erodibility factor over the whole watershed was estimated to be 0.0159 t.ha.h.ha-1.MJ-1.mm-1.

A B

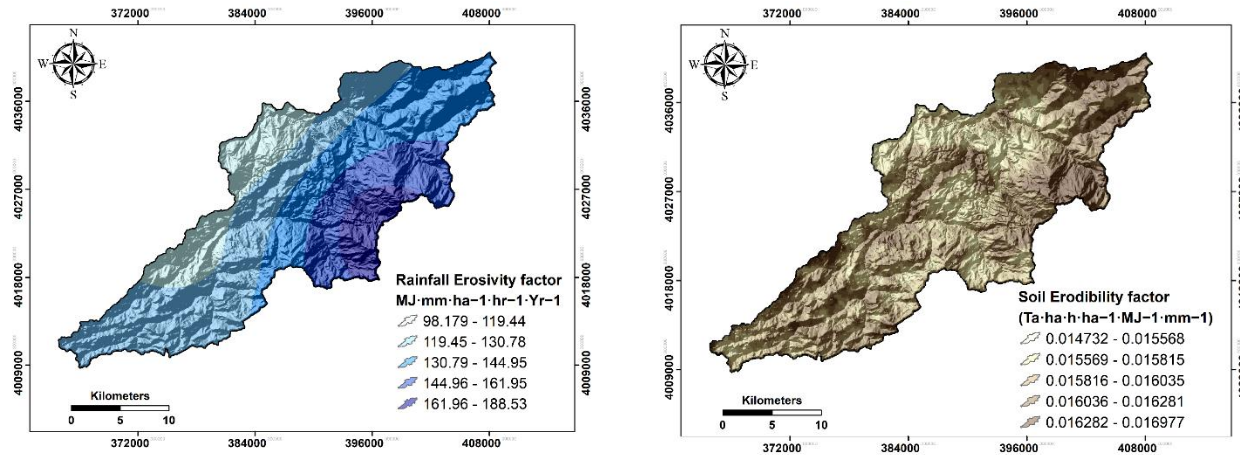


Figure 4.1: Rainfall Erosivity Factor (A) and Soil Erodibility Factor(B)

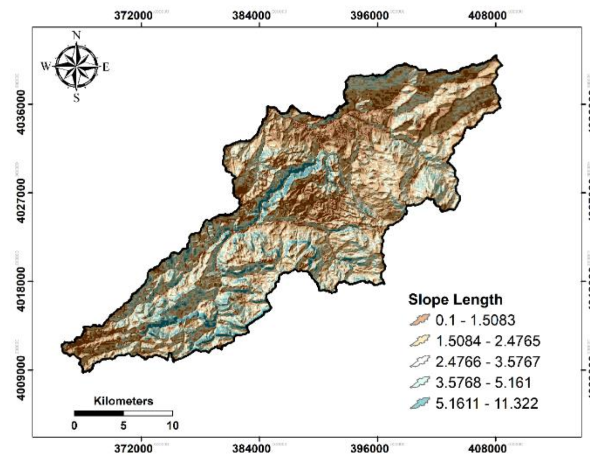
4.2.3. Slope Length and Steepness Factor (LS):

LS factor was calculated using flow accumulation and slope as input data. LS factor was derived from DEM of USGS Earth Explorer Web Site, with a spatial resolution of 30 m. Using the natural break method, the LS map was generated using (Eq. 3.18) presented in chapter three. The LS map was subdivided into five classes as shown in Figure 4.2 (A). The five generated classes ranged from 0.1 to 11.3, with a mean value of 2.46. The highest LS factor value was observed in the center and the south upstream area of the basin while low values were observed in the north-eastern part of the basin due to steep slopes.

4.2.4. Crop Management Factor (C):

The Crop Management Factor (C) was prepared using NDVI based on equation (3.19) presented in chapter three. According to the spatial distribution of C factor Figure 4.2 (B) it is clear that C-values decreased from the north to the south, with values ranging from 0.32 to 0.5 (Fig 4.4) and a mean value was 0.454. The northwestern part shows the highest C-values while low values are mainly distinguished in the south.

A **B**



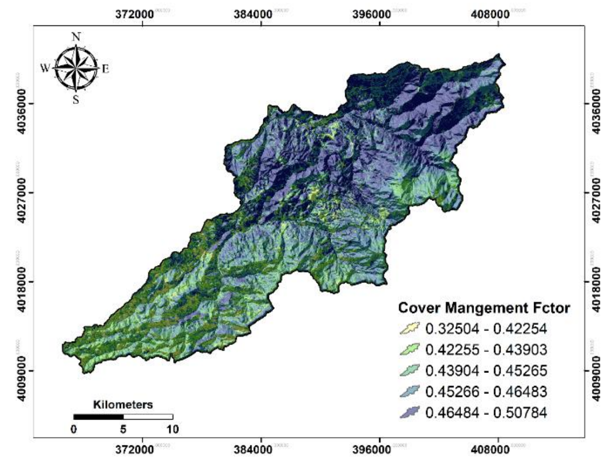


Figure 4.2: Factor Slope length factor.(A) Cover Management(B)

4.2.5. Conservation Practice Factor (P):

The P factor map values were derived from the slope class percentages using the classification of Shin (1999). The obtained P values varied between 0.55 and 1 Figure 4.3 (A) Nearly 60% of the P values in the basin were between 0.6 and 0.8, which represent the largest portion. Thus, most areas in the basin are forests and lands with vegetation cover, indicating that soil is sufficiently protected against erosion. Areas associated with high P-values are generally areas without conservation practices. On the other hand, areas with practices of soil conservation and cultivation are usually associated with low P-values.

4.2.6. Slope aspect:

Slope aspect is considered as an important factor influencing soil erosion. In this case study, the aspect slope was produced using the spatial analyst toolbox of ArcGIS, which resulted in dividing the study basin into nine categories Figure 4.3 (B) Areas having the southwest slope aspect (112.5–157.5) fall into the 'very good' category because of the nearly flat terrain and relatively high infiltration rate and least soil erosion. On the other hand, the area sloped to (247.5–292.5) is considered as 'extremely poor' and 'unsuitable' due to a high slope, which does not favor direct infiltration.

A **B**

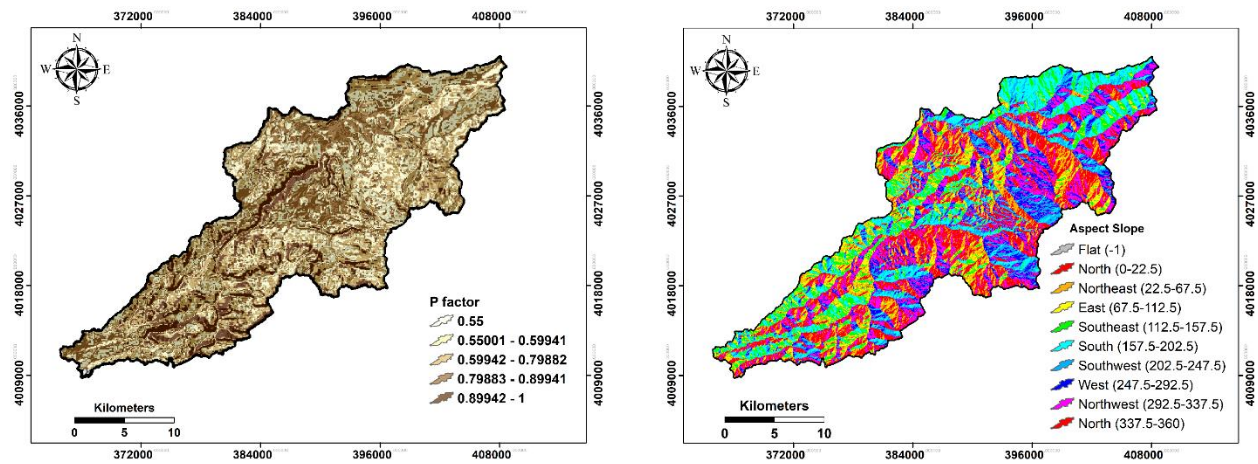


Figure 4.3:. Conservation Practice Factor(A). Slope Aspect Factor(B)

4.2.7. Land cover:

Land use was obtained using the Landsat 8 image and classified into five categories: Water body, barren land, dense forest, agricultural land, dense forest and urban area. Figure 4.4 (A). shows that the major land covers types are agriculture and bare lands, and dense forests, with more than 50 % of the total area while Water bodies represent only a low percentage in the basin.

4.2.8. Normalized Difference Vegetation Index:

The Normalized difference vegetation index (NDVI) was generated from satellite images. This index represents the condition of vegetation cover and reflects the background influence of the plant canopy including soil, wet ground, snow and surface roughness. NDVI map was classified into five intervals, with a mean value of 0.27 Figure 4.4 (B).

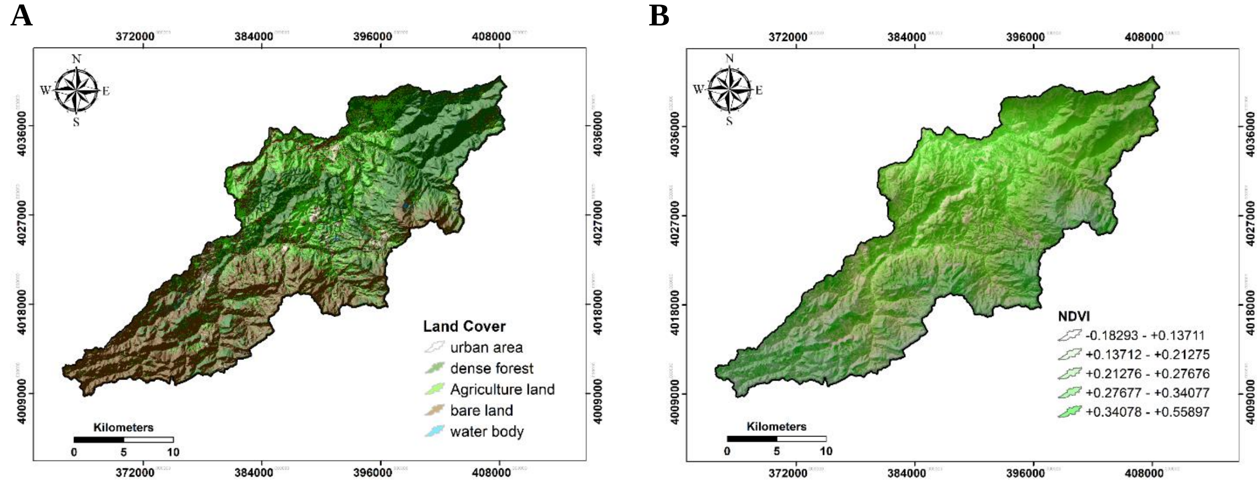


Figure 4.4: Land Cover Factor (A). Normalized Difference Vegetation Index(B).

4.2.9. Distance from stream:

The distance from stream represents an influence factor on soil erosion. In order to create the distance from stream map, the model builder in Arc map was used to create a Euclidean distance-based raster. In this case study, the distance varies from 0 to 41936m. For the north-eastern the distances near 500 m the closer distances from streams generally correspond to high to severe soil erosion susceptibility and a large number of soil erosion occurrences. Because closer distance to stream are affected to impact of water which eroded the soil close to stream Figure 4.5 (A).

4.2.10. Distance from road:

The study on distance from road showed that most of the major soil erosion locations are very close to the road area. The distance from road was also calculated in the ArcGIS environment. Five different buffer zones are created on the path of the road to determine the effect of the road on the stability of slope Figure 4.5 (B) The farthest regions from the road are located in the northwestern part and also in the south-eastern part, with distances exceeding 4000 m while the closest zones to roads are located in the center and the south-eastern part of the study basin.

A B

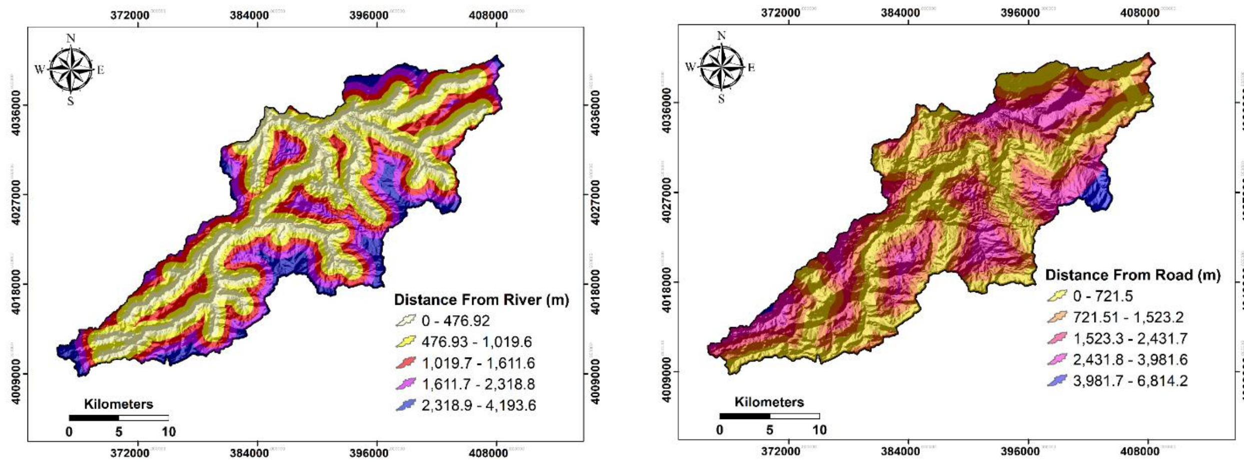


Figure 4.5: Distance from river (A).Distance from Road Factor(B)

4.2.11. Topographic Wetness Index (TWI):

This index is commonly used to quantify topographic controls on hydrological processes. It is established based on equation (3.21) presented in chapter three. The results of TWI map for Mellah Watershed are shown in Figure 4.6 (A).. TWI values are shown to vary from 3.1016 to 22.694, with an average of 6.82. The highest TWI values can be spotted around the natural water channels.

4.2.12. Digital Elevation Model:

The Digital Elevation Model (DEM) is used to represent land surface elevation; it is the basic topographic characteristic of the watershed. DEM was directly used as an assessment layer in many previous studies on soil erosion risk assessment. The range of elevation in the study area is from 95 to 1302m above sea level, with an average value of 639.3m. High elevations are mainly located in the south of Mellah Basin. Elevations gradually decrease in the North-west 380 to 588 m part of the basin, with values varying between 983 and 302m. Figure 4.6 (B).

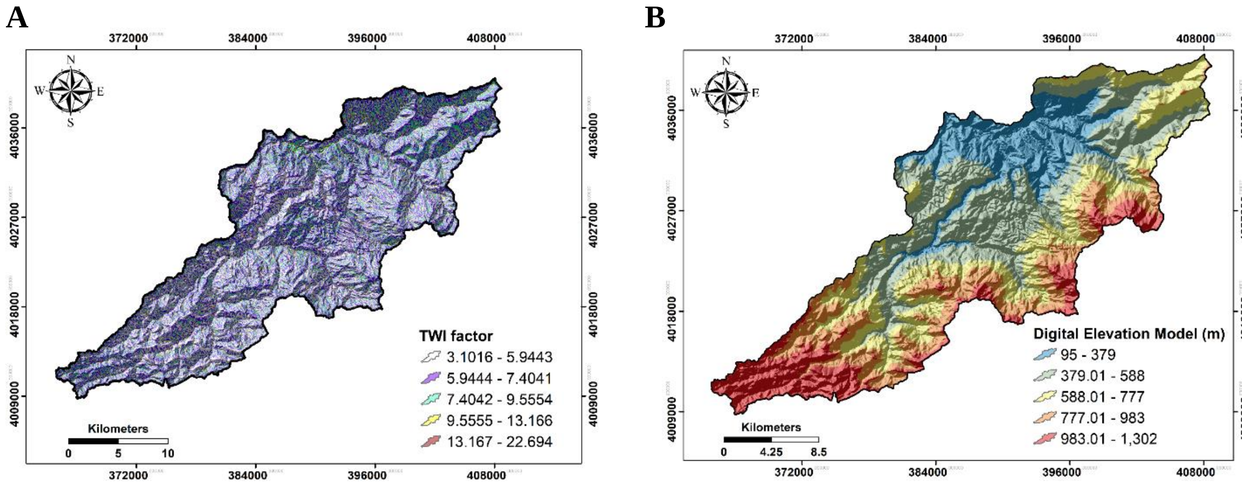


Figure 4.6: Topographic Wetness Index Factor(A).Digital Elevation Model Factor(B).

4.2.13. Stream Power Index:

The Stream Power Index (SPI) describes the erosive potential of flow at a given point on the topographic surface. As catchment area and slope gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increase and consequently stream power index and erosion risk increase. Similar to TWI, SPI is determined by its definition formula (Florinsky, 2011) and the ramifications of DEM using the raster calculator tool in GIS.

4.2.14. Sediment transport Index:

The sediment transport index is defines as the movements of the sediments due to the water movement. STI is one of the morphological factors associated with erosion because is considered as a good indicator of soil erosion occurrence STI is used to account for the effect of topography. Regarding how water and mass fluxes are considered for the mass balance for each pixel, This parameter was generated using the equation mentioned in appendix under Arc Gis tool from the result obtain the factor rang from 0 to 209900 which is shown in map below Figure 4.7 (B).

A B

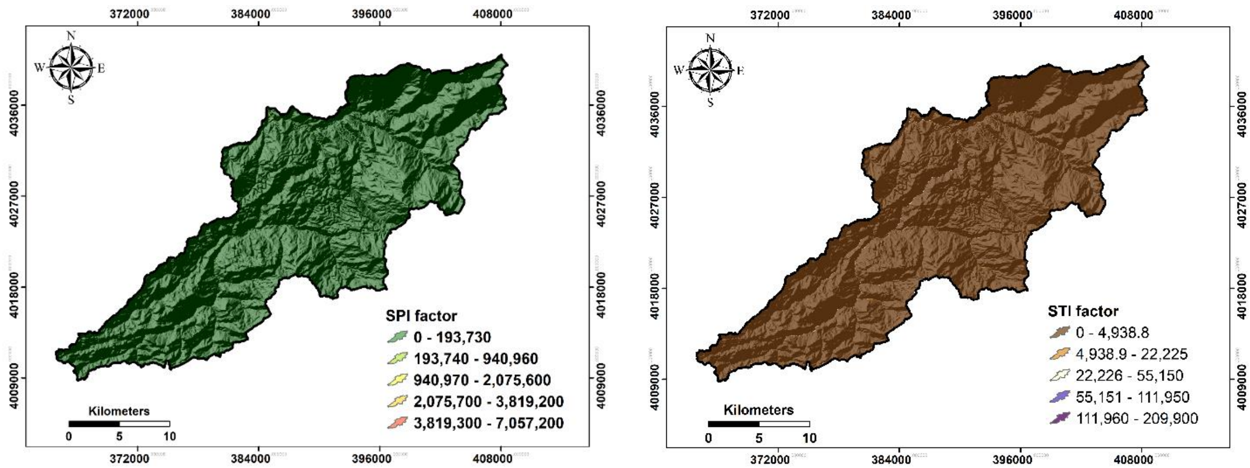


Figure 4.7: Stream Power Index Factor (A) .Sediment transport Index(B)

4.3. Water erosion simulation results

4.3.1. RUSLE results:

Soil erosion estimates for Mellah Basin with RUSLE model (Figure 4.8) was generated by overlaying all the parameter layers of the model, including erosivity factor R, erodibility factor K, slope length LS, vegetation cover C and the management factor P. The combination of these factors resulted in the development of the erosion susceptibility map. The obtained results showed that annual soil loss in Mellah Basin varied from 0 to 10.4 t ha−1 yr−1, with a mean value of 4.9 t ha−1 yr−1.

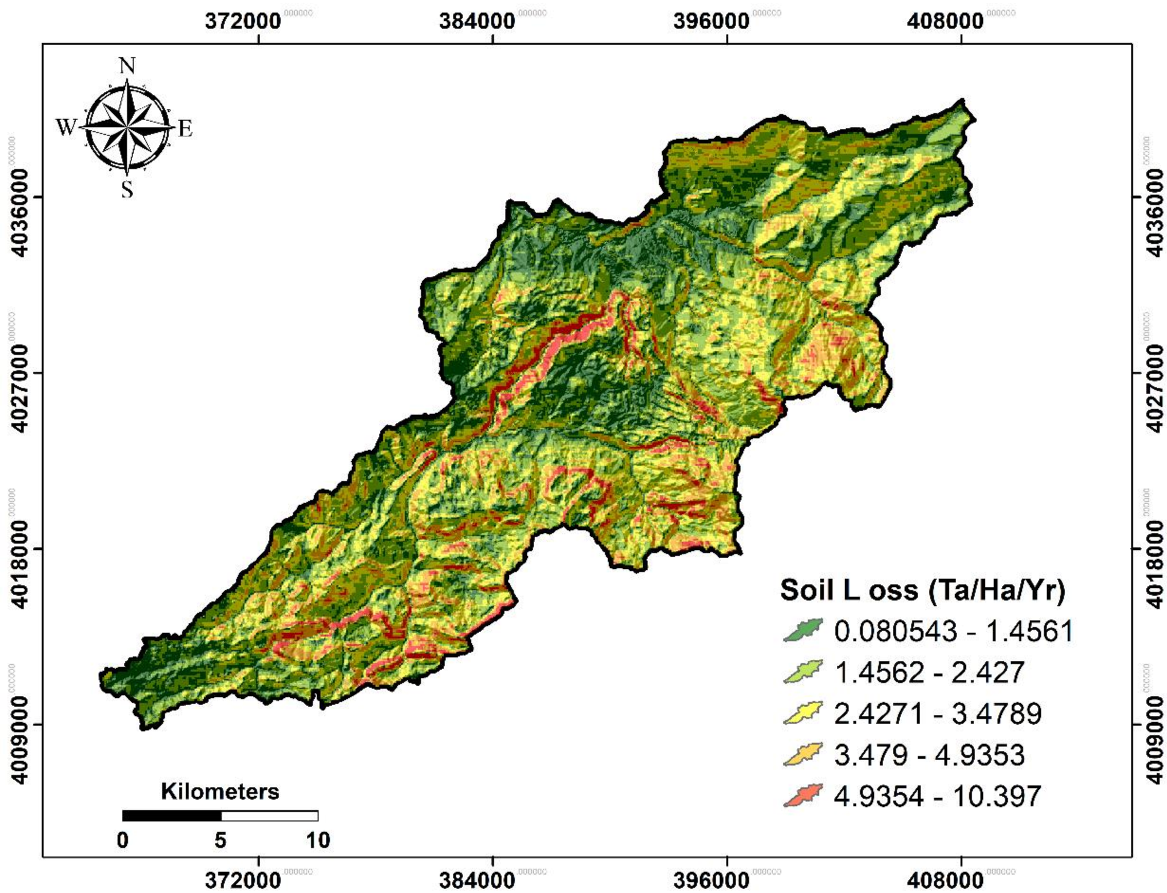


Figure 4.8: Soil erosion susceptibility map based on RUSLE model.

Using the natural break classification, the following five classes were identified: very low (0.0805 to 1.4561 t ha^{-1} yr^{-1}), low (1.4562–3.4789 t ha^{-1} yr^{-1}), moderate high (>4t ha^{-1}) per annum and very high (<11 t ha^{-1}). According to Bougherra (2018), the tolerable soil erosion rate for the Maghreb Region is 7 t/ha per annum. In this study, 17.4% of the total area was found in the class of very high and high soil erosion susceptibility.

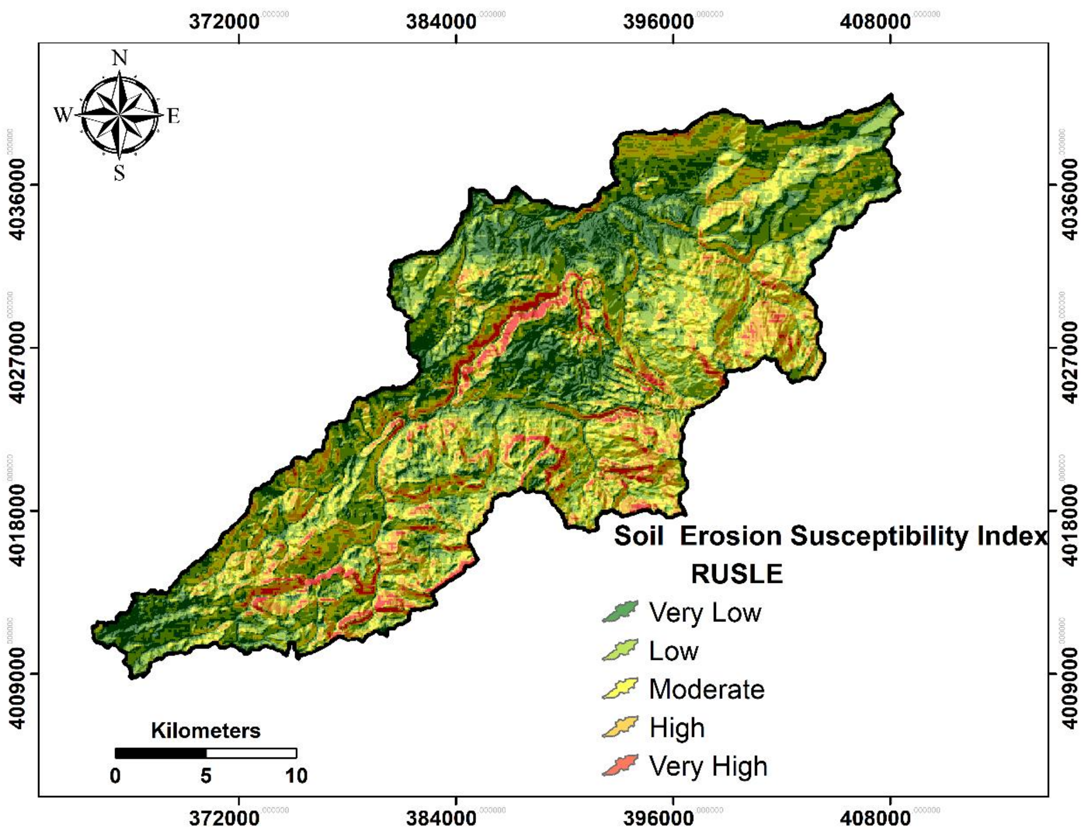


Figure 4.9: Soil erosion susceptibility map based on RUSLE Model.

4.3.2. The AHP results:

The application of the qualitative model AHP (Analytic Hierarchy Process) was based on experts' opinions to arrange the factors in a hierarchical structure and produce the relative importance of erosion conditioning factors. The relative importance between factors was determined by applying the paired comparison matrix and the Consistency Ratio (CR), found to be 0.043. The results obtained (Table 4.1) show that the highest weight of the AHP corresponds to the R factor (0.247), which was considered as the most important variable for this watershed while SPI and STI were treated as the least important factors, with weight values of 0.024 and 0.019 respectively. Using the natural break approach, the erosion risk sensitivity map extracted from the AHP model was classified into five classes: very low, low, moderate, high and very high. Based on the results obtained from the spatial distribution of sensitivity to erosion risk generated with AHP, 10.07% of the total basin area is associated with very high risk while the values of the high and moderate sensitive area are relatively close, as they represent 22.8% and 25.1% of the basin area respectively. The areas of low and very low sensitivity represent respectively 13.7% and 28.4% of the total area.

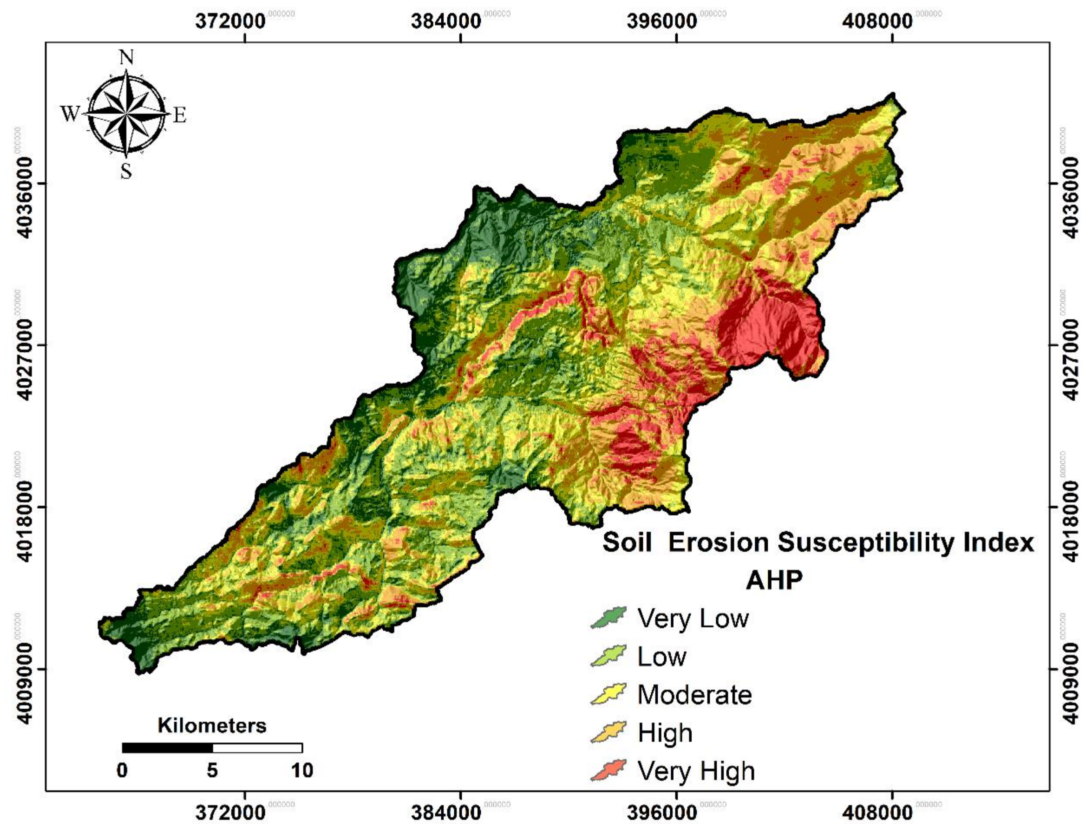


Figure 4.10: Soil erosion susceptibility map based on AHP model.

Table 4.1: Pairwise comparisons

Item Number	**Item Number** **Factors**	**1** **R**	**2** **LS**	**3** **DEM**	**4** **K**	**5** **DFR**	**6** **DFRI**	**7** **C**	**8** **TWI**	**9** **SPI**	**10** **STI**
1	**Rainfall**	1.00	2.00	3.00	4.00	4.00	3.00	5.00	6.00	7.00	7.00
2	**LS**	0.50	1.00	2.00	4.00	3.00	6.00	6.00	7.00	5.00	7.00
3	**DEM**	0.33	0.50	1.00	3.00	4.00	5.00	4.00	9.00	6.00	6.00
4	**K**	0.25	0.25	0.33	1.00	3.00	4.00	4.00	8.00	5.00	6.00
5	**DFR**	0.25	0.33	0.25	0.33	1.00	2.00	2.00	3.00	5.00	5.00
6	**DFRO**	0.33	0.17	0.20	0.25	0.50	1.00	2.00	2.00	4.00	4.00
7	**C**	0.20	0.17	0.25	0.25	0.50	0.50	1.00	1.00	3.00	3.00
8	**TWI**	0.17	0.14	0.11	0.13	0.33	0.50	1.00	1.00	4.00	2.00
9	**SPI**	0.14	0.20	0.17	0.20	0.20	0.25	0.33	0.25	1.00	2.00
10	**STI**	0.14	0.14	0.17	0.17	0.20	0.25	0.33	0.50	0.50	1.00
	Sum	3.32	4.90	7.48	13.33	16.73	22.50	25.67	37.75	40.50	43.00

Table 4.2: Standardized matrix **(1),(2)**

(1)

Item Number	Factors	R	LS	DEM	K	DFR	DFRO	C	TWI	SPI	STI	Weight
1	**Rainfall**	0.30	0.41	0.40	0.30	0.24	0.13	0.19	0.16	0.17	0.16	24.7%
2	**LS**	0.15	0.20	0.27	0.30	0.18	0.27	0.23	0.19	0.12	0.16	20.7%
3	**C**	0.10	0.10	0.13	0.23	0.24	0.22	0.16	0.24	0.15	0.14	17.0%
4	**K**	0.08	0.05	0.04	0.08	0.18	0.18	0.16	0.21	0.12	0.14	12.3%
5	**DFR**	0.08	0.07	0.03	0.03	0.06	0.09	0.08	0.08	0.12	0.12	7.5%
6	**DFRO**	0.10	0.03	0.03	0.02	0.03	0.04	0.08	0.05	0.10	0.09	5.8%
7	**DEM**	0.06	0.03	0.03	0.02	0.03	0.02	0.04	0.03	0.07	0.07	4.1%
8	**TWI**	0.05	0.03	0.01	0.01	0.02	0.02	0.04	0.03	0.10	0.05	3.6%
9	**SPI**	0.04	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.05	2.4%
10	**STI**	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	1.9%

(2)

	R	LS	DEM	K	DFR river	DFRO	C	TWI	SPI	STI	SUM
Rainfalll	0.25	0.41	0.51	0.49	0.30	0.17	0.20	0.21	0.16	0.13	2.86
LS	0.12	0.21	0.34	0.49	0.22	0.35	0.24	0.25	0.12	0.13	2.48
C	0.08	0.10	0.17	0.37	0.30	0.29	0.16	0.32	0.14	0.12	2.05
K	0.06	0.05	0.06	0.12	0.22	0.23	0.16	0.29	0.12	0.12	1.43
DFR	0.06	0.07	0.04	0.04	0.07	0.12	0.08	0.11	0.12	0.10	0.81
DFRO	0.08	0.03	0.03	0.03	0.04	0.06	0.08	0.07	0.09	0.08	0.60
DEM	0.05	0.03	0.04	0.03	0.04	0.03	0.04	0.04	0.07	0.06	0.43
TWI	0.04	0.03	0.02	0.02	0.02	0.03	0.04	0.04	0.09	0.04	0.37
SPI	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.04	0.24
STI	0.04	0.04	0.03	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.12

CI and CR worksheet : For the calculation an different equation presented before in chapter material and methods to identify the following factors of AHP approach Where CR =**0.043**

Where :**IA** = 1.49 from table 3.7.

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{10.578-10}{10-1} = 0.064$$

Where :

$$\lambda_{max} = \frac{\sum_{i=1}^{n} bi}{n} = \frac{105.78}{10} = 10.578$$

$$\sum_{j=1}^{n} bi = \frac{\sum_{j=1}^{n} Wj * aij}{Wi} = 105.78$$

4.3.3. Frequency Ratio Method:

The Frequency Ratio (FR) model was also used to map the susceptibility to erosion risk in Mellah Watershed. FR was used to characterize the relationship between the occurrence of erosion and the classes of each conditioning factor by dividing the erosion occurrence ratio by the area ratio. The obtained result showed that high R values are usually associated with high FR values. As for NDVI, it was characterized by the lowest value, which would imply that it has the least influence on erosion. Based on erosion probability index generated by the model, an erosion map was constructed. Using the natural break classification method, the study basin was subdivided into five susceptibility classes: very low, low, moderate, high and very high (see Figure 4.11). The areas with very low, low, medium and high risk represent respectively 4.1%, 9.4%, 26.8% and 29.3% of the total area. The high-risk area represents 30.4% of the total area.

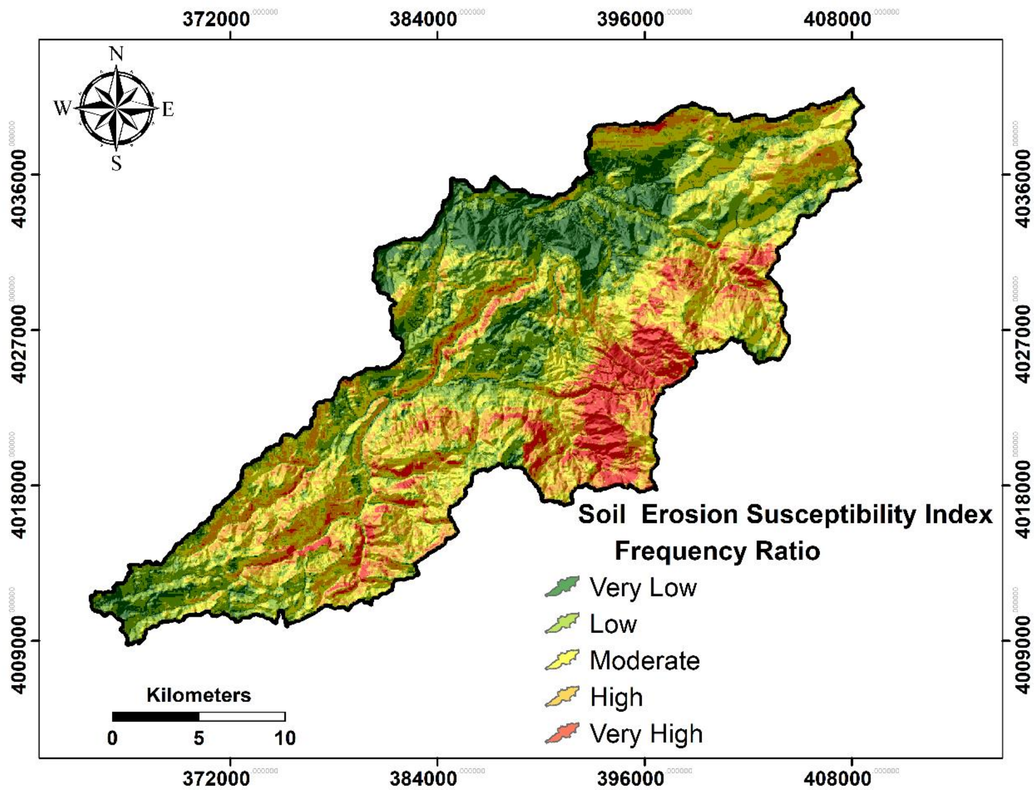


Figure 4.11: Soil erosion susceptibility map based on FR Model.

4.4. Validation of models performances:

ROC and AUC curves were adopted to validate the results given by the three proposed models. The AUC curve values for the RUSLE, AHP and FR models were 93.6%, 93.1%, and 95.7% respectively as shown in fig 4.12. RUSLE model had the highest area under the curve (AUC). At the same time, the three models used have a reasonably good accuracy to predict the sensitivity to erosion risk in the study area. The results of RUSLE, AHP and FR models are illustrated in Figure 4.12 .

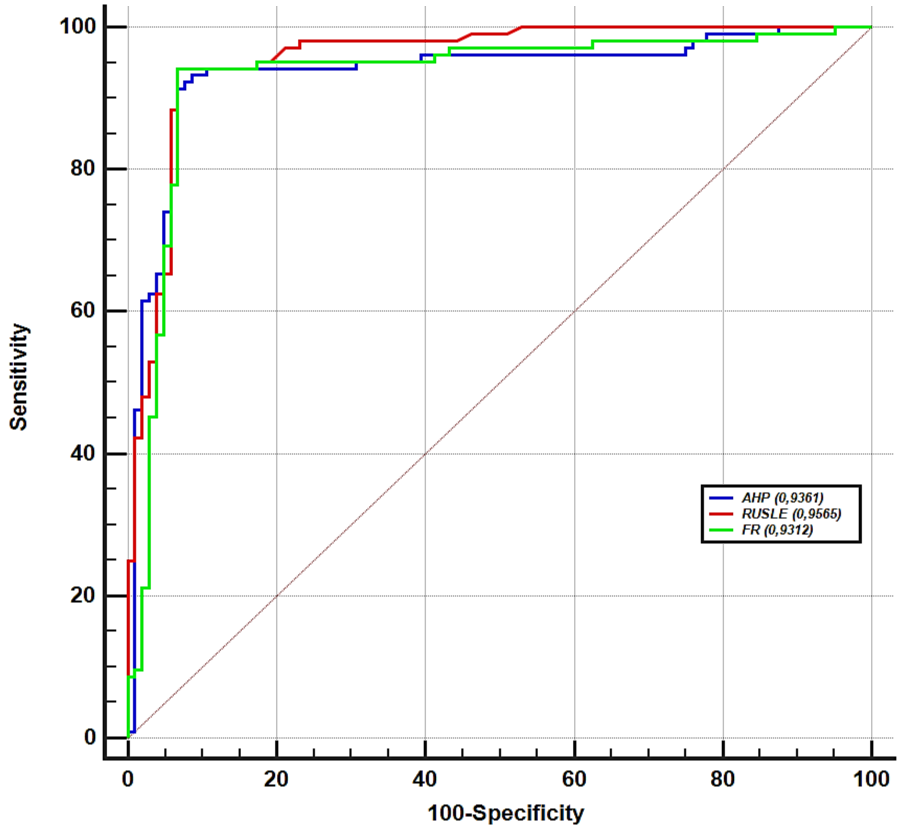


Figure 4.12: ROC curve for the three susceptibility models (RUSLE, AHP and FR)

4.5. Discussion and comparison of the results of the different models:

In this study, three different models (statistical, empirical and semi-qualitative models) were applied to map soil erosion sensitivity using a set of factors (rainfall, erodibility, slope length, crop management, land cover, topographic wetness index, stream power index) and GIS in Mellah Watershed. According to erosion susceptibility maps and using the natural break, five classes were generated: very low, low, moderate, high and very high. The results generated by RUSLE Model (shown in Fig. 4.13) indicate that 4.2% of the basin area corresponds to very high susceptibility, 13.2% in high susceptibility class, 25.3% in moderate class, 34.1% in low class and 22.4% in very low class. As for the results obtained by AHP and FR, they resulted in 10.07% and 9.8% for the very high class and 25.06% and 28.9% for the moderate class respectively. Figure 4.19 shows similar results for the three different models. Based on the obtained results, it can be concluded that more than 70% of the basin is associated with very low to moderate erosion because of dense forest and practical soil conservation measures. On the other hand, less than 30% of the basin shows high and very high erosion risk. These high erosion risk zones are especially agricultural lands located around Mechroha, Mahbouba and Kelaia Mountain. Areas associated with the highest soil loss rates (>7 Ta/ha/yr, which is the tolerance of soil erosion) are mainly located in the north, northeast, and southeast parts of Mellah watershed. This is due to the fact that it is characterized by extremely irregular and abundant rainfall, moderate natural forest and bare land, with mean steep slopes of 21% and 16%.

The results of the precipitation map show that susceptibility to erosion increases with increasing precipitation. On the other hand, the relationship between erosion location and lithology showed that erosion sensitivity is higher in areas of high K values. Moreover, the analysis of the slope map shows that there is a linear relationship between the slope increase and the susceptibility level to erosion. The steeper slope of basin influence on soil by controlling surface flow. Because where the slope high the areas are having higher vulnerability to soil erosion where also the Higher rainfall-runoff erosivity is observed in the area with high risk to erosion which shown that the rainfall has an important effect in erosion This may be due to increased precipitation in high altitudes. With regard to land cover and NDVI, the results indicate that agricultural areas are more sensitive to erosion, in particular areas close to streams. As for TWI, the results show that areas associated with high TWI values have a low susceptibility to erosion because high TWI areas are saturated soils. The human activities in the basin has a several effect to increase the soil losses risk in the basin While the Low soil erosion hazard in some area in the basin shown in area where presence of forest cover and agriculture are high.

This thesis attempts a new methodology approach to assess the soil erosion risk using RUSLE, AHP and FR techniques for the case study of Mellah Basin. According to current literature review these techniques were not previously used together for soil erosion modeling. Compared to AHP and FR techniques, RUSLE model had a slightly better prediction capability from the result given by the AUC curve (figure 4.13). The three different methods used in this study are valid for generalized planning and assessment purposes to identify areas vulnerable to soil loss. The AHP and FR are promising techniques that could be used for soil erosion susceptibility mapping using remote sensing data, especially when there is a lack of field data. They predict soil loss along the channel bed depending on rill and inter-rill erosion. The results of the proposed methodology can be considered as a decision support tool to facilitate land use planning and management, and to identify vulnerable areas. This may help reduce erosion damage in the study basin.

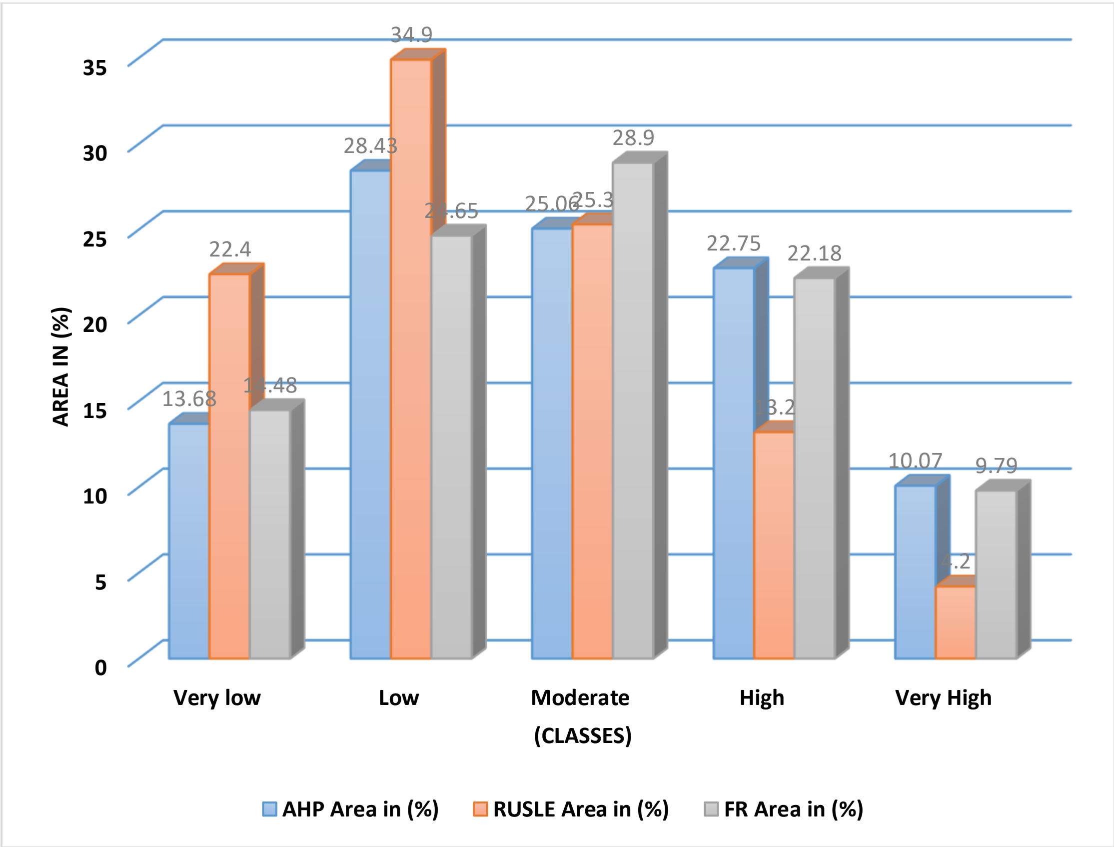


Figure 4.13: Sub-areas (%) for the different soil erosion susceptibility classes simulated by RUSLE, AHP and FR Models.

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions:

Soil erosion is a significant problem which usually results in important environmental and economic damages. It is a natural phenomenon, accentuated further by climate change and anthropogenic activities. In the present study, GIS with Revised Universal Soil Loss Equation (RUSLE), frequency ratio (FR), Analytic Hierarchy Process (AHP) methods were applied in Mellah Watershed as an example to assess the vulnerability and extent of erosion risk. In this study, the aforementioned models were used to define the spatial distribution of erosion risk by taking into account variables, such as elevation, slope, land use, drainage density, and distance from road and stream ,topographic wetness index ,stream power index and sediment transport index rainfall erosivity , crop management soil erodibilty conservation factor …... ext. .

The results obtained showed that the spatial distribution of vulnerability to erosion is highest in the upper portion of the basin due to human land-use activities (such as rapid deforestation) and site and situational variables (such as proximity to a lineament, and moderately steep slopes). Validation by 200 field observations of at-site rill erosion confirmed the satisfactory performance of the predictions of soil erosion. ROC curves were scrutinized to confirm that the models RUSLE, FR and AHP are good predictors of soil erosion susceptibility. AUC curve values were shown to be 93.6%, 93.1%, and 95.7% for RUSLE, AHP, and FR models respectively. From the results given by AUC, the three approaches show a high prediction capability, implying that the methods used in this study are valid for generalized planning and assessment purposes to identify areas vulnerable to soil loss. RUSLE, AHP and FR models were shown to be effective tools to characterize the spatial distribution of annual soil loss and delivery ratio in Mellah Basin using an integrated GIS technique. The results obtained by the different models may be used by planners, decision makers, and engineers as decision support tools for proper management and land use planning in the study watershed. The generated maps of soil erosion susceptibility can be valuable for soil conservation and sustainable planning of soil erosion-prone areas.

5.2. Recommendations:

- Soil erosion in Mellah Watershed can be simulated by applying other models, such as WEPP (Water Erosion Prediction Project), SWAT (Soil and Water Assessment Tool), and then the corresponding results may be compared with those found by the RUSLE, AHP and FR models
- The soil erosion susceptibility maps generated in this study can be used as decision support tools for proper water and soil conservation management and land use planning in the study watershed.
- The results obtained in this study may be further validated by extensive field surveys and sediment yield measurements performed at different scales.
- Sediment yield at the outlet of the basin can be related to the different causing factors and a corresponding simulation model may be obtained via the application of artificial neuron network or fuzzy logic methods.
- The methods and models used in this study to map water erosion risk in Mellah Watershed may also be applied to other watersheds.

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APPENDIX

Appendix A Different models for soil prediction

A1 Table of the different models for soil prediction

Models	Abbreviation	Name	Model references
Empirical Models	Musgrave	Musgrave Equation	Musgrave, 1947
	USLE	The Universal Soil Loss Equation	Wischmeier, 1965
	DBMF	Dendy-Boltan Method Flaxman	Flaxman, 1972
	MUSLE	Modified Universal Soil Loss Equation	Wischmeier, 1978
	SLEMSA	Soil Loss Estimation Model of Southern Africa	ELWELL, 1978
	MPSIAC	MPSIAC model	(PSAIC, 1986)
	RUSLE	the revised RUSLE universal soil loss equation, version 1 ,version 2	(Renard et al., 1997) (Foster et al., 2003)
Conceptual models	R-L M	Renard-Laursen Model	Renard and Laursen, 1975
	ERM	Ediment Routing Model	Williams and Hann, 1978
	DDM	Discrete Dynamic Models	Sharma and Dickinson,
	HSPF	Hydrologic Simulation Programme, Fortran	Bicknell,1997
Physically-Based Models	KWM	Kinematic Wave Model	Hjelmfelt, Piest and Saxton, 1975, Shirley and
	ANSWERS	Areal Non-point Source Watershed Environment Response Simulation	Beasley, 1980
	CREAMS	Chemical Runoff , Erosion from Agricultural Management Systems	Knisel, 1980
	WEPP	The Water erosion prediction project model	Lane and Nearing, 1989
	SWAT	The Soil Water and Assessment Tool	Arnold, 1993
	LISEM	The Limburg Soil Erosion Model	DE ROO,1995
	EUROSEM	The European Soil Erosion Model	MORGAN, 1998

Appendix B

B1 : rainfall data for different station (1970-2002) ANRH

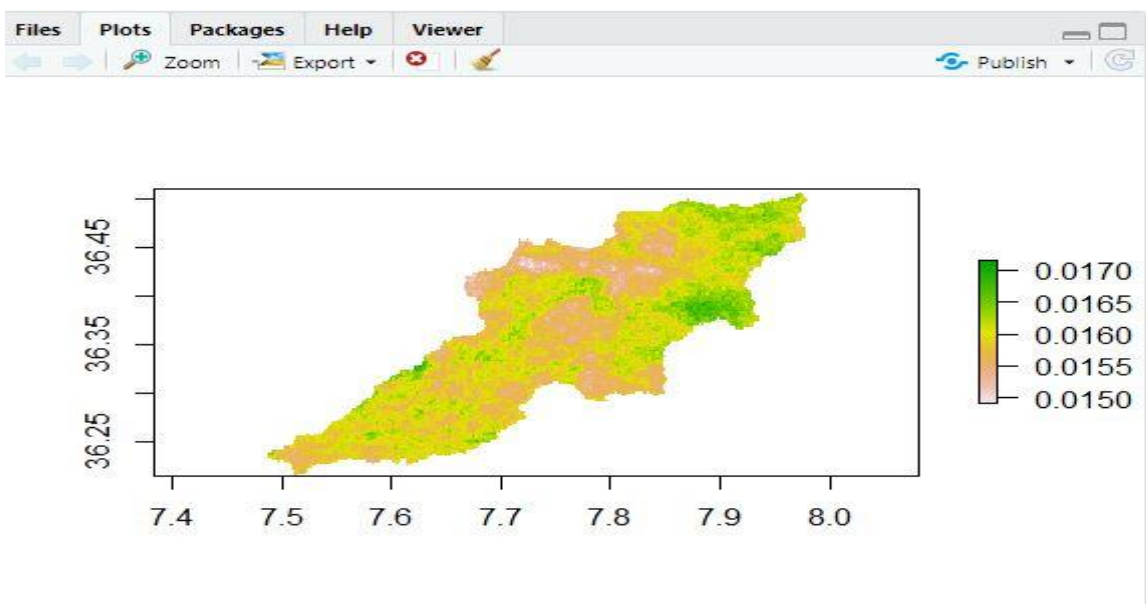
Station	Sep	Oct	Nov	Déc	Jan	Fév	Mar	Avr	Mai	Jui	Juill	Aoû	an
SOUK AHRAS	34	42.9	52.5	82.9	82.1	70.7	73.4	62.0	42.8	15.6	7.1	16.4	582.5
AIN SENOUR	39.6	70.9	109.2	143	158.23	142.9	132.9	118.6	63.79	24.9	7.73	15.02	1027.7
Chafia Barrage	59.5	66.6	85.75	131	122.5	107.13	75.06	81.23	45.52	17.2	3.04	10.7	805.6
Aïn Kerma	45.6	69.2	83.08	111.5	129.9	115.8	69.90	85.72	57.48	10.6	1.67	6.57	787.01
Lac des Oiseaux	55.6	78.9	97.15	127.3	108.6	88.66	74.98	75.40	36.76	15.7	3.51	11.3	773.87
Lac des Oiseaux village	71.2	71.4	104.6	135.5	120.8	103.3	77.5	77.7	31.9	13.4	1.9	14.2	823.4
Bouteldja	54.5	63.9	77.7	105.7	90.7	89.6	47.8	63.5	28.1	12.7	1.68	8.9	644.9
BOUCHEGO UF	30.7	45.9	56.7	63.4	70.7	61.1	69.2	56.0	45.5	13.4	2.9	11.9	527.6
MECHROHA	50.8	77.5	124.5	139.9	143.7	154.5	166.4	117.3	125.1	33.8	2.5	6.9	1142.7
CHEIKH ABDELLAH	32.9	53.3	72.8	82.9	87.9	59.6	68.8	62.2	33.9	20.7	5.1	11.7	591.7
AIN MAKHLOUF	31.6	39.8	61.9	70.3	70.3	58.9	68.2	56.2	38.8	15.5	4.8	10.9	527.3
Héliopolis	32.3	55.3	64.1	81.9	82.5	72.1	69.4	56.1	41.8	16.5	4.9	8.6	585.5
Guelma	27.4	46.1	58.9	71.6	61.2	60.5	58.8	49.6	43.7	12.6	3.5	8.9	502.8
HAMMAM N BAILS	30.6	56.5	67.4	79.5	93.9	81.3	85.5	72.5	41.9	15.3	1.1	11.0	636.56
Boukamousa	33.6	59.4	74.9	89.5	84.7	71.9	77.1	64.1	38.4	17.2	2.9	8.5	622.2

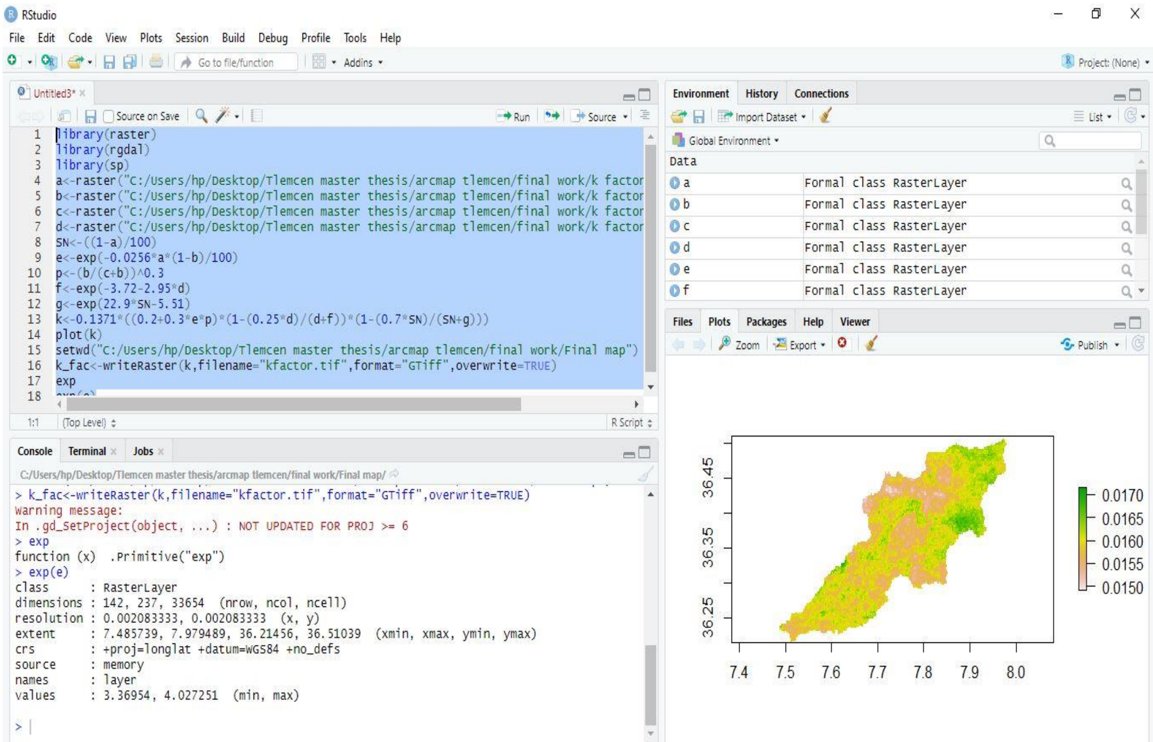
B2 : coordinate of some station and r facto values

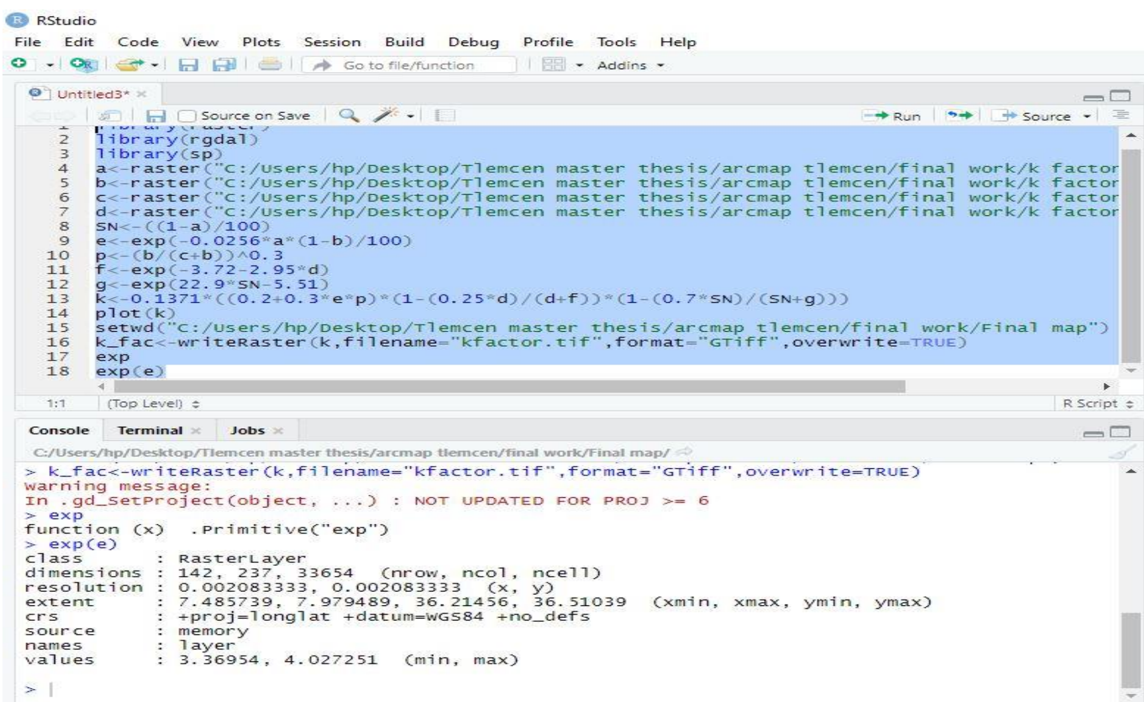
Station	X	Y	R
SOUK AHRAS	406603.51	4015784.82	128.70
AIN SENOUR	398609.42	4020010.91	340.18
Aïn Kerma	428167.84	4049311.25	155.96
Lac des Oiseaux	422401.94	4070879.11	141.57
Lac des Oiseaux village	422308.06	4069432.22	175.80
Bouteldja	429155.53	4071493.09	84.26
BOUCHEGOUF	384240.97	4035267.95	40.46
MECHROHA	395951.34	4023841.18	450.68
CHEIKH ABDELLAH	390545.53	4011563.80	138.05
AIN MAKHLOUF	342948.93	4012213.06	95.35
Héliopolis	357999.00	4041336.69	134.11
Guelma Lycée Ben Mahmoud	359592.19	4035770.79	83.46
HAMMAM N BAILS	378254.44	4020628.78	77.08
Boukamouza	388112.72	4049003.41	70.57

Appendix C

C1 calculation of K factor using R-Studio.




RStudio
File Edit Code View Plots Session Build Debug Profile Tools Help
Untitled3*
Source on Save
Run
Source
1 library(raster)
2 library(rgdal)
3 library(sp)
4 a<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
5 b<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
6 c<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
7 d<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
8 SN<-((1-a)/100)
9 e<-exp(-0.0256*a*(1-b)/100)
10 p<-(b/(c+b))^0.3
11 f<-exp(-3.72-2.95*d)
12 g<-exp(22.9*SN-5.51)
13 k<-0.1371*((0.2+0.3*e*p)*(1-(0.25*d)/(d+f))*(1-(0.7*SN)/(SN+g)))
14 plot(k)
15 setwd("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/Final map")
16 k_fac<-writeRaster(k,filename="kfactor.tif",format="GTiff",overwrite=TRUE)
17 exp
Console Terminal Jobs
C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/Final map/
> k_fac<-writeRaster(k,filename="kfactor.tif",format="GTiff",overwrite=TRUE)
Warning message:
In .gd_SetProject(object, ...) : NOT UPDATED FOR PROJ >= 6
> exp
function (x) .Primitive("exp")
> exp(e)
class : RasterLayer
dimensions : 142, 237, 33654 (nrow, ncol, ncell)
resolution : 0.002083333, 0.002083333 (x, y)
extent : 7.485739, 7.979489, 36.21456, 36.51039 (xmin, xmax, ymin, ymax)
crs : +proj=longlat +datum=WGS84 +no_defs
source : memory
names : layer
values : 3.36954, 4.027251 (min, max)
Environment History Connections
Import Dataset
Global Environment
Data
a Formal class RasterLayer
b Formal class RasterLayer
c Formal class RasterLayer
d Formal class RasterLayer
e Formal class RasterLayer
f Formal class RasterLayer
Files Plots Packages Help Viewer
Zoom Export Publish
36.45
36.35
36.25
7.4 7.5 7.6 7.7 7.8 7.9 8.0
0.0170
0.0165
0.0160
0.0155
0.0150


RStudio
File Edit Code View Plots Session Build Debug Profile Tools Help
Untitled3*
Source on Save
Run
Source
2 library(rgdal)
3 library(sp)
4 a<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
5 b<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
6 c<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
7 d<-raster("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/k factor
8 SN<-((1-a)/100)
9 e<-exp(-0.0256*a*(1-b)/100)
10 p<-(b/(c+b))^0.3
11 f<-exp(-3.72-2.95*d)
12 g<-exp(22.9*SN-5.51)
13 k<-0.1371*((0.2+0.3*e*p)*(1-(0.25*d)/(d+f))*(1-(0.7*SN)/(SN+g)))
14 plot(k)
15 setwd("C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/Final map")
16 k_fac<-writeRaster(k,filename="kfactor.tif",format="GTiff",overwrite=TRUE)
17 exp
18 exp(e)
Console Terminal Jobs
C:/Users/hp/Desktop/Tlemcen master thesis/arcmap tlemcen/final work/Final map/
> k_fac<-writeRaster(k,filename="kfactor.tif",format="GTiff",overwrite=TRUE)
Warning message:
In .gd_SetProject(object, ...) : NOT UPDATED FOR PROJ >= 6
> exp
function (x) .Primitive("exp")
> exp(e)
class : RasterLayer
dimensions : 142, 237, 33654 (nrow, ncol, ncell)
resolution : 0.002083333, 0.002083333 (x, y)
extent : 7.485739, 7.979489, 36.21456, 36.51039 (xmin, xmax, ymin, ymax)
crs : +proj=longlat +datum=WGS84 +no_defs
source : memory
names : layer
values : 3.36954, 4.027251 (min, max)

Appendix D

D1: different values used in this thesis

Parameter	Notation	Tool/Technique/Method	Author (s)
Rainfall erosivity factor (R)	***R***	$R=0.264*F^{1\cdot 5}$	formula of Arnoldus (1977)
Slope Length Factor (LS)	***Ls***	**Ls =a+b*(SL)4/5**	Formula of David (1988)
soil erodibility factor (K)	***K***	$K=0,1317(0.2+0.3* e^{\left[-0.0256*san\left(1-\frac{sil}{100}\right)\right]} * \left(\frac{sil}{cla+sil)}\right)^{0\cdot 3} * \left[1-\frac{0.25*toc}{toc+e^{(3.72-2.95+toc)}}\right] * \left[1-\frac{0.7*SN1}{SN1+e^{(22.9*SN1-5.51)}}\right]$	(Stone & Hilborne, 2012)
Crop Management Factor (C)	***C***	**C = 0.431 -0.805*NDVI**	De Jong & al.(1998)
Conservation practice Factor (P).	***P***	**Shin classification**	Shin (1999).
Slope	***θ***	***Using Arc-Gis***	
Aspect slope	$\vec{\theta}$	***Arc-GIS Proximity analysis – Esri***	Burrough and Mcdonnell (1998).
DEM	***h***	***30 m×30 m digital elevation model***	Li (2006)
Land cover	***luc***	***Arc-Gis Proximity Analysis***	Anderson (1971)
NDVI	***Ndvi***	$NDVI = \frac{NIR - RED}{NIR + RED}$	Carlson &Ripley (1997)
Stream power index	*spi*	$SPI = \alpha * \tan\beta$	The formula Moore & al. (1991).
Sediment transport index	*sti*	**STI = (m + 1)×(As/22.13) m×sin (β/0.0896)n**	Moore & Burch (1986)
Distance from river	***dri***	***Arc-GIS Proximity analysis – Esri***	Pavelsky& Smith (2008)
Distance from roads	***d**rd*	***Arc-GIS Proximity analysis – Esri***	Pavelsky& Smith (2008)
Topographic wetness index	*twi*	$TWI = \ln(\frac{\alpha}{\tan\beta})$	The formula given by Moore et al. (1991).

D2 : Morphometric, topographic and hydrographic parameters of the basin

characteristic			Symbol	Unit	Basin
Hydrographic	**Area**		**A**	Km ²	550
	Perimeter		**P**	Km	158
Topographic	**Altitude**	**Minimum**	**H** min	m	95
		Maximum	**H** max	m	1302
		Average	**H**moy	m	618
		Slope	Average slope	m/Km	0.017
Morphometric	**The compactness index**		KG	/	1.89
	The equivalent rectangle		L the length	Km	71.45
			l width	Km	7.7
	Drainage density		Dd	Km/km²	0.82
	Shape factor		Ff (R_f)	/	0.352
	Circularity Ratio (Rc) Miller		RC	/	0.276
	concentration-time		Tc	**h**	5.6
	Flow rate (velocity)		V	Km/h	12.75