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Topic: Evaluation of Erosion and Deposition process of soil by using RUSLE and GIS on Wadi El Malleh watershed, Morocco
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Software used: Idrisi Selva, ArcGIS 10.3, Google earth

PAN AFRICAN UNIVERSITY

Institute for Water and energy Sciences (Incl. Climate Change)

EVALUATION OF EROSION AND DEPOSITION PROCESS OF SOIL BY USING RUSLE AND GIS ON WADI EL MALLEH WATERCHED, MOROCCO

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DECLRATION

I hereby declare that "EVALUATION OF EROSION AND DEPOSITION PROCESS OF SOIL BY USING RUSLE AND GIS ON WADI EL MALLEH WATERCHED, MOROCCO" is in partial fulfilment of the requirement of the Master of Water Engineering in is an original work done by me and has not been submitted to any other University/Institution for the award of any other degree or diploma.

Signature ………

Ms. Asmaa Nasser Mohamed Eid

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ABSTRACT

EVALUATION OF EROSION AND DEPOSITION PROCESS OF SOIL BY USING RUSLE AND GIS ON WADI EL MALLEH WATERCHED, MOROCCO

Soil erosion by water considered as serious problem in the Mediterranean region due to the aggressive characteristics of the Mediterranean climate, the mountainous terrain, the traditional farming and other anthropogenic pressure on its land and soil.

In Morocco, food security is one of the major problems which face numerous challenges including climatic uncertainties and growing population. Demand for food is increasing rapidly at the same time that available natural resources are increasingly degraded. Huge land areas are used for agriculture purposes daily which lead to deforestation. Deforestation, poor land use such as construction of buildings on agricultural land and uncontrolled techniques for cultivation are the main factors of soil erosion.

Erosion affects about 13 million ha of cultivated land in Morocco and lead to huge loss of water storage capacity, about 50 million cubic meters annually. These challenges increased the need to better understand how to control soil erosion through assessment and mapping of the areas of level of risk and use soil erosion models to highlight the need of soil coverage by active green vegetation and residue and enhance watershed management.

The present study was scheduled to assess soil erosion in Wadi El Malleh watershed using Geographical Information System (GIS) and the Revised Universal Soil Loss Equation (RUSLE) together with the SEDIMENTATION model to evaluate the annual average soil loss and sedimentation rate from Wadi El Malleh watershed which located in the Northern-Fez city (Morocco), and covers an approximate area of $34km^2$.

First of all, the RUSLE and SEDIMENTATION models were combined with GIS technologies to predict the spatiotemporal distribution of erosion and deposition rates under different land uses. The different land uses were assessed using the Google Earth image, which has taken in 2013. The image was first geo-referenced and projected into (Datum: Merchich North Morocco); the Moroccan coordinates system and classified by Idrisi Selva software. The use of static RUSLE model allowed the estimation of soil loss. Then the results applied in the deposition modelling calculations to assess the spread loss of soil downstream by Sedimentation model.

By comparing the static and dynamic soil losses, the resulted annual average soil loss rates related to land cover type is between (0.760 to 294.41 t/ha/y) which consider a minimum annual average soil loss value in the urban areas followed by (5.726 t/ha/y) in the irrigated agriculture areas and a maximum annual soil loss value reported at the bad land. The watershed topographically characterizes by steep slopes which resulted in vulnerability to severe erosion at most of the watershed areas and caused sediment deposition. The values of the annual soil deposition rates resulted from the SEDIMENTATION model are (81.86 t/ha/y) in bad land and (-19.19 t/ha/y) in irrigated agriculture areas and (-13.66 t/ha/y) in reforestation land (the negative values means deposition). Taking into consideration the erosion and deposition processes at the same time, the low values of soil erosion calculated by the RUSLE model can be obtained. The results of this study recommends that further studies should be undertaken to identify the suitable soil and water conservation measures to eliminate soil degradation process for the whole region.

KEYWORDS: Net soil erosion; RUSLE; SEDIMENTATION; Wadi El Malleh; Morocco.

Résumé

EVALUATION DU PROCESSUS D'ÉROSION ET DÉPÔT DES SOLS EN UTILISANT LE SIG ET LE MODELE RUSLE DANS LE BASSIN VERSANT DE L'OUED EL MALLEH, MAROC

L'érosion hydrique des sols est considérée comme grave problème dans la région méditerranéenne en raison des caractéristiques agressives du climat méditerranéen, les terrains montagneux, l'agriculture traditionnelle et d'autres pressions anthropiques sur ses terres et sols.

Au Maroc, la sécurité alimentaire est l'un des principaux problèmes qui posent de nombreux défis, y compris les incertitudes climatiques et la croissance démographique. La demande alimentaire augmente rapidement en même temps les ressources naturelles disponibles sont de plus en plus dégradées. De vastes terrains sont utilisés à des fins agricoles ce qui conduisent à la déforestation. La déforestation, l'utilisation des terres pauvres, l'extension urbaine sur les terres agricoles et les techniques incontrôlées de culture sont les principaux facteurs d'érosion des sols.

L'érosion affecte environ 13 millions d'hectares de terres cultivées au Maroc et conduit à une perte énorme de la capacité de stockage d'eau, environ 50 millions de mètres cubes par an. Ces défis ont augmenté la nécessité de mieux comprendre la façon de contrôler l'érosion des sols par l'évaluation et la cartographie des zones de risque et d'utiliser des modèles d'érosion des sols pour mettre en évidence la nécessité de la couverture du sol par la végétation verte et par les résidus et d'améliorer la gestion des bassins versants.

La présente étude est prévue pour évaluer l'érosion des sols dans le bassin versant de l'oued El Malleh en utilisant le système d'information géographique (SIG) et le modèle de perte en sol: RUSLE (Équation Universelle de perte en sol Révisée ainsi que le modèle de déposition (SEDIMENTATION) pour évaluer le taux net annuel de perte de sol dans le bassin versant de l'Oued El Malleh qui est situé au Nord de la ville de Fès (Maroc), et couvre une superficie approximative de 34 Km^2.

Tout d'abord, les modèles RUSLE et sédimentation ont été combinés avec les technologies SIG pour prédire la distribution spatio-temporelle de l'érosion et de dépôt sous différentes utilisations des terres. Les différentes utilisations des terres ont été évaluées en utilisant l'image de Google Earth, prise en 2013. L'image a d'abord été géoréférencées et projetée dans le system de coordonnées marocain (Datum: Merchich Nord du Maroc); et classée par le logiciel Idrisi Selva. L'utilisation du modèle RUSLE statique a permis l'estimation de la perte de sol. Ensuite, ces résultats utilises dans les calculs de modélisation de dépôt afin d'évaluer la perte nette de sol.

En comparant les pertes de sol statiques et dynamiques, les moyennes des taux annuels de perte de sol liées au type de couverture du sol varient entre 0,760 et 294,41 t / ha / an. La valeur de perte de sol minimale annuelle moyenne se trouve dans les zones urbaines (5.726 t / ha / an) et dans les domaines de l'agriculture irriguée. Les fortes valeurs trouvent dans les badlands. Le bassin versant se caractérise topographiquement par des pentes abruptes qui ont abouti à la vulnérabilité à l'érosion sévère dans la plupart des versants et provoque aussi le dépôt de sédiments. Les valeurs des taux nets annuels de l'erosion du sol sont données par le modèle SEDIMENTATION (81,86 t / ha / an) les badlands et (-19,19 t / ha / an) dans les zones agricoles irriguées et (-13,66 t / ha / an) dans terres de reboisement (les valeurs négatives signifient des valeurs de dépôt). Prenant en considération les processus d'érosion et de dépôt en même temps, les faibles valeurs de l'érosion du sol calculées par les modèles RUSLE et Sédimentation peuvent être obtenus. Les résultats de cette étude recommandent que d'autres études doivent être entreprises pour identifier des mesures appropriées de conservation du sol et de l'eau pour éliminer les processus de dégradation des sols pour toute la région.

MOTS-CLÉS: Erosion nette du sol; RUSLE; SÉDIMENTATION; Oued El Malleh; Maroc.

Contents

List of Figures

List of Tables

CHAPTER ONE

1 INTRODUCTION

1.1 Overview

Soil erosion is a natural phenomenon, occurring throughout the world by the action of water or wind. It causes soil productivity loss as a result of plant removal, fertile topsoil loss, rooting depth reduction, and plant nutrients removal. There are many factors enhance the erosion such as: climate change, ecological factors, land use, steep slope and land cover (Gitas et al., 2009).

The 20th Century has evidenced spreading in the soil erosion phenomenon. Mainly 85% of the world land degradation is related to soil erosion. About 17% reduction in the production of crops has been noticed after the end of the Second World War (Shi et al., 2004).

By looking at the economic situation in Morocco, soil conservation and erosion control practices are important for enhancing the current crop production levels. From the other hand, identifying the sensitive areas help to direct the funds needed for erosion control. Erosion estimation models are useful tools in planning for long term land management under agricultural and natural conditions. It is difficult to find a model that deals with all erosion forms, but research is yet progressing and progressively concentrates on very detailed topics of soil erosion and deposition processes as well as its modelling.

The Revised Universal Soil Loss Equation (RUSLE) model, although it was developed to estimate water erosion in mild climate, it is easier to adjust to tropical climate than other models. RUSLE model is an empirical based, developed from the Universal Soil Loss Equation (USLE) (Wischmeier et al., 1978); however it is more advanced and has databases not exceeded in the USLE model (Renard et al., 1995). RUSLE is prepared to apply at the runoff plot or single hill-slope scales. The RUSLE model allows estimation of soil erosion annual rate average for specific area for identifying targeting management techniques, cropping systems and erosion control practices.

Sediment is the main output of soil erosion due to runoff of surface water. It deposited around the water courses in areas where the flow rates of the river are low and physical characteristics are proper for deposition. Hence sediments are outcomes whatever time soil is subjected to rainfall power and water flowing even if the location is rural or urban.

1.2 Statement of the Problem

Food security is one of the world major problems which face numerous challenges including growing population, and climatic uncertainties (Mohtar et al., 2012). Demand for food is increasing rapidly at the same time that available natural resources are increasingly degraded. In addition to that huge land areas are used for agriculture purposes daily (Eid et al., 2016). Deforestation, bad land use such as construction of buildings on agricultural land and uncontrolled techniques for cultivation are the main factors of soil erosion (Biard & Baret, 1997).

It is well known that erosion spreading is one of the major factors responsible for soil degradation. Soil erosion happens through the entire world, especially in the humid / sub-humid highlands regions (Oldeman, et al., 1990). Soil erosion is a significant environmental issue to soil productivity and sustainable agriculture capacity as it can affect soil characterstics such as: removing the topsoil which minimize soil volume and water holding capacity, increasing run-off which remove plant nutrients, reducing infiltration, limiting the water access for the crops and increasing the impact of flooding (Yang et al., 2003).

Soil erosion is the master economic and environmental issue that faces the dam reservoirs sustainability in the Rif Mountains. There are four types of erosion factors:

- Water erosion
- Wind erosion
- Physical erosion

- Chemical erosion (Dahan et al., 2012).

Mainly all Moroccan lands observe water erosion and around 2 million hectares of its agricultural land are water eroded. In Wadi El Malleh watershed only, an annual soil loss reaches to more than 41 ton per hectare, per year. Hence the challenges are to involve policy and to provide soil conservation practices to mitigate soil degradation in these areas.

These challenges increased the need to better understand how to control soil erosion through assessment and mapping of the areas of level of risk and use soil erosion models to highlight the need of soil coverage by active green vegetation and residue and enhance watershed management. (Melesse & Jordan, 2002).

Therefore the purpose of the project is to utilize GIS and Idrisi Selva techniques to evaluate RUSEL's parameters to predict the annual average soil loss as a result of erosion from entire Wadi El Malleh watershed.

1.3 Study Area

Wadi El Malleh watershed study area is located in the northern part of Fez city of Morocco in the boundary between Saiss plain and the southern Rif wrinkles (Tghat and Zalagh); it is surrounded by the Wadi Mekkes watershed from the north and west, to Saiss plain from the south and Wadi Sebou valley from the east. It extends over an area of $34km^2$.

1.4 Objectives

Specifically, the objectives of the project are:

- To utilise the application of GIS and RUSLE to compute soil loss.
- To estimate the amount of soil loss from Wadi El Malleh Watershed using Idrisi Selva and ArcGIS 10.3.

1.4.1 Sub-objectives

- To describe and identify the six parameters of the RUSLE model equation.
- To support the RUSLE model using the Sub-Rating Method.

- To evaluate the DEM to determine slope length and steepness of Wadi El Malleh watershed.

1.5 Organization of the Project

The project consist of (6) major chapters. In chapter one, the following topics are reviewed: overview on soil erosion, statement of the problem, objectives of the research, and project organization outlines. Chapter two covers scientific literature on the study including the following headlines: overview of erosion, soil erosion and deposition phenomena, review of soil erosion models, soil erosion modeling using the Revised Universal Soil Loss Equation (RUSLE) and input data for RUSLE model, Geographic Information System (GIS) and Remote Sensing support for RUSLE model.

Chapter 3 describes Wadi El Malleh watershed site, along with various data needed to analyze soil erosion in Wadi El Malleh watershed. Wadi El Malleh watershed, topography, soil types, land-use types, precipitation and runoff are illustrated for the application of soil erosion modeling. Precipitation data will be utilized to predict the rainfall-runoff erosivity factor, and soil type data will used to estimate soil erodibility factor, and land-use type data will be utilized to estimate the cover management factor. Also, DEM will be used to calculate the slope steepness and slope length factor.

Chapter 4 represents the technical analyses that have been done in the field and laboratory in order to make the data needed in the RUSLE and SEDIMENTATION models available. The permeability measurement, the measurement of soil texture to predict various particle sizes (sand, silt or clay). The Humidity of the watershed, the bulk density, soil porosity and the organic matter measurements are important in the calculation of the soil erodability factor.

Chapter 5 describes the basic concepts, the procedure of the RUSLE model, in addition to the methodology to estimate six parameters, and parameter prediction of the RUSLE model. Based on the rainfall storm events, DEM, soil type map, and land cover map, six parameters of the RUSLE model will be estimated and verified as to the reasonability of the parameter estimation results. And chapter 6 is a conclusion and recommendations on the study.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Overview of Erosion

In the past century, natural erosion caused by geological events and erosion due to human activities was widely recognized (Vanoni, 1975). Nowadays, this opinion is obsolete. When analysis done to the global volume erosion which estimated annually as a result of different factors, In1994, Hook came up with a conclusion that the most important geomorphic factor that presently shaping the Earth’s surface are humans, Despite the fact that, others such as (Valdiya, 1998) observed that mountainous geological erosion, like the one which occur in the Himalayas, holds on producing massive volumes of sediment.

The differentiation between the human induced erosion and the one that processes naturally is difficult generally. In spite of, several erosional processes such as landslides and gullying seem natural; they might have been aggravated or triggered by infiltration of irrigation, overgrazing or deforestation (McArthur et al., 2008).

2.1.1 Natural (geologic) erosion

The major reasons of the natural erosion are chemical decomposition, weathering, long term action of gravity, wind, water and ice and the tectonic uplift (McArthur et al., 2008). In 1994, Summerfield and Hutton pointed out that soil erosion rates are varying around the world over time and regions; by looking at major drainage watersheds widely. Controlling the natural erosion can be necessary for some regions, although it is not easy due to large distribution of areas affected by type of erosion or another between many owners. The rates of natural erosion can increase fast due to uncontrolled land use, and poor project designing of water use. There are many factors of natural erosion:

2.1.1.1 Climatic factor

Without atmospheric precipitation there is no water erosion, so water is the lifeblood of erosion. In 1960, Fournier has studied the relationship between soil erosion by water and weather conditions, and concluded that the rains act in a significant way on soil loss.

In the Mediterranean area, where rainfall is varying, but mostly low. It falls between November and March, during which agricultural soils are bare. During the rest of the year prevails a dry period (El Aroussi O. , 2013)

2.1.1.2 Topographical factor

The topography is a determining factor in the erosion process. The magnitude of this process is accentuated by the slope. Indeed, on an easily erodible geological substrate, the driving force on the soil particles increases with the slope.

The slope influences the importance of erosion but the existence of erosion and heavy runoff on gentle slopes indicate that by cons not need a steep slope to trigger this phenomenon: the action enough rain there (Fournier, 1967)

The slope is involved in the erosion phenomena due to its shape, its inclination and length.

- Form of the slope

For concave slopes, soil losses are largest next to the point upstream of the slope and decrease to the point where the inclination becomes critical. The inclination is critical as soon as sediments begin to form. For convex slopes, erosion gradually increases downstream slope.

- Slope gradient

When the inclination of the slope increases, the kinetic energy of rainfall remains constant but transportation is accelerating downwards because the kinetic energy of runoff increases and outweighs the kinetic energy of rain when the slopes exceed 15%. As the slope increases, the inclined surface to the rain is even greater than the slope is high. When the slope is low, runoff energy is not sufficient to carry away the relatively coarse sand particles

- Length of slope

In principle, the steeper the slope, the more runoff accumulates, gathers speed and energy and erosion intensifies. The influence of slope length on runoff is even less clear. It is sometimes positive, sometimes negative, sometimes zero, according to the prior humidity and the surface condition of the ground (Wischmeier, 1966).

2.1.1.3 Vegetation cover factor

Soil erosion is strongly controlled by the vegetation upon which the production of biomass. This is the primary factor in protecting the soil against erosion. The action of the vegetation is manifold:

- Intercepting drops of rain allows the dissipation of kinetic energy, which decreases in a great extent the effect "splash".
- Its root system holds the soil in place and it promotes infiltration.

Incidentally, transpiration of the plant by drying the soil increases its capacity of infiltration. Its development slows surface runoff. The organic matter intake improves soil structure and cohesion.

2.1.1.4 Lithological factor

The various rock types and structures provide a valuable indication of the infiltration capacity of areas occupied by the rocks and soils and as a result the amount of soil that can be eroded (FAO, 1990). Low infiltration of outcropping rocks indicates that a large amount of water flows, therefore, a large amount of soil can be washed away.

(Wischmeier et al., 1971) could show that the intrinsic soil erodibility can be determined from their analytical characteristics. The latter defines a monogram that can calculate the factor "K" erodibility, which is based on:

- Rate of organic matter;
- The texture;
- Of the structure;
- Permeability;
- The percentage of fine lands and coarse elements.

2.1.2 Human-induced or accelerated erosion

Human activities are the main reason of the quickened of the soil erosion. The human activities impacts start slowly but can cause many changes in sediment production, deposition rapidly. The intensity of soil erosion by water is significantly affected by human activities that increase or decrease in the land. There are many reasons for quickened erosion including repeated fires and illegal logging deteriorate existing forests, this strongly encourages runoff and leads eventually to severe erosion (Benchaabane, 1997). The cultivation of soil makes it more susceptible to erosion, given the high sensitivity of its physical properties to the types of land use. (Lahlou, 1994) showed that the destruction of the soil is quite common following the agro-pastoral level operations clay and loam soils, which reduces the ability of infiltration and runoff becomes excessive. Note that the effect of the human factor cannot be separated from other effects, but evaluation is complex.

2.2 Soil Erosion and Deposition Phenomena

Erosion is the process of topsoil removing from a specific area and deposition of it to new depositional zone because of the action of water, ice, wind, gravity, animal grazing and human activity (FAOSTAT, 2014). Human activities can enormously disturb the natural phenomena of the earth's surface. However, the erosion process occurs naturally but human activities such as agriculture and deforestation can disturb its rate. According to the U.N. Millennium Ecosystem Assessment, approximately 40% of the world's agricultural land is seriously degraded (Sonneveld & Dent, 2009).

Water erosion is the main focus of the research, it happens naturally as a result of rainfall. The velocity of the runoff flow depends on the land slope, the soil characteristics, and the vegetation cover. These characteristics that affect water erosion are demonstrated in the following figure (Ecology, 2016).

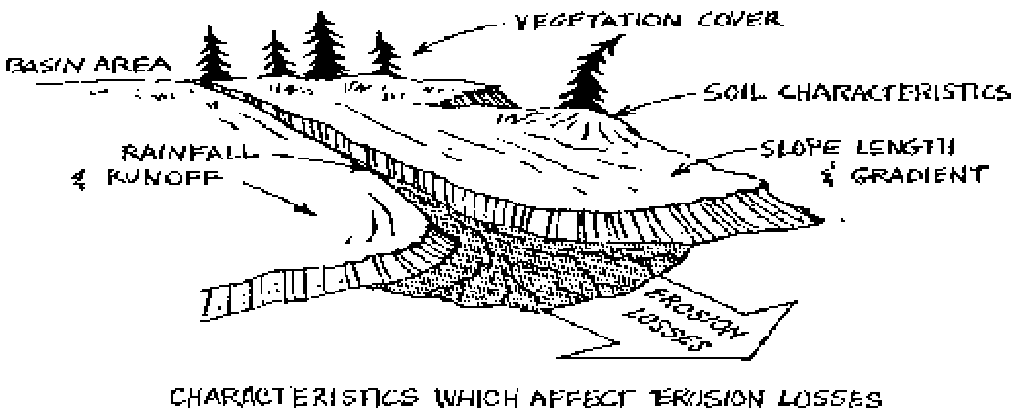

Figure 2-1: Soil Erosion (Water Quality Guide, 2016).

Soil loss has negative impacts on agricultural production of crops, infrastructure and water quality (Schertz et al., 1989). The topsoil removal by water comes as follows:

- Rill erosion
- Gully erosion

- Sheet erosion (Inter-rill erosion)
- River erosion
- Stream bank erosion

2.2.1 Rill and gulley erosion

It is the soil removal by concentrated flow in small streamlets or channels. Detachment in a rill strongly depends on the hydraulic conditions and soil properties. The rill erosion occurs if the flow is higher than the resistance of soil to detachment and if the sediment in the flow is lower than the amount the load can transport. As a result of low infiltration rates and the rainfall occurrence, the surplus water accumulates very slowly along land surface and into the rill. As the collected water continues, the water depth, kinetic energy, velocity, and soil particle increases.

When rainfall intensity exceeds the infiltration capacity of the ground surface, it is first formed puddles; then these puddles communicate through streams of water and when these streams of water have reached a certain speed, 25 cm per second from (Hjulstorm, 1935) they acquire clean energy that will create a limited erosion in space by flow lines. This energy is not dispersed over the entire surface, but is concentrated on lines of greatest slope. Rill erosion is an indication that the runoff was held has gained momentum and kinetic energy capable of cutting into the ground and carries particles bigger and bigger: not only clay and silt as erosion selective panel, but gravel or pebbles and even blocks (Roose, 1994).

Linear erosion is expressed by all linear depressions that cut into the surface of the ground following various shapes and sizes (claws, ditches, ravines, etc.). In fact, linear erosion occurs when the sheet flow is organized, it hollow shapes more and more profound. There is talk of claws when small channels have a few centimetres deep ditches when channels exceed 10 cm deep but still erasable cultivation techniques. Indeed, on a watershed or a parcel, erosion ditch in succeeding sheet erosion by concentrating runoff in the hollows. At this stage, the channels do not converge but form parallel streams. The rill evolves into gulley erosion

2.2.2 Sheet erosion

It occurs as a result of soil compaction or swing and when the rain water does not infiltrate but flows on the surface. It is characterized by a uniform removal and transport of thin layer of soil by the impact of splash erosion raindrops and overland flow through runoff with no visible furrows or scratches. This phenomenon is observed on gentle slopes, where water cannot focus the size of the removed soil depends on the kinetic energy of soil texture and raindrops. The runoff notices when the rainfall intensity increases over the soil infiltration capacity, this known as Hortonian flow (Bodoque et al., 2005).

After the storage spaces of soil depression are filled and at the end of the soil saturation process, the runoff starts. Initially it is counted to be small erosion as it move a thin sheet of soil and it has low kinetic energy which is not able to damage soil particles or transport them. If rain continues, the water depth will increase and the amount of soil accumulated downslope increase in size as a result of kinetic energy increase which becomes able to remove soil particles and transport them.

From the other hand, the rain water accumulated on the soil surface decrease the intensity of splash erosion as it reduces the forces of raindrops. Therefore, the soil erosion caused by runoff and raindrops is a complex process which requires specific analysis. The sheet erosion evolves into rill erosion.

Sheet erosion depends on:

- The maximum intensity of rainfall that can cause runoff
- Duration of rainfall and / or humidity percentage before the rain
- The kinetic energy of rain which moves the particles and carries it out easily
- The nature and land use
- The slope and exposure to slopes

The signs that characterize the sheet erosion are the appearance of pale patches to the most stripped places and lift stones to the surface. The consequences of sheet erosion are:

- Levelling of the soil surface.
- Skeletonization of surface horizons.

- Stripping resulting in the appearance of clear tasks (Whiting et al., 2001).

2.2.3 River erosion

It takes place specifically in rivers in which regular water flow occurs with different rate. River erosion is more active in water channels which have minimal proper conditions for drainage discharge or those of smaller catchment (Yearke, 1971).

2.2.4 Stream bank erosion

It is a natural part of the stream stability process, results in the loss of fertile soil from the bottomland of the stream bank, takes place due to damaging stream side vegetation or changes in land use for development or agriculture purposes. Understanding the management of streamside vegetation and stream dynamics is required to address the stream bank erosion problem.

Many scientific searches have shown that soil erosion is directly impacted by climate change (Mullan et al., 2012). Precipitation amount is the most direct reason affecting soil erosion rate after which comes the intensity impacts of climate change on soil moisture and plant biomass, and plant growth and production rates due to increases in CO2 concentrations among others (Zhang & Nearing, 2005).

2.3 Review of Soil Erosion Modelling

Soil erosion modelling use mathematical equations requires many data measurements as well as physical description of the erosion phenomena. The data measurements are important to estimate the inputs in the model equation and to legalize the model. The physical description utilises to identify the main variables which formulate the quantitative mathematical relations of the erosion process. Regarding to the soil which we rely on for food, carbon balance, clean water, row material for infrastructure and buildings; huge efforts are undertaken to develop universally applicable soil erosion and deposition models (Merritt et al., 2003).

Much research and articles have been made about the risks of deterioration of agricultural land, simultaneously with the development of the world population. Different approaches have been developed to assess the risk of water erosion. However, we can distinguish qualitative approaches based on expertise and quantitative approaches.

Scientists around the world are not only interesting in determining the amount of soil loss caused by soil erosion using different models but also to predict the impact on the population around the affected areas. Erosion models are used to determine the processes of detachment, transport and deposition of eroded soil. Various soil erosion models have been developed in the recent decades. Generally, there are different types of models: such as empirical models, conceptual models, and physically-based models (Renschler & Harbor, 2002).

- Empirical models:

The simplest models; require less data than conceptual and physically-based models. Empirical models are statistical in nature; they works on representing natural processes using empirical observations from the environment (Nearing et al., 1994). Empirical models are generally used to model soil erosion complicated processes, furthermore useful for identifying the sediment source.

Table 2-1: Examples of Empirical Models.

Model Name	**Model Reference**
Musgrave Equation	Musgrave, 1947
USLE (the Universal Soil Loss Equation)	Wischmeier, 1965
Dendy-Boltan Method Flaxman Method	Flaxman, 1972
MUSLE (Modified Universal Soil Loss Equation)	Wischmeier, 1978
Soil Loss Estimation Model of Southern Africa (SLEMSA)	ELWELL, 1978

- Conceptual models:

They are a combination of empirical and physically-based models. Conceptual models are utilised to model quantitative and qualitative processes in the watershed (Merritt et al., 2003).

Table 2-2: Examples of Conceptual Models.

Model Name	**Model Reference**
Hydrologic Simulation Programme, Fortran (HSPF)	Bicknell,1997
Renard-Laursen Model	Renard and Laursen, 1975
Sediment Routing Model	Williams and Hann, 1978
Discrete Dynamic Models	Sharma and Dickinson, 1979

- Physically-based models:

They are used to provide the mechanisms needed to control erosion (Sharma & Correia, 1987). Initiations have been developed in the last decades to change the methodology of soil erosion models from empirical approaches in the 1970s to physically-based and conceptual approaches in the recent time. Most of these models take into account other parameters such as land use, landform, soil type, vegetation cover, climate, and topography to calculate soil loss (Zhang et al., 1996).

Table 2-3: Examples of Physically-Based Models.

Model Name	**Model Reference**
Kinematic Wave Model	Hjelmfelt, Piest and Saxton, 1975, Shirley and Lane, 1978, Singh and Regal, 1983
The Water erosion prediction project model (WEPP)	Lane and Nearing, 1989

Areal Non-point Source Watershed Environment Response Simulation (ANSWERS)	Beasley, 1980
The European Soil Erosion Model (EUROSEM)	MORGAN, 1998
Chemical Runoff , Erosion from Agricultural Management Systems (CREAMS)	Knisel, 1980
The Limburg Soil Erosion Model (LISEM)	DE ROO, 1995
The Soil Water and Assessment Tool (SWAT)	Arnold, 1993

2.3.1 The approaches based on modelling

- The Musgrave equation (Musgrave, 1947) :

It is an equation which estimate soil loss from individual simple slopes as a result of sheet erosion using input data as climate, soil, land cover, land use, slope degree and expected half an hour rainfall intensity per 2 years. The equation is:

$$ER = FR \times \left(\frac{S}{10}\right)^{1.35} \times \left(\frac{L}{72.6}\right)^{0.35} \times \left(\frac{P_{30}}{1.375}\right)^{1.75}$$

Where:

- E is the sheet erosion in ton/acre/year.
- F is the soil factor, in ton/acre/year.
- R is the cover factor.
- L is the length of land slope in feet.
- P_{30} : is the maximum half-an hour, 2 years rainfall in inches.

The Musgrave equation has been modified and used together with the USLE to study the present soil erosion and predict the worst condition in case of absence of vegetation cover and estimate the least erosion in case of high potential of vegetation cover in many regions. The modification of the equation was by replacing the rainfall index and K-factor of USLE by the rainfall adjustment factor and F-factor of the Musgrave equation to be as the following equation:

$$E = KCR \times \left(\frac{S^{1.35}}{10}\right)^{1.35} \times \left(\frac{L}{72.6}\right)^{0.35}$$

Where:

- E is sheet erosion in ton/acre/year.
- K is erosion rate in ton/acre/year/unit rainfall index.
- C is cover factor.
- R is rainfall factor.
- S is land slope in per-cent.
- L is length of slope in feet.

The Musgrave equation is an acceptable equation to be used for comparative analysis of sheet erosion especially when no real erosion measurements have been done for the region (Muhammad, 2013).

- The Universal Soil Loss Equation (USLE), (Wischmeier & Smith, 1958):

It became the most used equation for calculating inter-rill and rill erosion. It is an empirical erosion model which was designed to compute soil loss in specific conditions from agriculture fields annually. The equation as follows:

$$A = RKLSCP$$

Where

- A is the average annual soil loss, ton/ha/year.
- R is a measure of the erosion forces of rainfall.
- K is soil erosion factor.
- L is slope length factor.
- S is slope steepness factor.
- C is crop management factor.

- P is conservation practice factor.

It has been noticed that the USLE applicable only for field application (sheet erosion) but if it applied for sediment yields of watersheds, most of its factors has to be modified (Williams B. , 1972). Due to the limitations that faced the model as lake of accuracy in some places and disability to provide physical separation and sediment transport processes which hinder the method; development of the USLE technologies continued since then and led to a modified revision MUSLE (Modified Universal Soil Loss Equation) (Wischmeier & Smith, 1978). In addition, this model places a high value on topographic factor relative to other factors. This model is established for conditions existing circles in the US which means that this model cannot be applied as in Mediterranean countries (Comary & Masson, 1964)

- Hydrological Simulation Program, Fortran (HSPF):

Is a conceptual model, was developed in the early 1960 as the watershed model of Stanford and modified by Fortran who added the water quality processes in 1970's, the EPA and USGS modified the model again in 1980's by developing the pre and post-processing algorithm and since then the modification was still progressing until the recent version of the model which also developed in 1990's by USGS.

HSPF used to estimate surface runoff, water content, soil moisture and the stream flow hydrograph. Furthermore, it computes the sediment destruction and transport. The HSPF data requirements are continuous rainfall records and other meteorological data such as air temperature, wind, solar radiation, cloud cover, snowmelt, groundwater recharge and related parameters that can describe land area and reservoirs. The output of the model can be flat file or printed tables. The model has been applied globally on large scale and small scale regions and it performed well (Bicknell et al., 1997).

- Areal Non-point Source Watershed Environment Response Simulation (ANSWERS):

It is designed to estimate soil erosion inside a watershed by subdividing the watershed into a uniform grid of square cells. The ANSWERS assumes slope, soil characteristics, vegetation cover and land use are uniform inside each cell and the differences between the cells allow the model to estimate the soil erosion (Beasley et al., 1980). ANSWERS-2000 is the current version of the ANSWERS model; it is a continuous simulation model was tested on two watersheds in Georgia, Watkinsville and resulted well in computing dissolved phosphorous losses, sediment, sediment-bound TKN, nitrate, and runoff in both watersheds. In addition, the groundwater component was added to the model version (Bouraoui et al., 1997).

- The Chemicals, Runoff and Erosion from Agricultural Management (CREAM):

It is physically-based model which has been developed by the U.S department of agriculture-agricultural research service (Kinsel, 1980). CREAM model has been used to estimate sediment yield, particle size, soil moisture, infiltration, percolation, evapotranspiration, peak runoff and runoff volume. It is a model for agricultural best management practices assessment to control pollution and has been tested globally in many regions and performed well, however some limitations have been noticed as it is not suitable for regions with un-uniform cropping and soil, and not suitable for estimating runoff volumes over small scale periods, day and month (Smith et al., 1980).

- The Agricultural Nonpoint Source Pollution Model (AGNPS):

It is physically-based model that has been developed by the U.S department of agriculture-agricultural research services for watershed best management practices assessment to control pollution. AGNPS utilises to estimate sediment yield, transport of nutrients, soil erosion and runoff volumes through agricultural watersheds (Young et al., 1987).

The required data for AGNPS model are divided into GIS data and watershed data, soil type, wind speed, daily precipitation, temperature, dew point temperature and land use within the region. One of the AGNPS advantages is that it perform well in watershed analysis however, the model limitations comes when it applied to non-US watersheds. Some studies have been done to adapt the model to the real world however it needs high level of computer skills of the researcher.

The Morsa catchment of south-eastern Norway was chosen for the study due to the availability of the required data for the analysis such as land use, topography, meteorology, soil types and water quality. Generally, the disadvantages of the model are requirements of huge amount of data and time consuming specially during the initial stage (Eriksson, 2003).

- The Water erosion prediction project model (WEPP) (Lane and Nearing, 1989):

It was developed by the United States Department of Agriculture-Agricultural Research Services (USDA-ARS) to replace the USLE. The WEPP is process based model, which specifically applied to predict soil and deposition apart from soil loss average (Tiwari et al., 2000). The WEPP is continuous simulation model, which simulates a lot of physical processes such as runoff, sediment transport; infiltration and vegetation cover which are important in soil erosion (Pieri et al., 2007). The data required in the WEPP model are soil characteristics, slope, climate, land use (Renschler, 2003).

- The Limburg Soil Erosion Model (LISEM):

It has been developed between 1991 and 1994. It is a powerful physically based model used to simulate the sediment transport and hydrological processes during and after a single rainfall event in a small catchment's with about 10 to 300 ha. LISEM is utilised also to compute the effects of soil conservation measures and the current land use. Initially the model was made for the province of south Limburg, the Netherlands, to estimate the effects of soil conservation and land use on the soil loss.

The LISEM model has been applied by the local government, the Utrecht University, the Free University of Amsterdam and the Altera University of Physical Geography which studied 3 catchments of Limburg for 5 years. The model depend on the user knowledge of what she/he is doing as it does not show if a related variable such as surface roughness or infiltration variables should be change or not. The input data required for the model are GIS Raster including catchment maps, soil surface maps, erosion maps and vegetation maps and the outputs are GIS Raster including erosion maps, hydrograph and time series data (Offermans & De Roo, 1995).

- The soil and Water Assessment Tool (SWAT), Arnold (1993):

It is a physically-based model, computationally efficient and able to do continuous simulation over long term. The SWAT model has been designed to estimate the impact of land use and management on sediment and water in a given watershed. The SWAT required data are temperature, soil temperature, land management, hydrology, weather, vegetation cover, nutrients, and pathogens (Bouslihim et al., 2016). The SWAT model has been used in the entire world and well performed in many researches in watersheds with various climate characteristics (Zhang et al., 2008).

2.3.2 The qualitative approaches based on expertise

(De Pley et al., 1989) established the risk of erosion map of West soils of Europe using methods based on expertise. Several experts marked the areas where the erosion process was very important. The weakness of this approach is that the researcher has not defined the criteria for defining these areas (Yassoglou et al., 1998).

In 1992 the European Union adopted the CORINE method to estimate the risk of water erosion in the Mediterranean region. This model, based on points assigned to related factors to the angle of the slope (8 classes), vegetation cover (9 classes), the capacity of soil to crusting (4 classes) and erodibility (3 classes), helped draw up the erosion risk maps for 17 European countries and 2 African countries. But it is important to note is that these cards have not been completed to test the relevance of the applied model. Moreover, there is no current information on the accuracy of their results.

In 1998, estimation of soil erosion in France based on a method of some expertise. To do this, they studied the factors contributing to water erosion: vegetation cover (9 classes), the soil's ability to form a crusting (4 classes), the slope angle (8 classes) and erodibility (3 classes). The advantage of the method is that it takes into account the different types of erosion that can be found in cultivated areas or in the mountains (Montier et al., 1998).

In 1998, the National Institute for Agricultural Research (INRA), developed a model MESALES to assess the hazard of water erosion in France. The developed model was improved later, following several tests at different scales and in an approach based on a decision tree to define qualitative classes of erosion hazard. The researchers grouped the factors contributing to erosion in several classes: 9 land use classes, sensitivity to the formation of slaking crusts 4 classes, soil erodibility 3classes and slope with 8 classes. The combination of these factors led to establish the map of the sensitivity to erosion. The latter was to cross with the intensity and volume of rainfall, which helped to set the hazard map for each season. This model simulates the evolution of risks in France and updates various data, also allows the comparison between different regions as well as a seasonal mapping of erosion hazards.

The advantage of the decision tree is that it is simple to build and classifies a large number of samples into classes. Despite the advantage of this method, however, and if the new data should be integrated, it would be necessary to build a new decision tree. This means that this model will not be easily adapted if a new criterion would be considered important after the validation of the model (Cerdan et al., 2006).

In 2003, some researchers developed an approach, the MEH-SAFER (of Water Erosion Model in Semi-arid relief of Forte Energy backgrounds) to study the risks of water erosion in the watershed of Lake Laka-Bolivia, which is a semi-arid high energy relief. The developed model is based on the crossing of the potential runoff and topographical vulnerability on satellite images from multiple sources and digital terrain models to map the topography of the surface. For this model, the researchers used a generalized DTM: A less crude MNT gives more details for the study, adding that this model does not quantify the losses eroding (Quattara et al., 2003).

In 2003, some researchers evaluated the accuracy of three models for estimating water erosion of soil, USLE, INRA and PESERA to validate the estimates of the hazard of soil erosion in Europe. This estimate is from reservoirs to measure the sediment volume carried in different watersheds. After defining the catchment area of each tank and determined sediment deposits of the ratio coefficient, this method was applied in different European countries such as Spain, Italy. These researchers found that the models can provide a satisfactory estimate in some European countries (Belgium and the Czech Republic) but not in others (Spain and Italy). The reasons come from the remaining uncertainty about the data sedimentation in reservoirs and not taking into account all the processes of production and transportation of materials (Van Rompey et al., 2003).

In 2004, other researchers have established the hazard mapping of erosion of the Aisne department from a model "expert system type" and using the geographic information system. The various factors that contribute to soil erosion by water were crossed, to map the erosion hazard. The seasonal change was highlighted in this approach to better study the interaction between the soil cover and climate. The model used is the same model established by INRA in 1998 to assess the hazard of water erosion in France; the researchers used more precise data as to the DTM which was established from remote levels of curves five meters. In this study the researchers took into account the role of the organic material to study soil susceptibility to erodibility and crusting (Le Bissonnais et al., 2004).

In 2006, some expertise, have adapted a model to estimate the hazard of erosion risk in the Mediterranean context: the example given was the Languedoc-Roussillon region. The approach used for mapping the hazard of erosion risk is an approach expertise based on the combination of the following factors: land use, crusting, slope erodibility and rainfall intensity, and made with a System Geographic Information. This approach, inspired by the model of the IFEN / INRA developed by (Le Bissonnais et al., 2004), was used to map the erosion hazard areas, specifically takes into account the stony rate, organic matter content and iron and soil texture (Antoni et al., 2006).

Now, there are much more availability of erosion models that can be applied to many cases and able to answer a wide range of the question however the progress is yet undertaken in order to get more developed models.

2.4 Soil Erosion Modeling Using the Revised Universal Soil Loss Equation (RUSLE) and Input Data for RUSLE Model

The Universal Soil Loss Equation is an outcome of many years of analysis and studies which began by the National Runoff and Soil Loss Data Center in 1930s. In 1985, at the meeting held at U.S. department of agriculture-agricultural research services, improvement of the erosion simulation models was considered as a direct need in the conservation plane. One of the outcomes was a decision to enhance the Universal Soil Loss Equation (USLE) that has been developed by (Wischmeier & Smith, Predicting rainfall erosion losses, 1978) by revising and adding recent information to: the soil erosivity factor, the weather factor, slope (length and gradient) and cover management factor in order to continue its modification since then (Renard et al., 1997).

In 1992 the revised USLE version was released as the Revised Universal Soil Loss Equation (RUSLE). The RUSLE is empirically-based equation which assumes that the detachment, transport and deposition are related to the sediment content of the flow (Pitt, 2007). It has been derived from huge amount of field data, addressees the sheet and rill erosion and simulate climate change, land use change that could affect soil loss. The RUSLE equation is a worldwide accepted as reliable, effective and accurate method for identifying the spatial pattern of soil erosion within large regions which make it possible to identify the most impacted catchments or areas by soil loss. The RUSLE equation as follows:

$$A = R.K.L.S.C.P$$

Where:

- A is the computed annual soil loss in (ton/ha/year).
- R is the rainfall-runoff erosivity (climate erosivity) factor in MJ.mm/ (ha.hr.year).
- K is the soil erodibility factor in ton.ha.hr/ (MJ.mm.ha)
- L is the slope length factor.
- S is the slope steepness factor.
- C is cover management factor.
- P is the supporting practices factor.

The RUSLE equation can be divided into two parts according to its variables: a) management variables include the P and C factors which may change over time and b) the environmental variables include the R, S, K and L factors which mainly stay constant over time (Hickey et al., 2005).

2.4.1 R factor:

Climate involved in the process of erosion, by means of precipitation and to a lesser degree by the temperature. Precipitation in the form of rain is the main cause of the destruction of soil and sediment transport by runoff aggregates. (Roose, 1977) showed that there is no relation between the height of rainfall, runoff and soil loss. It is the intensity of rainfall is a factor highly correlated with erosion.

Generally, represent the rainfall-runoff erosivity in units of (MJ.mm/ha.hr.year). It is derived from analysing precipitation data and erosion index (EI) summation average for each storm annually. The EI is the erosion force of a specific rainfall. The product of the kinetic energy and maximum 30-minute intensity are directly proportional to the storm losses from rainfall. The R factor represents the EI summation average of the storm for the recorded period divided by the number of years. The R factor indicates the amount of peak and rainfall intensity which are the most important parameters to calculate storm erosivity (Williams et al., 1996).

To calculate the rainfall-runoff erosivity factor using the original method described by (Wischmeier & Smith, 1978) and by (Renard et al., 1997) precipitation records of at least 20 years is required, with temporal resolution less than or equal to 30 minutes are strictly required to accommodate apparent cyclical rainfall patterns. However, in many parts of the world like in Central Africa, this kind of information is difficult to obtain and its processing is time-consuming and hardworking. Determining the R factor by Wischmeier and Smith

Maintaining constant soil conditions, slope, slope length and vegetation on several experimental plots Wischmeier and Smith (1978) showed the statistical treatment of results that sheet erosion and rill is proportional to aggressiveness of the rains. The value of the R factor is proportional to two characteristics of the rain:

- Responsible kinetic energy of detachment of soil particles under the impact of raindrops.

- The maximum intensity in 30 minutes of rainfall which expresses the effect of runoff.

The R factor is expressed by the equation:

$$R = E \, . I_{30}$$

Where

- E = kinetic energy of rainfall (MJ / ha)
- I30 = maximum intensity of rainfall in 30 minutes in mm / hour.

- The rainy kinetic energy is given by the following formula:

$$E = 210 + 89. \log 10 \, I$$

Where

- I = rain intensity.

In Morocco, the calculation of the R-factor by the direct method Wischmeier and Smith cannot be applied in some regions that are equipped with a rain gauge that instantly records the rain. Most stations record only the average daily. The data series of precipitation available from the relevant services are mostly monthly and annual averages. A number of authors have developed alternative formulas that are based on the data available to determine the climatic aggressiveness (El Aroussi O. , 2013).

Fournier (1960) in (Heusch et al., 1970) found that there is a kind of parabolic relationship between specific global erosion and climatic aggressiveness factor that called C. This factor is defined by the following formula:

$$C = \frac{{P_i}^2}{P}$$

Where:

- Pi is the average precipitation of the wettest months.
- P is the annual precipitation.

In 1967, Kalman worked on the basin of Sebou and observed a linear correlation between the logarithms of the product $(P.P_{24}^2)$ and has developed the following formula:

$$R = 143.\log(P.P_{24}^2.10^{-6}) + 89.7$$

Where:

- A is the average value of climatic aggressiveness. foot-ton / acre.mm / 1000 hours
- P is the average annual precipitation (mm / year)
- P_{24} is the average maximum 24-hour rainfall in the period (mm / day), For R Newton / hour multiplied by 0.6706

In 1980, Arnoldus worked in Morocco and also has established the following relationship:

$$R = 1.735.10\left[1.50.log\sum_{i=1}^{12}(\frac{P_i^2}{P}) - 0.8188\right]$$

Where:

- A is average value of the annual index of aggressiveness

- Pi is the monthly precipitation
- P is the annual Precipitation

In 1987 Rango, Arnoldus and changed the formula of Arnoldus (1980) that became:

$$logR = 1.74 \times \log\left(\sum (\frac{P_i^2}{P}\right) + 1.29$$

Where:

- R is the coefficient of average erosivity of rain in (MJ.mm/ha/.hour).

For the watershed of Wadi El Malleh, the Rango and Arnoldus (1987) used for the calculation of climatic aggressiveness factor. For several reasons:

- The encouraging results obtained by the aforementioned authors.
- The diversity of Moroccan communities where this formula has been applied.
- This formula was developed taking into account the characteristics of the Moroccan climate.

2.4.2 K factor:

Ideally, represent the soil erodibility of a given soil in units of (ton.acre.hour/hundreds of acre.foot.ton.inch). The K factor is the susceptibility of soil to be eroded by water. It is a measure of the rate of soil loss per erosion index for a given soil. Soil structure, texture, organic matter and permeability measure the erodibility of a given soil. Values for K range according to the soil characteristics as example: soils high in clay or sand typically have low K values from about (0.05 to 0.15) for clay-soil and about (0.05 to 0.2) for sandy-soil due to low run-off, loamy-soil has moderate erodability from about (0.25 to 0.45) and soils high in silt typically has higher K values from about (0.45 to 0.65).

The nomograph of soil erodibility is a broadly used tool for measuring K values, but it does not work for some soils. The organic matter of the soil decreases erodibility but applying the nomograph of the K factor of an organic matter more than 4% is not advocated by RUSLE model or NRCS. The soil permeability affects run-off and hence, affects K. The soil structure affects the soil resistance to detachment and infiltration (Jones et al., 1996). Modifying the K-factor for RUSLE involved updating guides that enable the user to identify soils where the nomograph is not working and measure K using alternative ways. Globally, Erodibility data have been reviewed, and an equation has been derived to estimate K as an average diameter of the soil particles. Soils with less than 10% of rock fragments were only considered (Renard et al., 1991).

- Determination of the factor K under standard conditions

Many authors have ensured that all the factors that control erosion in the USA are equal to 1 except the climatic aggressiveness. The recorded loss is only the result of climatic aggressiveness (factor R).

For Wischmeier and Smith, the parameters that affect the soil erodibility are:

- The percentage of silt plus fine sand (0.002 to 0.10mm).
- The percentage of coarse sand (0.01 to 2 mm).
- The percentage of organic matter
- The soil structure.
- The permeability of the soil.

The relationship between these parameters according to (Wischmeier & Smith, Predicting rainfall erosion losses, 1978) is:

$$100K = 2.1M^{1.14}10^{-4}(12 - a) + 3.25(b - 2) + 2.5(c - 3)$$

Where:

- M = (fine sand % + silt) (100 –clay %).
- a = organic matter %.
- b = permeability code.
- c = structure code.

The permeability values and structure are expressed as numbers corresponding to codes. For these figures the structure listed from 1 to 4, they indicate increasing degrees of structuring. For the permeability figures are from 1 to 6 and correspond to a descending drainage.

Table 2-4: Structure classes, (Jahn et al., 2006).

Code	Class of structure
1	Very fine/thin <1
2	Fine/thin 1-2
3	Medium 2-5
4	Coarse/thick 5-10
5	Very coarse/thick >10

Table 2-5: Permeability classes.

Code	Class of permeability
1	Fast drainage > 60mm/h
2	Fast/moderate drainage 20-60 mm/h
3	Moderate drainage 5-20 mm/h
4	Moderate/slow drainage 2-5 mm/h
5	Slow drainage 1-2 mm/h
6	Very slow drainage < 1mm/h

In 1971, Wischmeier established a nomograph which facilitates assessment of the K factor. This is a chart that reads the value of the K factor when the following data are available:

- Percentages silt + sand (0.002 - 0.1mm)
- Percentage coarse sand (0.1 - 2 mm)
- Percentage of organic matter,
- Codes of structure and permeability class.

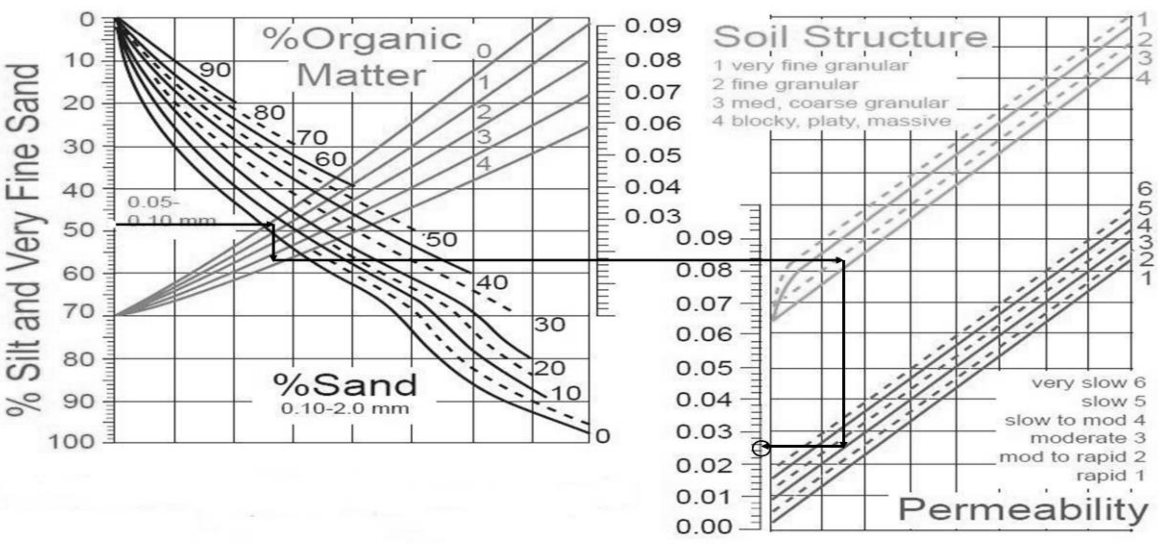

Figure 2-2: Soil erodibility nomograph, Source (Wischmeier et al., 1971).

2.4.3 LS factor:

The slope length factor L and the slope steepness factor S together are referred to the slope factor and represent the topography of a given region on RUSLE soil erosion modelling (Renard et al., 1991). The LS calculation method which used by the USLE is as follows:

$$LS = \left(\frac{\lambda}{22.1}\right)^{m} (65.41\, sin^{2}\,\theta + 4.56 \sin\theta + 0.065)$$

Where

- λ: is the horizontal plot length.
- θ is the slope angle.

- m is a variable plot exponent adjusted to match terrain and soil variants, and its range from 0.5 to 0.2

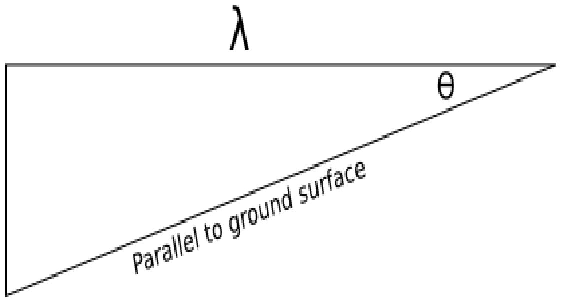

Figure 2-3: Illustration of the values used in the LS.

In the RUSLE model the L and S factors are calculated separately and can be generated from a DEM (Digital Elevation Model) within ArcGIS. (Pelton et al., 2015)

2.4.3.1 L factor:

The L factor represents the effect of slope length on soil erodibility. It is unit-less factor. The slope length is the horizontal distance from flow origin to the point where deposition begins (Wischmeier & Smith, 1978). The values of soil loss are not affected by the slope length, and the slope length range of about 10% is not important on most slopes. In 1987, McCool provided new relationship to determine slope length for cropping land and its being used by RUSLE

According to the following schematic profile, the slope length L is the ratio of soil loss from the field of slope length to that from a 72.6 ft length under otherwise identical conditions.

$$L = \left(\frac{X_h}{72.6}\right)^m$$

Where:

- X_h is the horizontal slope length
- m is a variable slope length exponent, which is related to the ratio of rill to inter-rill erosion by the following equation:

$$m = \frac{\varepsilon}{1 + \varepsilon}$$

ε is calculated for conditions when the soil is moderately susceptible to both rill and inter-rill erosion using the following equation:

$$\varepsilon = \frac{\sin\theta}{0.0896\ [3.0(\sin\theta)^{0.8} + 0.56]}$$

Where

- θ is the slope angle.

2.4.3.2 S factor:

The slope steepness is unit-less factor defined as the slope gradient to the ratio of soil loss from the erodible surface gradient on a 9% slope. Slope steepness affects soil loss more than slope length. Soil erosion increase by increasing slope steepness due to the velocity increases. The RUSLE’s slope steepness factor depends on data from slopes range from 0.1 to 18%. There were many relationships which describe the slope steepness impact on soil loss which resulted from runoff and rainfall on hill-slopes but in 1987, McCool provided new relationships which are being used by RUSLE to describe the slope steepness impact as a linear function of the sine of the slope angle.

RUSLE uses two functions:

$$S = 10.8\ \sin\theta + 0.03\ when\ \ \sigma \leq 9\%\ ,$$

$$S = 16.8 \sin\theta - 0.5\ \ when\ \ \ \sigma > 9\%$$

Where

- S is the soil loss at slope with angle θ
- θ is the slope angle
- σ is the slope gradient in %. (Nearing , 1997)

2.4.4 C-factor:

The cover and management factor is a unitless factor which represents the soil cover characteristics. It represents the effect of soil cropping, practices of management and soil-distributing activities on soil erosion rates. The C-factor is mostly used in USLE/RUSLE models to estimate values of soil loss ratio as well as it reflects the best management options to reduce erosion. Values for C are a weighted average of soil loss ratios which can vary following the concept of deviation from a standard according to the given time and conditions. As example if C is about zero that reflects a very well-conserved soil and if C is about 1.5 that reflects high soil sensitivity to rill erosion (Williams et al., 1996).

The C factor can be calculated using the following formula:

$$C = SLR.EI$$

Where

- C is the crop and management factor
- SLR is the soil loss ratio (ratio of soil loss under specific practice during crop stage to soil loss on a similar field of bare soil)
- EI is the erosivity index

$$C = \frac{(SLR_1EI_1 + SLR_2EI_2 + \;\; \cdots SLR_nEI_n)}{EI_t}$$

Where

- C is the average annual or crop value.
- SLR_1 is the value for time period 1.
- EI_1 is the percentage of the annual or crop EI occurring during that time period.
- N is the number of periods used in the summation
- EI_t is the summation of the EI percentages for the entire time

The Soil Loss Ratio (SLR):

Takes into account the relative and compounded impact of crop canopy, tillage practices, crop residues and residual soil quality for particular crop. SLRs will vary throughout the year and for different crop-stages.

The Erosivity Index (EI):

It is the proportion of annual erosive rainfall occurring during each crop-stage. The key variables, under which C factor considerations are grouped, are as follows:

Table 2-6: C factor related variable (Nearing et al., 2005).

Variable	Calculation components
Surface residue	- % cover after planting - % cover after harvest - Residue effectiveness - Residue weight after planting, harvest - Type of erosion process (rill, inter-rill or combination)
Land use residuals	- Use of forages - Effects of forage crop for up to two years after crop change accounted for - More detailed information on prior land use (including tillage, biological activity, crops consolidation, forage and crop effects over time)
Crop canopy cover	- Crop type - Crop/vegetation height - Yield - Quality of growth - % cover at maturation - Crop stage periods (15 day intervals)
Tillage	- Type - Number of passes - Timing
Crop rotations	- Sequence of crops - Number of crops
Additional variables	- Adjustment for soil moisture depletion possible - Antecedent soil moisture taken into Consideration for low rainfall areas
Incorporated residues	- Type of tillage - Residue management

2.4.5 P factor:

The support practice factor is a unitless factor represents the external and general supporting effects of agricultural practices such as: cross-slope farming, terraces, contouring strip cropping, and buffer strips on the average erosion rate annually. P is the ratio of soil loss which not reflects the surface conditions impact on the amount and rate of water runoff and flow path as well as it give various scenarios of best management options in order to reduce the amount of erosion. The P factor function in RUSLE model is to represent the practices of conservation on a given area such as land imprinting, ripping, root plowing and pitting. Some of the P-factor measurements depend on slope (Renard et al., 1991).

In 2001, Blazczynski proposed that the RUSLE model not only utilize to evaluate soil loss vulnerability for agricultural regions but also for non-agricultural regions like: roads and trials. It also can estimate regional level analysis of soil erosion, such as the state of Oregon which used the GIS applications of the RUSLE to estimate soil erosion vulnerability of the state in order to compute the most susceptible areas to soil erosion (Hickey et al., 2005).

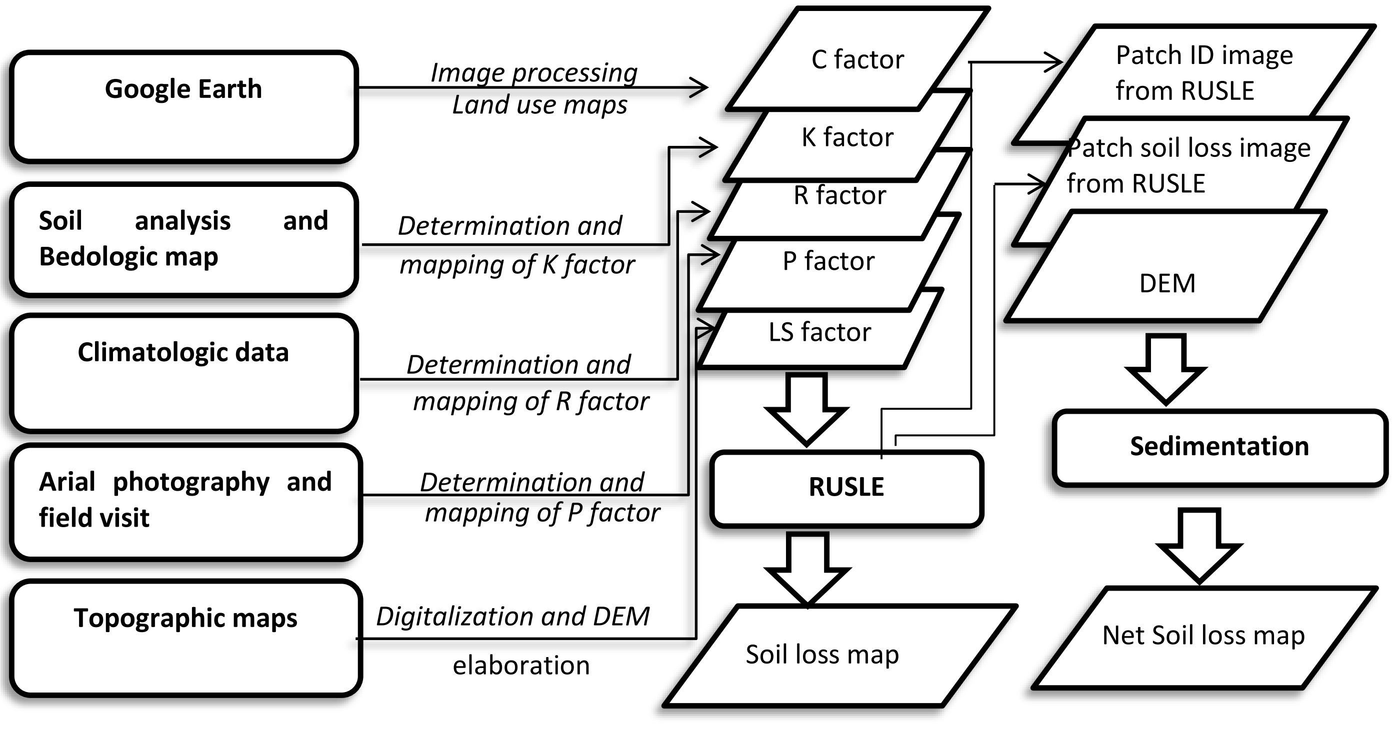

Figure 2-4: Schematic of the methodology, (El Garouani et al., 2009).

2.4.6 The RUSLE model limitations

The RUSLE model limitations are categorized in 3 main parts:

- The location of the research:

Firstly, the RUSLE model was purposed for disturbed and agricultural regions and its input data based on disturbed slopes and croplands that is why the results of the soil erosion analysis for non-agricultural area are incompatible. Soil scientists and agricultural-industry specialists and engineers totally approve that annual soil loss estimations should not be utilized non-agricultural uses. Generally, this is due to in non-agricultural regions, the cover management factor and practices management factor cannot be defined correctly which will hinder the RUSLE equation to give the right values.

- The mathematical calculations:

In the RUSLE equation, the environmental variables do not change with time, but the management variables might change with time which makes it difficult to get an accurate and current management variable (Hickey et al., 2005). The RUSLE equation based on multiplying 6 inputs together, many calculations are required for each input, which increase the possibility of presence of errors in the resulted soil loss values (Shi et al., 2002).

- The scale:

The RUSLE model is not able to provide watershed scale sediment yields and the model output has to be treated as qualitative not quantitative since the erosion processes are mainly operated by small features (Breiby, 2006).

- The hill-slope :

In the RUSLE model, the hill-slope lengths range from 35 ft to 600 ft should not be used on slope greater than1000 ft and hill-slope gradients range from 3% to

35% should not be used on hills-lopes with gradients greater than50% (Matherne, 2006).

2.5 Geographic Information System and Remote Sensing Support in RUSLE Model

The Geographic Information System (GIS) is a computerized system use software, hardware, and geographic data to identify relationships, and analyse data which can help people to visualize problems and find solutions to it. It can also collect, store, manipulate, manage, and analyse geographic information data in analysis where the geographical location is needed (ESRI, 2005).

GIS is a combination of statistical and geo-statistical analysis, database that allows the user to provide geographic information for definite locations on the earth (El Aroussi O. , 2013). GIS applications in flood mapping and management and hydraulic and hydrologic modelling began only in 1990s; although GIS have been applied in many other environmental fields since 1970s (Moore et al., 1991).

In geomorphological analyses and DEM, representing the elevation in terms of topographic surface is essential (Schmidt et al., 2003). Soil erosion is influenced by the spatial vegetation, topography, land-use and soil properties. GIS is a very helpful system for decision making as it can accord with large number of spatial data and interact with soil erosion modelling process to solve erosion problems. There are some advantages of applying GIS in the soil erosion models such as the following:

- The ability to maintain input data to simulate different frameworks rapidly. GIS implement spatial overlays and time consuming geo-referencing through its spatial and analytical function to provide the model input data at different spatial scales (Sharma et al., 1996).
- The potential of presenting the outputs of the model. Visualization can be used to present and animate series of model output images through space and time. Thus, visualization allows objects to be observed from all

external spectacles, and to highlight data through visual representations able to be manipulated (Tim, 1996).

- The possibility to simulate the catchments with many details as it can use large number of catchments with many pixels (De Roo, 1996).

GIS applications in soil erosion prediction are increasing daily. There are various examples for the integration of GIS with erosion models: De Roo (1989) linked ANSWERS with GIS; Mitchell (1993) combined AGNPS with GIS technology (Kim, 2006).

First of all, The USLE model was developed to estimate long term annual erosion average. Kinnell (2000) indicated the available procedures of determining the slope length factor. The Chaudiere basin in Canada has been studied by Julien and Frenette (1987) to examine the ability of the USLE to be applied to large watersheds. They added a correction factor to the large areas to extend the ability of the USLE. Molnar and Julien (1998) compared soil erosion rate of different size areas to and they found that large size areas underestimate soil erosion because of the effects of the terrain slope. They recommended that a correction factor is required to maintain the underestimation of soil erosion loss in the macro-scale. (Kim, 2006).

The GIS software used in this study is ArcGIS10.3. Because of satellite image treatment capabilities, the software Idrisi Selva 17.02 is coupled with ArcGIS 10.3 to implement RUSLE factors, Sedimentation model to model the soil erosion rate in the Wadi El Malleh watershed.

CHAPTER THREE

3 SITE DESCRIPTION AND DATA SET

3.1 Wadi El Malleh Watershed Description

Wadi El Malleh watershed located in the northern of Fez city (Morocco), in the boundary between the southern-Rif winkles (Zalagh Mountain and Tghat Mountain) and the Sais basin. It is surrounded by the Wadi Mekkes watershed from the north and west, to Saiss plain from the south and Wadi Sebou valley from the east. It covers an approximate area of $34km^2$.

Figure 3-1: Wadi El Malleh watershed.

The bio-climate is semi-arid with a rainfall annual average of 320 mm. the altitude is ranging from 250 to 870 meters. Geologically, the area is still characterized by large outcrops of Triassic series of red clay. Several soil types were identified such as: vertisoils, fersialitics, calcimagnesics and poorly evolved soils.

Based on data from Fes-Sais Climate and Temperature station, the temperature in the study area is about $17.76^{\circ}C$ on annual average. The precipitation rate is changeable yearly with annual average of 484.75 mm and monthly average of 40.36mm. Specifically, July is the driest month and December is the wettest month. According to the aridity index calculation, the study area has semi-arid climate.

Geologic formations along the watershed are extremely divers. Different depositions of different ages have been detected: at Zalagh Mountain, Jurassic formations are Liassic dolostones, Liassic limestones and marls. The tertiary formations consist of marly sand and conglomerate and Plio-Quaternary conglometric formation. Tghat Mountain’s structure has similarities to that of Zalagh Mountain. Its formations are marls and conglomerates of Plio-Quaternary age and molasse of Miocene age (Chalouan et al., 2006).

3.1.1 The shape of the basin

The watershed is characterized by the following parameters: hypsometric curve, the slope index, pool shape, perimeter, compactness index.

The perimeter (P) and the surface (A) of Wadi El Malleh watershed are automatically measured using the GIS software ArcGIS10.3 after scanning the boundary of the watershed of two topographic maps of Fez and East Fez West (scale 1:25 000).

The compactness index accepted by hydrologists to characterize the shape of the watershed is the index of compactness GRAVELIUS which is the ratio of perimeter of the pool to that of a circle of the same area.

If A is the area of the basin in km² and its perimeter P in km, the K_c coefficient is given by the following formula:

$$K_c = 0.28 \frac{P}{\sqrt{A}}$$

- If K_c = 1, we have a square pool.
- In our case P = 27.64 Km, A= 33.85 Km^2 and K_c= 1.33
- The basin of Wadi El Malleh is not stretched.

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

Let (L and l) the length and width of the rectangle, and A and P the perimeter and area of the basin slope. It has, according to the above definitions:

$K_c = 0.28\frac{P}{\sqrt{A}}$ $\quad$ $2(L + l) = P = \frac{K_c\sqrt{A}}{0.28}$ $\quad$ and $A = L + l$

$L = \frac{K_c\sqrt{A}}{1.12}\left[1 + \sqrt{1 - \left(\frac{1.12}{K_c}\right)^2}\right]$ $\quad$ and $\quad$ $l = \frac{K_c\sqrt{A}}{1.12}\left[1 - \sqrt{1 - \left(\frac{1.12}{K_c}\right)^2}\right]$

In the case of Wadi El Malleh watershed:

L = 10.63 Km and l = 3.59 Km

The following table summarizes the physical characteristics of the watershed of Wadi El Malleh.

Table 3-1: Physical characteristics of Wadi El Malleh watershed.

Area (Km^2)	Perimeter (Km)	Length of the trough (Km)	H max (m)	H min (m)	Average %	Rectangle length (Km)	Rectangle width (Km)	Shape index	Drainage density $(\frac{Km}{Km^2})$
33.85	27.64	9.42	900	250	6.9	10.63	3.59	1.33	2.74

3.2 Data Set of Wadi El Malleh Watershed:

Soil erosion process is directly affected by several factors such as, precipitation rate, land cover, land use and topography of the watershed. To estimate the soil erosion and sediment deposition ratio in Wadi El Malleh watershed, the following dataset are required.

3.2.1 Digital elevation model

The Digital Elevation Model (DEM) of Wadi El Malleh watershed is presented in Figure 3.1. With a spatial resolution of 30 m x 30 m, this DEM is derived from the Advanced Spaceborne, Thermal Emission and Reflection Radiometer (ASTER), Global Digital Elevation Model Version 2 (GDEM V2), released jointly on October 17, 2011 by the Ministry of Economy, Trade, and the United States National Aeronautics and Space Administration (NASA) and Industry (METI) of Japan. This version 2 of ASTER GDEM has less voids than the previous one (ASTER GDEM V1) and gives better results than the SRTM DEM for flat areas (Guosong Zhao, 2010), like the major part of Wadi El Malleh watershed. Also, the spatial resolution of 30 m x 30 m is the determinant advantage for ASTER GDEM V2 over the SRTM DEM, which has a poor spatial resolution (90 m x 90 m). According to figure 3.1, Wadi El Malleh elevation ranges from 870m to 258m. Elevation, drainage area, stream relief, slope length and slope steepness factors of the RUSLE model and other features can be measured from DEM.

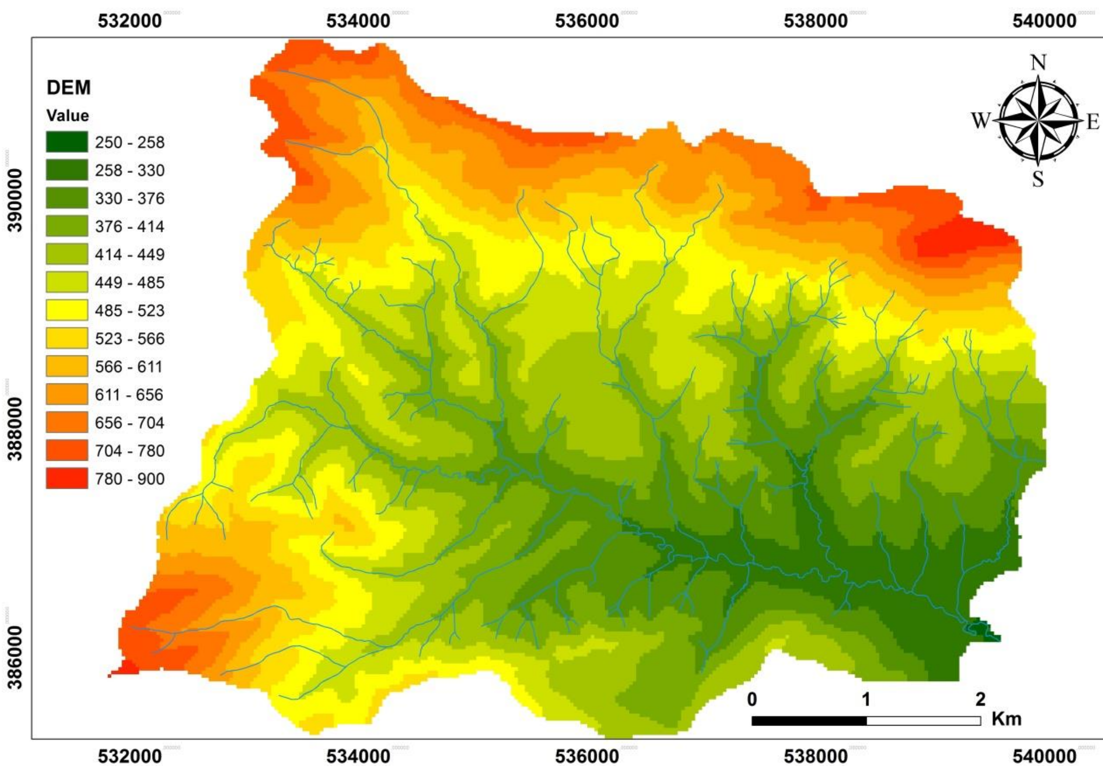

Figure 3-2: Digital Elevation Model (DEM) of Wadi El Malleh watershed.

3.3 Land Use

Google Earth provides freely accessible images with high spatial resolution which can be used to estimate land use in a certain area, especially for areas with high numerous landscapes. Google Earth imagery has been utilized to determine the existing geographical data, for example: Google Earth can estimate the spatial distribution of natural disaster insurance mapping and evaluate land use maps (Nowak & Greenfield, 2010). The land use situation map in Wadi El Malleh watershed was structured from Google Earth image processed in 2013.

The Google Earth software has poor spatial characteristics, hence, it shows some limitations in those cases require high spectral characteristics, such as: woodland and grassland, however it has good spatial characteristics in terms of context, geometric and shape, such as: river and road (Nowak & Greenfield, 2010). In our case, the photo interpretation method is used for land use classification; interpreted points were classified into 9 classes (Bad land, Cereal, Dump, Olive, Olive+Cereal, Irrigated agriculture, Reforestation, Raw land, Urban) (Fig. 3-3).

Figure 3-3: Google Earth image (12 September 2013).

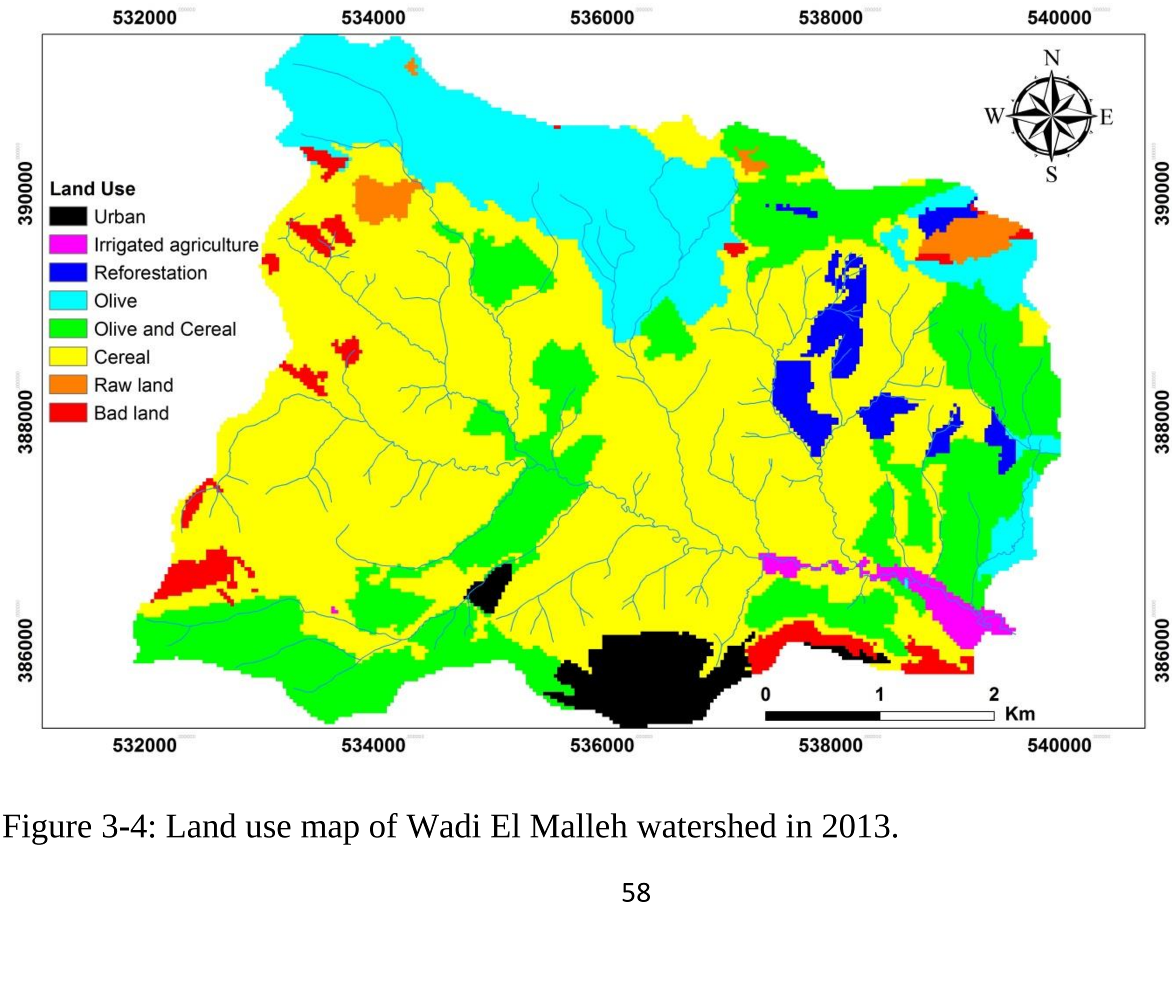

Figure 3-4: Land use map of Wadi El Malleh watershed in 2013.

The following table represents the land use classification condition of Wadi El Malleh watershed in 2013. This land use classification has nine classes (Bad land, Cereal, Olive and Cereal, Olive, Urban, Irrigated agriculture, Row land, Dump, and Reforestation). As shown in the land use map, cereal is the most widespread category in Wadi El Malleh watershed followed by land covered by olive and cereal, while irrigated agriculture, is the least spreading category.

Table 3-2: Land use classification of Wadi El Malleh watershed in 2013.

Category	Area (Hectares)	%
Bad land	86.26	2.52
Cereal	1799.38	52.54
Olive and Cereal	736.93	21.52
Olive	511.89	14.95
Urban	103.80	3.03
Irrigated agriculture	38.87	1.13
Row land	45.88	1.34
Dump	9.76	0.29
Reforestation	91.95	2.68

3.4 Climate

3.4.1 Precipitation data

Precipitation is one of the main components of the hydrological cycle and one of the major factors responsible for the erosion phenomena. The study of rainfall is important for better understanding the climate behaviour in the area.

For Wadi El Malleh Watershed, monthly average precipitation data from 5 gauging stations located around the watershed region were obtained and processed to determine the rainfall-runoff erosivity factor of the RUSLE model equation. Based on the Paper of Wischmeier and Smith (1978), the R factor of the RUSLE model should be calculated using at least 20 years of rainfall records in order to estimate the variation of the climate. There are some limitations that may appear on calculating the R factor in this study since the data provided are on monthly average and the correct assessment of the R factor requires rain gauge recording at short time intervals not more than 30 minutes.

3.4.1.1 The annual variability of precipitation

Table 3-3: Rainfall gauge stations of Wadi El Malleh watershed.

ID	Rainfall station	Longitude X(m)	Latitude Y(m)	Altitude (m)	Available recorded year	Average precipitation(mm/y)
1	Fes-Sais	536459	381970	400	1987/2014	412.9
2	Dar El-Arsa	543327	397418	138	1979/2014	418.9
3	Sidi Chahed	506741	390017	190	1994/2014	337.5
5	DRH-Fes	535400	384800	415	1981/2014	410.8
6	Bridge Sebou	523250	412200	85	1979/2014	366.9

For the station of Fes-Sais, the annual average precipitation for 27 years is about 412.9 mm/y.

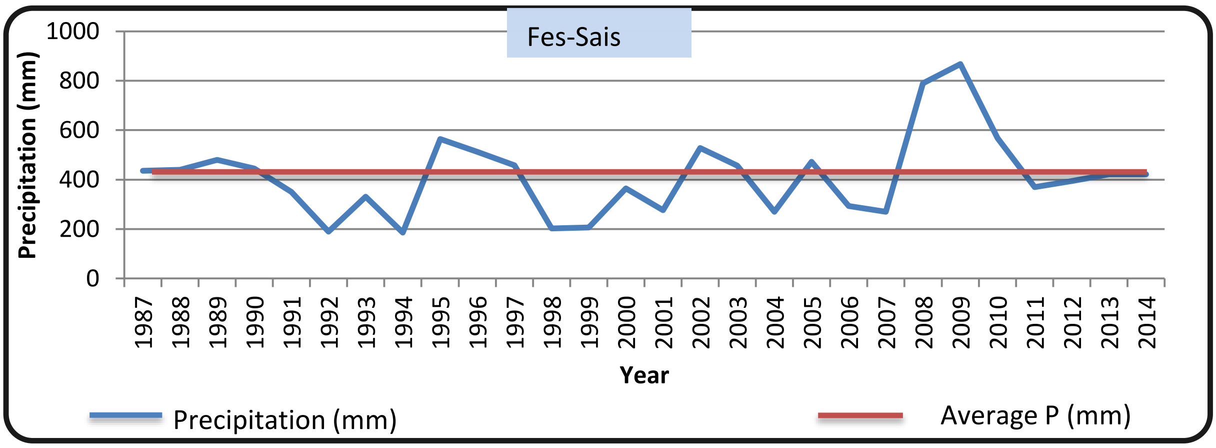

Figure 3-5: Fluctuation of the annual precipitation (station of Fes-Sais 1987/2014).

3.4.2 Temperature:

Table 3-4: Average months temperature (Fes-Sais station 1987/2014).

Month	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Average T	22.8	19.1	14.1	11.1	9.8	10.7	13.3	14.8	18.5	22.7	26.4	26.5

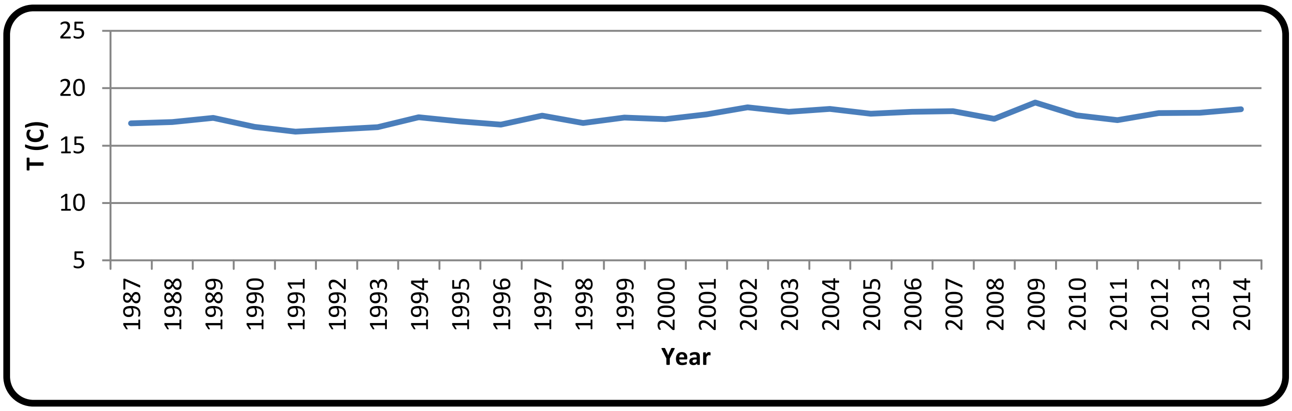

Figure 3.3: Annual average temperature (station of Fes-Sais 1978/2014).

3.4.2.1 Evapotranspiration

The concept of evapotranspiration encompasses the processes of evaporation and transpiration. Associated with a particular region, it must take account of all water loss through plant transpiration and evaporation. There are two types:

- Potential Evapotranspiration (ETP).
- Actual Evapotranspiration (ETR) (Jensen et al., 1990).

3.4.2.1.1 Evapotranspiration potential

$$ETP = 16 * \left(\frac{10T}{I}\right)^a$$

Where

- ETP: Potential Evapotranspiration
- T: Average annual temperature
- I: aridity index, can be obtained from the following formula:

$$i = \left(\frac{T}{5}\right)^{1.514}$$

The coefficient is a correction factor that differs for each month.

$$a = 0.94239 + (1.792 * 10^{-5} * I) + I^2 + (675 * 10^{-9} * I^3)$$

To simplify this formula, Serra proposed the following expressions:

$$I = 0.09T^{(3/2)} \text{ and } a = I\left(\frac{1.6}{100}\right) + 0.5$$

The calculation results of the ETP, obtained at the Station of Fes-Sais are summarized in Table 3.3 below:

Table 3-5: ETP values (Fes-Sais station).

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
$T^{\circ}C$	22.8	19.1	14.1	11.1	9.8	10.7	13.3	14.8	18.5	22.7	26.4	26.5
P(mm)	15.1	38.7	68.1	64.6	62.3	44.7	42.9	43.1	28.6	9.3	0.88	1.9
i	9.94	7.6	4.8	3.3	2.7	3.2	4.4	5.2	7.3	9.9	12.5	12.5
a	0.65	0.62	0.57	0.50	0.54	0.55	0.56	0.58	0.61	0.65	0.69	0.69
ETP (mm)	122	118	110	93	111	110	108	111	115	122	131	132

It shows that the maximum potential evapotranspiration obtained is August with 131.6 mm, and the minimum potential evapotranspiration is 92.8 mm in December (Figure 3-4).

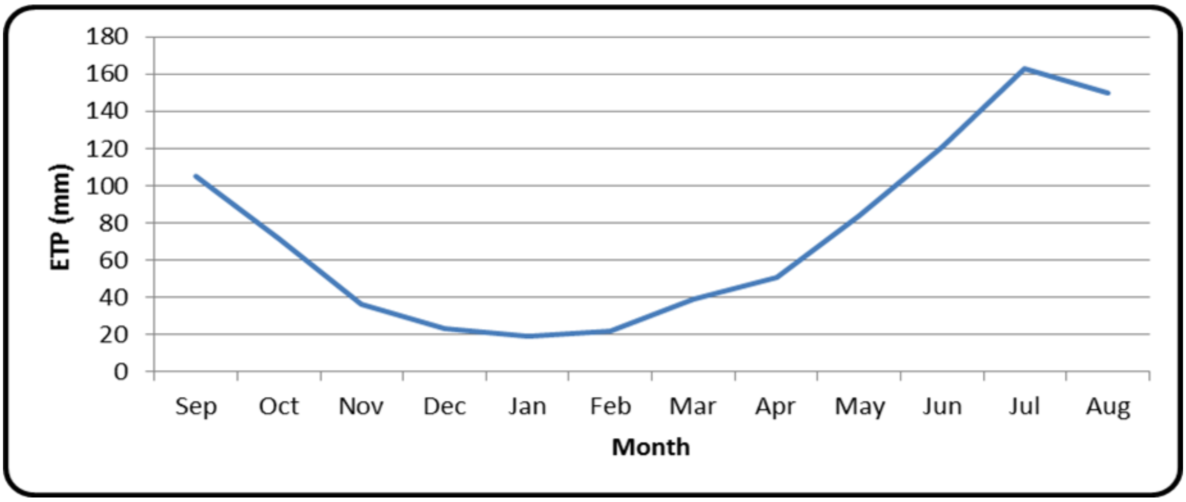

Figure 3-6: Evaluation of potential evapotranspiration based on months (Fes-Sais station).

3.4.2.1.2 The actual evapotranspiration

Evapotranspiration is the summation of transpiration of vegetation cover (through plant stomata) and evaporation of soil. The actual evapotranspiration (ETR) is the value of the flow at a given time or its average over a given period for a given station. It can be estimated from climatic data (temperature, precipitation) associated with empirical formulas:

The following formulas are most used to calculate the ETR:

Turc (1961) formula

$$ETR = P/(0.9 + (P/L)^2)^{1/2}$$

Where:

- ETR: is the actual evapotranspiration;
- P: is the annual average precipitation height (mm);
- T: is the annual average temperature (° C);
- L: is the Turc coefficient L = 300 + 25 T + $0.05T^3$.

Coutagne formula

$$ETR = P - \lambda P^2$$

Where:

- ETR: is the actual evapotranspiration;
- P: is the annual average precipitation height (m);
- T: is the annual average temperature (° C);
- Λ: is the regional coefficient: λ = 1 / (0.8 + 0.14 T).
- Note: this formula is only valid for 1/8 λ <P <1/2 λ.

The results of calculating the ETR by the different methods used are summarized in Table 3.5.

Table 3-6: Values of ETR using different methods (Fes-Sais station).

Station	P (mm)	T (°C)	ETR Turc (mm)	ETR Coutagne (mm)	Average ETR (mm)
Fes Sais	412.9	17.5	399.42	359.7	379.56

Note that:

- For the Turc method, the value of the ETR calculated on an annual basis is very high and close to that of precipitation. This shows that almost all precipitated rainfall evaporates;
- For method of Coutagne, the annual value of the ETR is lower than that of rain; thus the value of ETR will be adopted after the average of the two methods is 379.56 mm, or 92% of the total precipitated amount. The rest will fuel seepage into the basement and main flow, if necessary.

3.4.3 Aridity index

Aridity index formula (Martonne, 1942) is a function of the annual precipitation and the mean annual temperature, used to characterize the climate of a region.

$$I = P/(T + 10)$$

Where:

- If $I < 5$, hyper climate.
- If $5 < I < 10$, arid climate.
- If $10 < I < 20$, semi-arid climate.
- If $I > 20$, humid temperate climate.

By calculating the annual aridity index from the data of Fes Sais station, it resulted to be = 15.014 which mean that it belongs to semi-arid climate.

To calculate the monthly aridity index in Wadi El Malleh region, the following relationship used:

$$i = 12[P/(T + 10)]$$

Table 3-7: Monthly aridity index (Fes-Sais station).

Month	P (mm)	T °C	I	Aridity class
Sep	15.1	22.8	5.52	Arid
Oct	38.7	19.1	15.95	Semi-arid
Nov	68.1	14.1	33.90	Humid-temperate
Des	64.6	11.1	36.7	Humid-temperate
Jan	62.3	9.8	3.14	Hyper-arid
Feb	44.7	10.7	25.91	Humid-temperate
Mar	42.9	13.3	22.09	Humid-temperate
Apr	43.1	14.8	20.85	Humid-temperate
May	28.6	18.5	12.04	Semi-arid
Jun	9.3	22.7	3.41	Hyper-arid
Jul	0.88	26.4	0.29	Hyper-arid
Au	1.9	26.5	0.624	Hyper-arid

3.5 Summary

Chapter Three demonstrates Wadi El Malleh watershed site description and data set: topography, land use characteristics, Precipitation and temperature data. Precipitation data is needed to calculate the rainfall runoff erosivity factor (R). Digital Elevation model is needed to estimate the slope length (L) and slope steepness (S). A land use map, structured from Google Earth image, is used to estimate the cover management factor (C), which is one of the most important factors in determining the soil loss rates of the RUSLE model.

CHAPTER FOUR

4 TECHNICAL ANALYSIS

4.1 Introduction

In order to estimate the parameters the RUSLE model, some technical and field analysis have been done.

4.2 Permeability measurements:

Soil infiltration rate is used to determine the soil permeability in a certain region. Infiltration rate is the velocity of water entry into the soil. It is usually estimated from field data. An infiltration rate of 20 mm/ hour indicates that a sheet of water of 20 mm on the surface of soil will infiltrate in one hour (FAO). Soil permeability can be measured using various methods and types of equipment. The main used methods are determination of water entry from cylinders which called infiltrometer rings, and flooding basins method (Johnson, 1963).

4.2.1 Double ring-infiltrometer (Muntz method)

The double-ring device is one of the common methods that can assess infiltration rate of soil by a field test. According to Lai and Ren (2007) this method is usually used to estimate the saturated hydraulic conductivity of the outer layer of the soil. To measure the soil infiltration rate in Wadi El Malleh watershed, the Muntz method of double-ring has been applied to different soil units. In order to evaluate the spatial variability in the study area, many measurements have performed on each unit of soil. Soil texture (the soil particles size) measurements and other characteristics of soil such as: soil structure (the soil particles arrangement), soil type, land cover, slope and coordination for each measurement have been observed as well.

4.2.2 General principle of the method

- The principle of the double ring infiltrometer method based on the measurement of water infiltration from a surface flow under one or more hydraulic loads. In the case of double ring, the outer ring function is to maintain the vertical flow in the inner ring.
- This measurement is to determine the water infiltration rate of the field under a constant load of 3 cm. This constant load is laid down through a 6 cm metal cylinder in the soil. The same charge added in the outer cylinder in order to force the flow to be vertical in the inner cylinder.

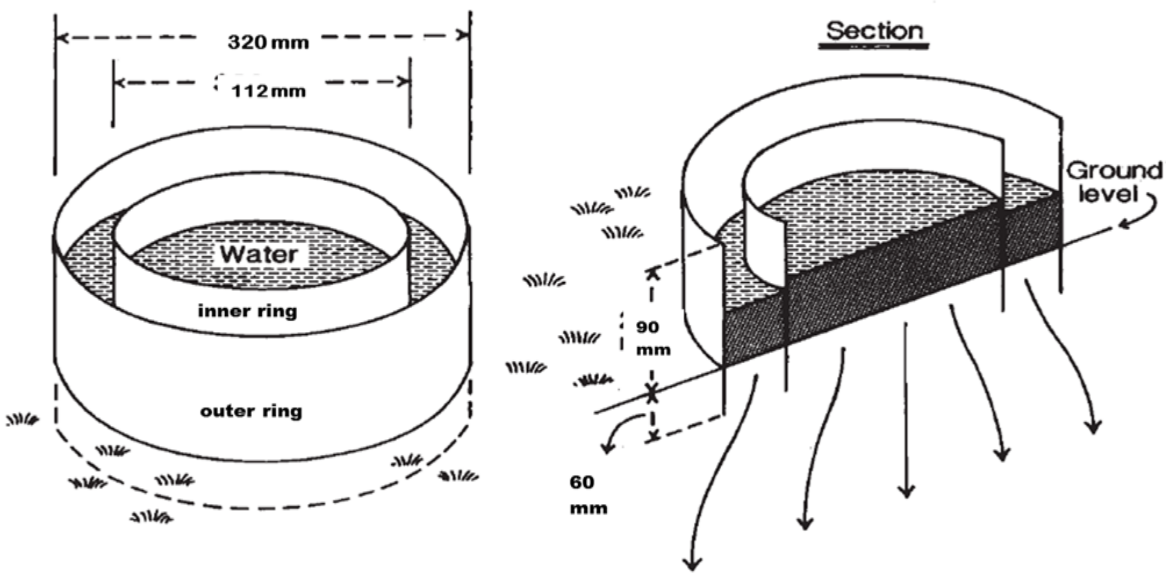

Figure 4-1: Double ring infiltrometer and its cross section **(Lai & Ren, 2007)**.

The test is usually conducted as follows:

Figure 4-2: Double ring infiltration test (photos from the field).

- Hammer the inner cylinder vertically (the bevelled side down) to the mark of 6 cm.
- Hammer the outer ring as well to protect the soil surface when pouring in the water.
- Start the test by pouring water quickly into the inner and outer ring. The water between the two rings is to force the flow to be vertical and to prevent any lateral spread of water outside the infiltrometer.

- Start the timer and measure the volume of infiltrated water after 2 minutes from the start using measuring cylinder.
- Repeat the same measurements after 5 minutes and every 5 minutes until stabilization point when the water level is the same over the same time interval.

Infiltration is continued until saturation point when it obtains a stable infiltration rate. The infiltration rate has been calculated by applying the law of Darcy, which resulted directly the degree of permeability of the soil equivalent to the speed of filtration expressed in mm/h.

For all its comparative value, this method should strictly follow the procedure and the defined standards. One of Muntz method advantages is that it can accurately measure the vertical permeability and well quantifies the superficial differentiation effect.

4.2.3 Measurement results

In this study, test for each soil unit in the study area have been performed. In addition to the physical analysis of the soil, many other parameters of the surface state are required to explain the infiltration of water into the soil.

Examples of the worked test:

Test number (1):

- Slope: 15°
- Land cover: Cereal
- Coordination: $34^{\circ}5'16,682'$ N, $5^{\circ}1'48,001'$ W
- Infiltration test results, table 4.1.

Table 4-1: Infiltration test results for the first stop in Wadi El Malleh region.

Time (mm)	Water volume (ml)	Infiltration rate (mm/h)
2	80	240
7	150	180
12	110	120

17	105	132
22	105	126
27	110	126
32	100	132
37	100	120
42	100	120
47		
52		
57		
62		

Test number (2):

- Slope: 11°
- Land cover: Cereal
- Coordination: $34^{\circ}\, 1'19,859'$ N, $5^{\circ}\, 0'33{,}457'$ W
- Infiltration test results, table 4.2.

Table 4-2: Infiltration test for the second stop in Wadi El Malleh region.

Time (mm)	Water volume (ml)	Infiltration rate (mm/h)
2	140	420
7	165	198
12	200	240
17	170	204
22	175	210
27	160	192
32	170	204
37	170	204
42	170	204
47		
52		
57		
62		

Test number (3):

- Slope: 25°
- Land cover: Olive and Cereal
- Coordination: $34^{\circ}09'86, 74'N$, $4^{\circ}97'64, 00'\ W$

- Infiltration test results:

Table 4-3: Infiltration test results for the third stop in Wadi El Malleh region.

Time (mm)	Water volume (ml)	Infiltration rate (mm/h)
2	155	465
7	185	222
12	125	150
17	135	162
22	115	138
27	95	114
32	100	120
37	70	84
42	80	96
47	80	96
52	80	96
57		
62		

4.3 Soil texture measurements

Texture indicates the relative abundance in the ground, of various particle sizes (sand, silt or clay), and it depends on the amount of water and air that it retains, and the rate at which water can enter and flow into the soil (FAO, 1990). The texture of a soil influences all its other physical properties, including drainage, retention capacity, temperature, aeration and structure.

4.3.1 Grain size

The Particle size analyses were performed by the sieve analysis. Sieve analysis is the oldest and best well-known method. It is used to divide the soil particles; namely sand, silt and clay into size fractions and to calculate the weight of these fractions. Particle size measurements are important for the calculation of the soil erodibility factor of the RUSLE model.

Firstly, twelve soil samples were chosen from nine different locations in Wadi El Malleh watershed. Dry and wet sieve methods were used as follows:

- The procedure of the wet sieve method:

- 150 grams of soil weighted from each soil sample and crushed using mortar and pestle
- Each sample put in a separate container, and then 1000 ml of distilled water added on it, and put on rotating shaker for 45 minutes.
- After shaking, the soil sample sieved using 0.2 mm mesh size firstly to separate the visible organic matter, 0.001 mm mesh size to separate the coarse sand, and finally 0.063 mm mesh size in order to separate the fine sand from Clay+silt particles
- Finally, the samples dried at 105℃ , and weighted in order to calculate the percentage of the sand, silt and clay in each sample.

Figure 4-3: wet sieve method analysis.

- The procedure of the dry sieve method:
    - All visible organic matter removed from each soil sample
    - 150 gram of each sample weighted and crushed using a mortar and pestle.

- The sieve with the largest mesh stacked on the top, then the finer mesh and the finest mesh on the bottom, then covered and secured on the sieve shaker. (Shaking turned on for 10 minutes).
- The residue collected from each sieve and weighted.

Figure 4-4: Dry Sieve method analysis **(Brittain, 2002)**.

- Method to separate clay and silt particles:

Figure 4-5: Method to separate clay and silt particles (Lab. work).

- Measure 10 gram from each sample from the residue of the dry sieve analysis and put it separately to each tube.

- Use the fixed tube method by adding 1 litter of distilled water to each tube and leave it for 16 hours.

- Use a pipette to take 10 ml from the top of each tube and dry them at 105℃ for 8 hours.

- Measure the weight of the residue after heating and it refers to the clay weight.

Table 4-4: Grain size classes.

	Grain size	Soil Units											
		1	2	3	4	5	6	7	8	9	10	11	12
Clay %	< 2 µm	26.4	9.1	11	19.8	11	9.2	26.4	40.7	27.4	22.2	9.1	32.1
Silt %	Between 2 µm and 50 µm	51.1	12	22.7	28.7	22.7	22.6	51.1	49.7	48.4	31	12	64.3
Fine sand	Between 50 µm and 1000 µm	1.5	20	9	16.4	9	9.1	1.5	0.4	1.1	3.2	20	0.1
Coarse sand	Between 1000 µm and 2000 µm	20.9	58.9	57.3	35.2	57.3	59.1	20.9	9.2	23.2	43.6	58.9	3.5
Sand %	Between 50 µm and 2000 µm	22.5	78.9	66.3	51.6	66.3	68.2	22.5	9.6	24.3	46.8	78.9	3.6

Analysis of the texture triangle shows that more than half of the study area (52%) to a balanced structure especially for little evolved soils (Units 3, 4,5and 6), the isohumic soil (unit 10), and the complex unit 2 and 11. Clayey soils occupy 17% of the area and are composed of (27.4 to 40.4% of clays rates) particularly at Calci-magnesium soils (Units 8 and 9) and Unit 12, while the silty texture (51.1% silt rate) is represented by vertisols (Units 1and 7) (30% of the total area of the study area).

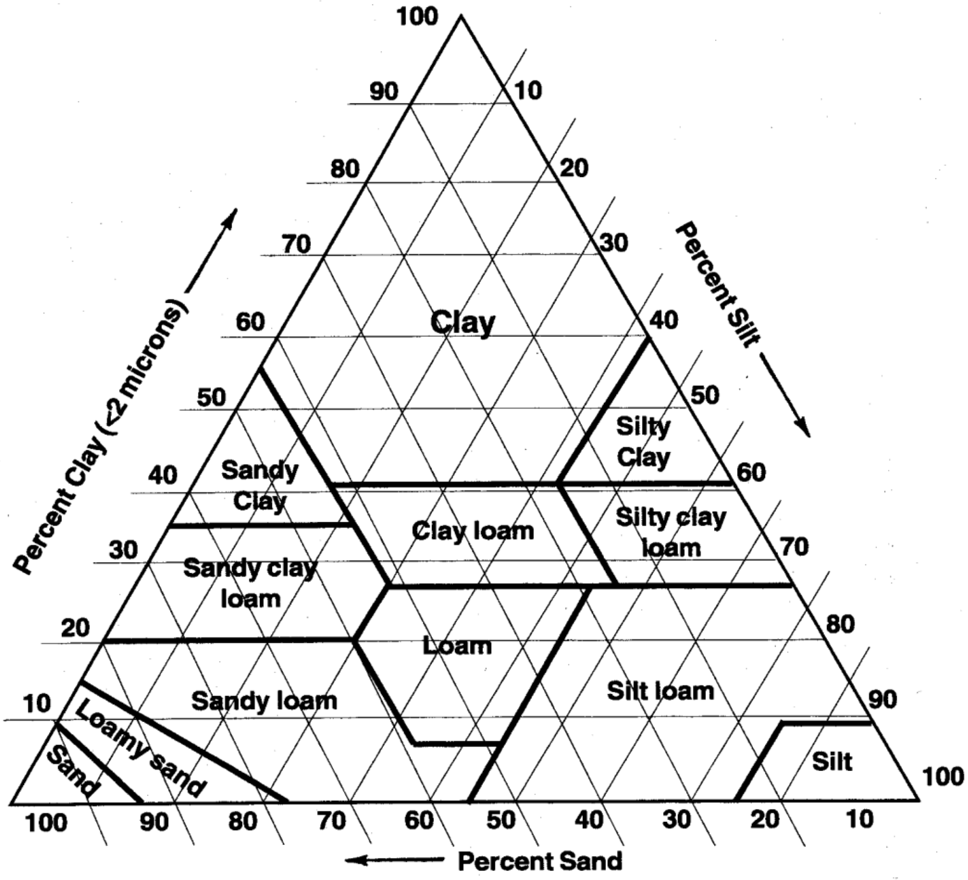

Figure 4-6: Soil texture triangle (Brant et al., 2006).

4.3.2 Humidity

Soil humidity is an important parameter that should be considered due to its impact on soil erosion risk. The more the soil is humid before a rainfall event, the more runoff will be efficient. This humidity depends on climate conditions, vegetation and soil development (Igue et al., 1972).

4.3.2.1.1 Measuring procedure:

After drying the collected samples of known weight in an oven at 105℃ for about 15 hours; the soil water content can be obtained from the difference between the weights before and after drying the samples.

H (%) = ((mf + t) – (ms+t) / ms) *100

- mf is the :mass of the sample before drying
- ms is the mass of dry sample

Table 4-5: Humidity measurements.

Soil unit	1	2	3	4	5	6	7	8	9	10	11	12
Humidity %	5.3	5.5	5.1	11.2	5.1	8.4	5.3	14.8	2.7	9.0	5.5	5.7

4.3.3 Bulk density

The soil bulk density of corresponds to the weight of dry soil ($m\ solids$) divided by the total volume ($Vsoil$). The worked method consists of taking soil sample by pressing a metallic cylinder of known volume ($7cm$ height and $3.5cm$ radius) into the soil and measuring the weight of the dry sample after heating it in an oven to $105℃$ for 24 hours. Taking into consideration that the unit of collected soil volume is (cm^3) and dry weight is (g), so it is possible to calculate the bulk density of the sampled soil (g/cm3) as following: (McKenzie et al., 2004).

$$BD\left(\frac{g}{cm^3}\right) = ms/V$$

Where

- BD: Bulk density
- ms: Weight of dry sample
- V: volume of the metallic cylinder $= (296.3cm^3)$

Figure 4-7: Soil density measurements (Field work) (Eid et al., 2016).

4.3.4 Soil porosity:

It is the volume of soil voids that can be filled with water or air. Since the bulk density takes into account the porosity of soil and the soil compaction increases the density by compressing the pores, the measurements of the bulk density of the soil used to confirm a diagnosis of compaction.

According to (Black, 1965) the soil bulk density is determined as following:

$$P(\%) = 100\% - \left(\frac{BD}{AD}\right) * 100)$$

Where

- $P(\%)$: total Porosity
- BD: Bulk density
- AD: Actual density $\left(2.65 \frac{g}{cm^3}\right)$

Table 4-6: Porosity and bulk density for different units of soil.

Soil unit	BD (g/cm^3)	Porosity (%)
1	0.59	77.74
2	0.58	78.11
3	0.55	79.25
4	0.66	75.09
5	0.55	79.25
6	0.49	81.51
7	0.59	77.74
8	0.58	78.11
9	0.58	78.11
10	0.54	79.62
11	0.58	78.11
12	0.51	80.75

The porosity of the soil is a major feature controlling the hydrodynamic properties of the soil and root development of the plants, but also a physical indicator of soil quality influenced by the different farming techniques. Generally, the bulk density is between (0.49) g / cm3 and (0.66) g / cm3 for different soil samples in the study area.

4.3.5 Organic matter

The organic matter is an important source of nutrients for plants and its total content is a useful tool to know the fertilizing potential of the soil.

The organic matter as well has an important role in development of the unstable soil structure (Shepherd, 1986).

4.3.5.1 Measuring procedure

By drying the soil samples of known weights to 375℃ for 16 hours to remove any organic matter, clay water or carbonates. The organic matter is the weight difference between the soil samples before and after drying.

- Note that soil moisture is directly dependent on the rate of organic matter in the soil.

Table 4-7: Organic matter measurements

Soil unit	1	2	3	4	5	6	7	8	9	10	11	12
Organic matter %	6	7	8.7	14.1	8.7	7.7	6	10	1.4	7.9	7	5

4.4 Summary

Chapter 4 represents the technical analyses that have been done in order to make the data needed in the RUSLE and SEDIMENTATION models available. The permeability measurements have been done to estimate the infiltration rate using the double ring-infiltrometer (Muntz method), the soil texture measurements used to predict various particle sizes (sand, silt or clay) by calculating the grain size to estimate the grain size classes using the soil texture triangle. The Humidity of the watershed estimated and varies from 5.1 to 14.8 %. The bulk density and soil porosity determined and varies from (0.49 to $0.66 g/cm^3$) and (75.09 to 81.51 %), respectively. The organic matter measured and varies from 1.4 to 14.1 %.

CHAPTER FIVE

5 RUSLE PARAMETERS ESTIMATION METHODOLOGY AND MAPPING

5.1 Introduction

To achieve the objectives of this study that seeks mainly to the quantification of the water erosion in the watershed of Wadi El Malleh, an exploration of the physical environment has been made firstly through field studies. After that spatial distribution of water erosion has been conducted in the concerned area by looking at the parameters that enhance the erosive dynamics. The applied methodology is depending on collecting, analysing and spatial processing of data of land use, physical constraints and geomorphology of Wadi El Malleh watershed. Hence, thematic informations have been extracted from satellite images and produced a digital elevation model (DEM) and other data such as: the Slope length and steepness. In this project the ArcGIS 10.3 software has been used for scanning information layers required. Then, Idrisi Selva software has been used for modelling soil erosion and deposition.

5.2 Mapping land cover using pictures of remote sensing

The variation in land use was assessed using the Google Earth image, which has taken in 2013. The image was first geo-referenced and projected into (Merchich Northern zone); the Moroccan coordinates system and classified by Arc GIS 10.3 and Idrisi Selva software. Then, a cutting image assisted by selecting the parts related to the same portion of space of the study area from the geographical coordinates. The integration of satellite imagery in the GIS of the concerned area has been allowed by these geometric pre-treatments. The visual quality of images and good photo interpretation has been made by enhancing operation of channels. From the previous perceptions, land use map has been performed based on agriculture land use and soil characteristics references obtained from the field.

5.3 RUSLE parameters estimation and mapping

Water erosion quantification in Wadi El Malleh watershed is obtained by the integration of RUSLE model in the Idrisi software. This model allowed the estimation of the annual erosion rate average (A) through the watershed, building on the soil erodibility aggressiveness, rainfall distribution, topography, crop management practices and soil occupation. The history of the model has been discussed in the Literature review, chapter two.

Under the RUSLE model, the annual erosion rate average (A) estimated through the multiplication of six parameters as follows: A = R*K*SL*C*P (ton/ha/year). (R) is the rainfall erosivity parameter, (K) is the soil erodibility or the medium resistance to erosion, (SL) are the topographic parameter, (C) is land cover parameter and (P) is the erosion control parameter.

The annual average erosion rate for the watershed of Wadi El Malleh has been estimated and compared with previous studies, in order to understand the real situation of the region.

5.3.1 R factor

The evaluation of R is based on the formula of Rango and Arnoldus (1987) that reflects the monthly and annual rainfall in mm in 5 stations surrounding Wadi El Malleh watershed.

$$R = 1.753 * 10(1.5 \log(P_i^2)/P) - 0.8188$$

Where

- R is the average value of the annual index of aggressiveness
- P is the average annual precipitation in mm.
- Pi is the average monthly precipitation in mm.

Table 5-1: The R value results.

Station	Fes Sais 1987/2014	Dar Arsa 1979/2014	Bridge Sebou 1979/2014	Sidi Chahed 1994/2014	DRH Fes 1981/2014
R Value	70.79	72.08	60.52	71.09	71.36

R Average	69.17

5.3.2 K factor

To determine the K factor in Wadi El Malleh watershed, samples collection from various units of soil made in the basin (collection started after about 20 cm soil depth), after we have provided for each collected sample the average K values.

The K factor has been calculated by the nomograph of (Wischmeier et al., 1971) and its formula to check the results.

The results of the K factor varies from 0.07 determined on the limestone formations at Zalagh mountain and 0.58 is determined on bad land west of the watershed of Wadi El Malleh. The K factor distribution map thus matches that of the lithology of the watershed.

Table 5-2: The K factor and its characteristics for Wadi El Malleh watershed.

Bedologic unit	Structure class code	Permeability class code	Clay %	Fine sand%	K
1	3	1	26.4	1.5	0.18
2	3	2	32.1	0.1	0.53
3	3	2	11	9	0.36
4	0	0			0.07
5	3	2	11	9	0.36
6	3	2	9.2	9.1	0.35
7	3	1	26.4	1.5	0.18
8	3	2	40.7	0.4	0.58
9	2	1	27.4	1.1	0.12
10	2	2	22.2	3.2	0.26
11	3	2	32.1	0.1	0.53
12	2	2	9.1	20	0.17

To simplify the reading of the results and their graphical representation, it was useful to group the close values of K distributed in an increasing gradient erodibility. Then we could have the spatial distribution of these classes.

Table 5-3: Distribution of K factor values in the watershed of Wadi El Malleh.

Bedolo	4	9	12	7	1	10	6	5	5	11	2	8

gic unite												
K	0.07	0.12	0.17	0.18	0.18	0.26	0.35	0.36	0.36	0.53	0.53	0.58
Surface (ha)	30.85	424.9	609.8	1020.6	1020.6	74.6	109.4	774	744	70	70	90.6
Surface / Basin %	0.96	13.26	19.03	31.85	31.85	2.33	3.41	24.15	24.15	2.18	2.18	2.83

According to the classification (Bolline & Rousseau, 1978):

- K < 0.1 Soils very resistant to erosion
- 0.1 to 0.25 Soil fairly resistant to erosion
- 0.25 to 0.35 Soils moderately sensitive to erosion
- 0.35 to 0.45 Sols very sensitive to erosion

On the whole, over 64% of the watershed area of Wadi El Malleh has soils that are in the class quite resistant to erosion, while soil class quite sensitive to erosion dominates 35% of the territory concerned.

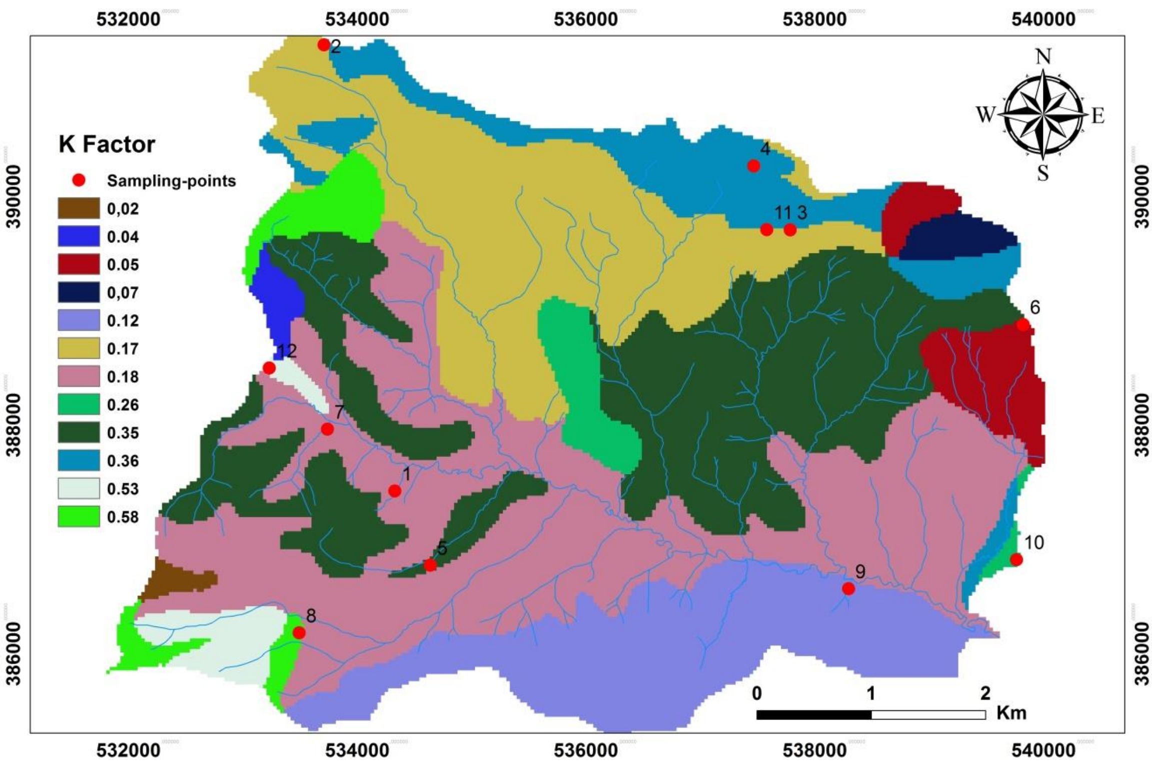

Figure 5-1: Map of Soil Erodibility Factor.

5.3.3 LS factor

The biggest relief parameters which determine the intensity of the water erosion in the watershed are the gradient and slope length. The combined effect of the gradient of the slope and its length is taken up by the topographic factor or factor LS (in the RUSLE approach) (Roose, 1977).

The calculation of this factor (LS) is performed using the IDRISI Selva software from the DEM with a resolution of 30 m.

5.3.4 C factor

Despite the number of experimental studies that have been made in Morocco on the quantification of erosion by USLE or RUSLE, there is still a lack of experimental factor C for different types of Moroccan plants. For the determination of C-factor values in Wadi El Malleh Watershed, the values have been extracted from the work done in the Rif by (Ahmed et al., 2012).

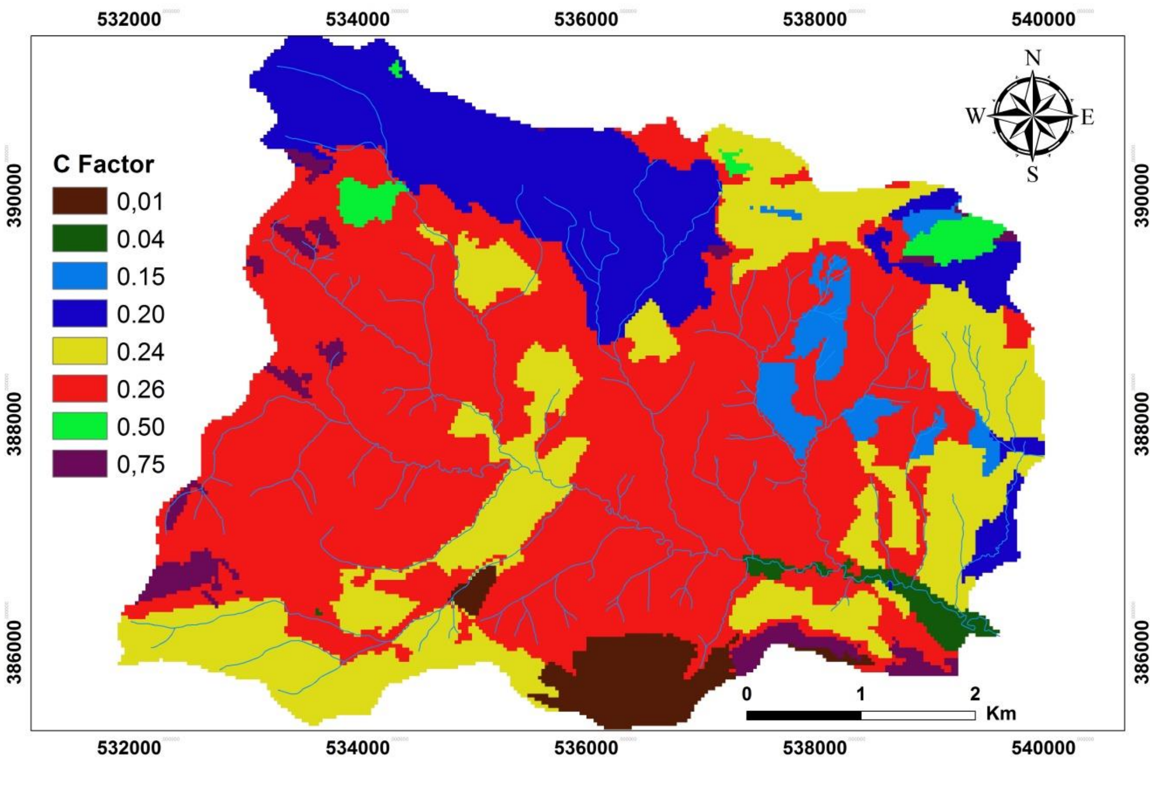

Figure 5-2: Map of cover management factor of Wadi El Malleh watershed.

Figure 5-3 C factor values (Ahmed et al., 2012).

Land Use	C factor
Bad lands	0.75
Urban	0.01
Dump	0.01
Reforestation	0.15
Raw land	0.50
Olive and Cereal	0.25
Cereal	0.26
Irrigated agriculture	0.04
Olive	0.20

The values assigned to different land use patterns for the watershed of Wadi El Malleh, are between 0.04 and 0.75

5.3.5 P factor

Factor expressing the protection of soil from agricultural practices, erosion control practices of soil (P) says human intervention in creating practices that conserve soil and reduce land degradation, such as crops curves level in alternating strips or terraces, reforestation benches, mounding and ridging are the most effective soil conservation practices.

The value of P = 1 is given to the land on which none of the cited practices are used. P values vary the practice and also depending on the slope. P values less than or equal to 1 when there is intervention to fight against erosion

Across the watershed of Wadi El Malleh, there is no anti-erosion development, and farmers do not use conservation tillage practices. Crops are mainly grain and blowing is rarely parallel to contour lines. There are some forest rehabilitation trials by reforestation of how random trees between the original feet. For all these reasons, we assigned the value P = 1 for the entire basin area.

After determining all factors for RUSLE model was introduced all these parameters in an integrated module in Idrisi Selva GIS software.

5.3.6 The annual average soil loss rate by RUSLE model

The soil erosion occurrence closely related to the land use situation, the cover management status, the slope length and the slope steepness. In order to estimate the annual average soil loss rate in Wadi El Malleh watershed, the six factors of the RUSLE model are multiplied by the raster calculator function tool of the Arc GIS.

After mapping of land use, soil losses were estimated by the integrated RUSLE module in the Idrisi Selva GIS software. This module not only calculates the soil loss for each pixel of the grid but also the group pixels into homogeneous polygons based on the orientation of slope length and slope criteria as they may be adjusted by the user (El Garouani et al., 2009).

The following table shows the annual average soil loss rate based on land use type. The total annual average soil loss rate of Wadi El Malleh watershed is about 327 thousand tons/year (Eid et al., 2016).

Table 5-4: The annual average soil loss rate based on the land use type.

Land Use	Area (ha)	Unit soil loss (t/ha/y)	Total soil loss (t/field/y)
Bad land	86.26	294.4	25396.49
Reforestation	91.95	74.62	6861.88
Cereal+Olive	736.93	86.507	63749.84
Cereal	1799.36	93.54	168312.53
Irrigated agriculture	38.86	5.726	222.526
Raw Land	45.88	257.97	11836.10
Olive	511.88	98.63	50491.52
Urban	113.56	0.760	86.327

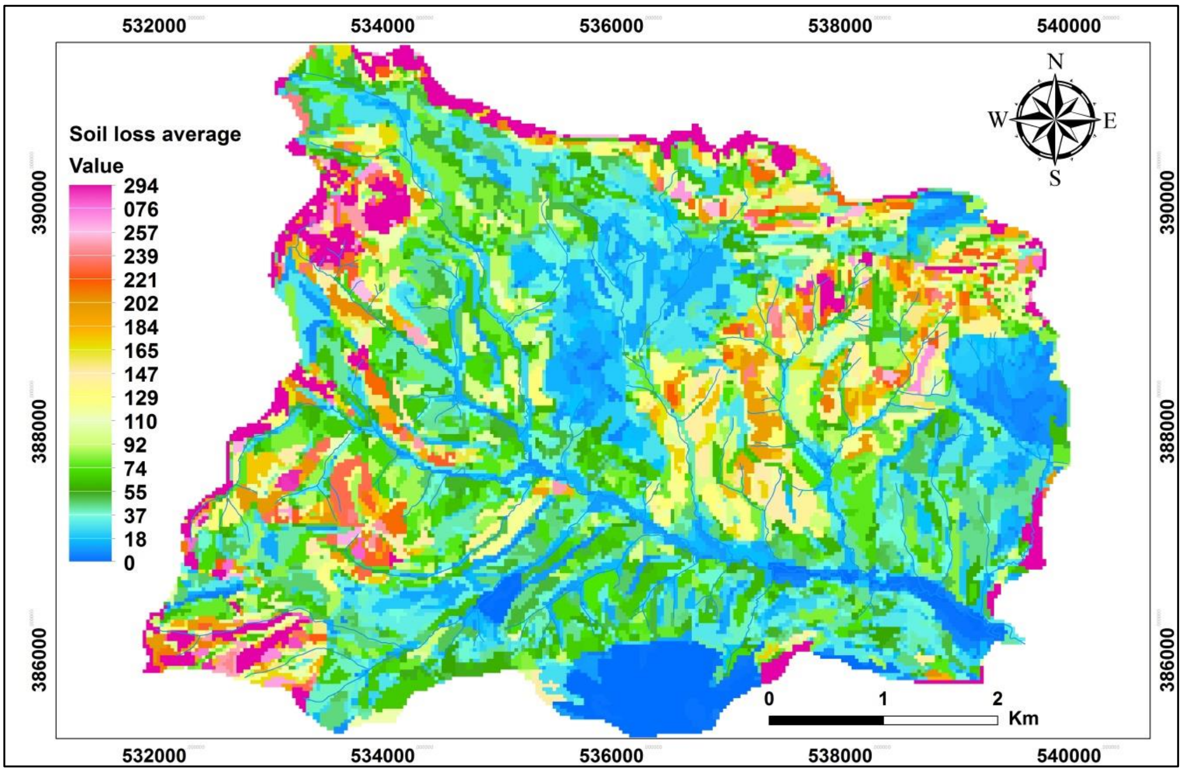

Figure 5-4: Annual average soil loss rate map of Wadi El Malleh watershed.

The resulted annual average soil loss rates determined by RUSLE by type of land use is between (0.760 to 294.41 t/ha/y) which consider a minimum annual average soil loss value in the urban areas followed by (5.726 t/ha/y) in the irrigated agriculture areas and a maximum annual average soil loss value reported at the bad land. The watershed topographically characterize by steep slopes which resulted in vulnerability to severe erosion at most of the watershed areas and caused sediment deposition.

The RUSLE model may overestimate erosion because it ignores the redistribution of particles in the basin; that is to say, the soil loss calculated for the RUSLE model is assessed for each homogeneous unit of land (patch) independently. It excludes deposits of trade between these homogeneous units following the break of slope. So in this case RUSLE overestimate the actual losses in each ground motion between the upstream and downstream (El Garouani et al., 2009). It was necessary to think about the quantities that will be eroded and deposited near where slope places in the watershed. To this end, we applied the SEDIMENETATION model based on static results of the RUSLE model, and it helped in calculating net soil loss for each patch (homogeneous unit).

5.4 Net Soil Loss (By Sedimentation Model)

It is based on the results of RUSLE model, used to calculate the erosion balance in each homogeneous considered basic plot. It uses homogeneous polygons resulting from the calculation of RUSLE model to assess the net movement of soil (erosion or deposition) in plots or sub watersheds (Lewis et al., 2005). If the data are analysed throughout the watershed, a report from the issuance of the sediment can be entered to determine the amount of sediment out of the basin. The implementation of this model will come after that of RUSLE. It also requires the digital terrain model (DTM) and homogeneous polygons identifying images and that of soil losses resulting from the calculation made by RUSLE.

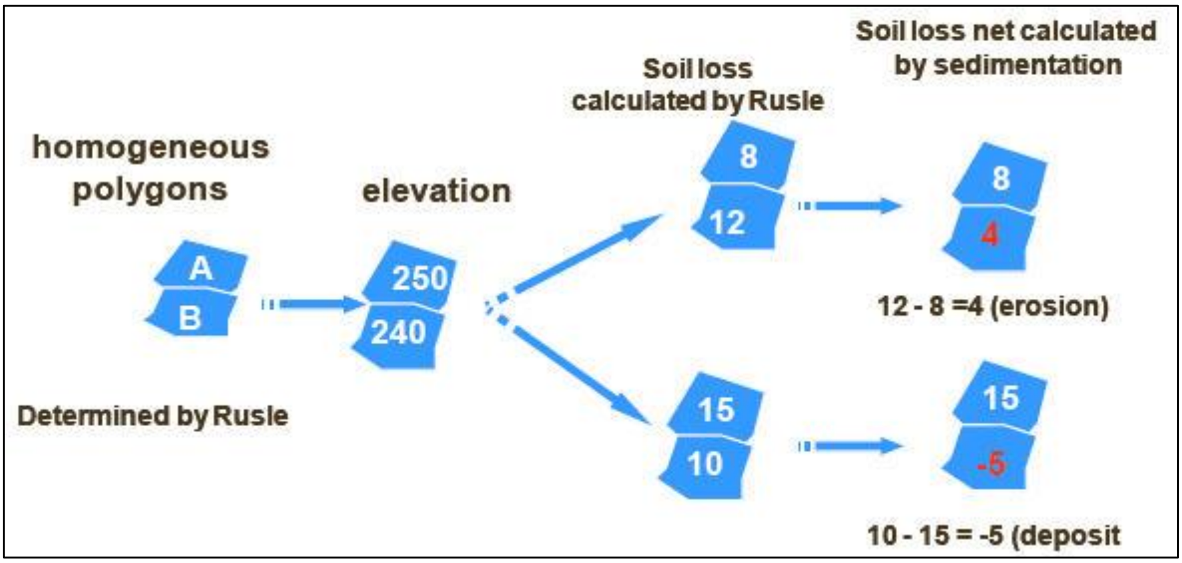

Figure 5-5: Principle of deposition: Sedimentation model (El Garouani et al., 2007).

The determination of net erosion or deposition starts with the calculation of total soil loss for each homogeneous product polygon from RUSLE model.

The unit first determines the average altitude for each polygon and the location of the highest altitude in the catchment area or in the relevant field. The direction of movement of the soil is then determined by the relative differences in altitudes between adjacent polygons. So the movement is always in the direction of the downward 78slope. The amount of soil loss that goes into the surrounding lower polygon is proportional to the length of the common border between the top polygon and one below.

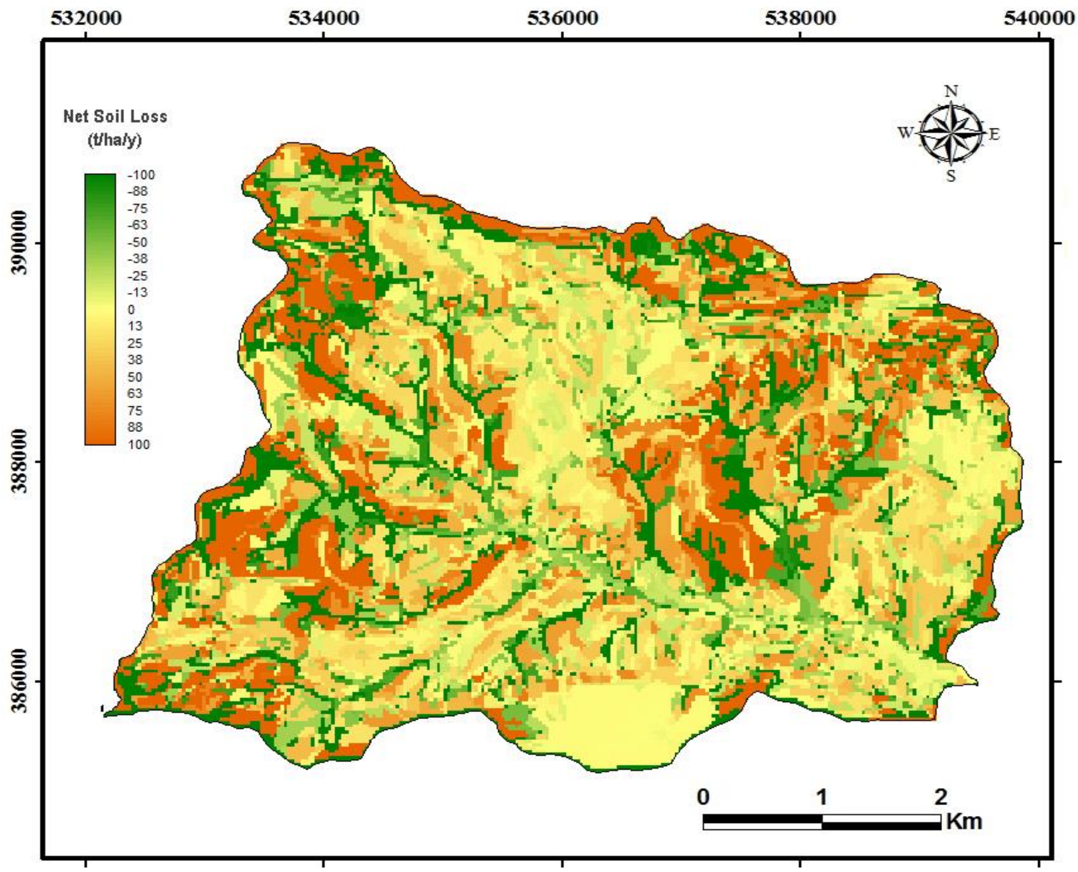

Figure 5-6: Net annual soil loss map for Wadi El Malleh watershed.

Table 5-5: Net annual soil loss for Wadi El Malleh watershed.

Land Use	Area (ha)	NASLA (t/ha/y)	NASL (t/field/y)	%
Bad land	86.26	81.86	7061.4	2.52
Reforestation	91.95	-13.66	-1255.62	2.68
Cereal+Olive	736.93	7.37	5433.62	21.52
Cereal	1799.36	-1.13	-2041.12	52.54
Irrigated agriculture	38.86	-19.19	-745.65	1.13
Raw Land	45.88	41.33	1896.24	1.34
Olive	511.89	5.27	2697.64	14.95

Urban	113.56	-4.94	-561.29	3.32

Negative values indicate a deposit and positive values mean erosion. The results of calculations of losses in annual net show floor:

- A great fragility of the East and South-East part of the basin consists mainly of marl and sandstone of Miocene marl (up to 50 t / ha / year). About 1150 ha, or 9.5% of the total basin area.
- The low erosion rates (<7 t / ha / year) mainly dominate the slopes of the right bank of the pond where the dominance of arable land and olive trees cover the sandy terrain.
- The areas of low soil loss or deposition correspond to areas of low slope or plains (up to 50 t / year / ha sedimentation).

The technique allows the evaluation of the net erosion in the basin scale and identifying areas that need interventions to fight against land degradation. In addition, it makes sense to complete this work to highlight the influence of the intrinsic parameters of soils (texture), erodibility and soil saturation time on water erosion, so it can judge the importance of each variable when the influence of others is considered.

5.5 Summary

Chapter 5 represents the methodology and procedure of the RUSLE parameters evaluation. The RUSLE model has six factors, which are rainfall-runoff erosivity factor (R), soil erodibility factor (K), slope length and steepness factor (LS), cover management factor (C), and the support practice (P).

In Wadi El Malleh watershed, the annual average R value is 69.17 (based on five rainfall stations). Counting on the organic matter and soil classification, the soil erodibility (K) is evaluated and varies from 0.07 to 0.58. Slope length and steepness (LS) is estimated using the DEM and Idrisi Selva. The cover management (C) is determined with values varies from 0.01 to 0.75. The support practice parameter (P) equal 1, because there is no supporting (conservation) practices in the region.

CHAPTER SIX

6 CONCLUSIONS AND RECOMMENDATIONS

Soil erosion by water is marked critical problem in Wadi El Malleh watershed due to climatic uncertainties and anthropogenic pressure on its landscape. The study area is characterized by a Mediterranean climate, semi-arid marked by heterogeneity of precipitation (annual average 389.4 mm / year), due to its position in the Rif area. The river system of the study area is highly developed and densely branched (drainage density is $2.74 Km/Km^2$). The dominance of impermeable bedrock low permeability and strong slopes, make most of the precipitated water sheet runoff. The geological structure of the study area is very diverse and lithology of materials ranges Secondary Quaternary. Overall soft rock and susceptible to erosion predominate. Soil distribution in the landscape is not done randomly. It depends on factors such as topography, the nature and importance of the vegetation cover and the nature of the rock. The studied soil marked by the dominance of few developed soils and vertisols rich in organic matter, rich in limestone, moderately erodible and have good structural stability of the surface horizon.

The study aims to estimate the spatial distribution of soil loss and to analyse the effect of slope exposition and land use on soil erosion. Both quantitative and qualitative approaches were used in this study to evaluate soil erosion risk. Soil erosion hazard mapping made by application of GIS based models with parameters derived from satellite remote sensing. The study was carried out in Wadi El Malleh watershed (3424.7 ha) in the north of Fes city, Morocco.

The identification of the spatial variation of the land in the study area was carried out from the photo interpretation of an image from Google Earth. The dynamics of land use showed that the study area is experiencing expansion of uncultivated land to the detriment of reforestation areas and urban land. The presence of urban areas in the fields of agriculture shows an intrusion of the local population with the consequent degradation of natural resources. After mapping of land cover, soil losses were estimated. SEDIMENTATION model which use the results of the calculation of RUSLE model integrated in ArcGIS to assess the net movement of soil erosion or deposition in plots or sub watersheds.

In general, this study comes up with an approach for the soil erosion loss evaluation in Wadi El Malleh which builds on complex of RUSLE and ArcGIS 10.3. This is a successful way to predict and map the soil loss due to erosion in specific areas. Nevertheless, errors in any factor value could result a similar percentage errors in the estimation of the soil erosion.

By analysing the map of the spatial distribution of soil loss calculated by the sedimentation model, we find that the area’s most sensitive to erosion are located in the South and Southwest of the basin and are characterized by soil silt-sandy clay texture. From this map we can make out the priority areas to receive the facilities, and we can conclude that land use is the parameter on which the management actions of the territory must rely for limiting sensitivity to erosion of the region.

In light of the results obtained and after the objectives for this study, the following conclusions can be drawn:

- The method used to better understand the differences observed in the production of sediments at different scales of observation consisted in spatial-temporal comparisons of the average values of the two models of erosion and deposition, (RUSLE and SEDIMENTATION).
- The results clearly showed that soil losses calculated by the SEDIMENTATION model are significantly lower than those calculated by the RUSLE model.
- Urban land, reforestation and olive trees cover more than 42.5% of the area of land studied with remarkable extension of uncultivated land.
- Approximately 62% of the basin area is dominated by soil units very sensitive to water erosion namely unsophisticated soil and vertisols.
- With existing production systems, 4% (132 ha) of catchment shows a water erosion of soil that exceeds the acceptable threshold of (11.5 t/ ha / y)

generally accepted, especially on bare soils and degraded than on cultivated soils.

Far from being regarded as absolute values, the results obtained in this study represent only relative values can help in the planning of soil conservation activities. The relativity of these results is inherent limitations of the methodology used for this study.

It is possible not only to integrate SEDIMENTATION model parameters in a spatial database but also to achieve an adaptation to the specific conditions in the watershed of Wadi El Malleh, that’s why the future research should include the following:

- Installation of rainfall stations (incorporating pluviography recorders) to obtain the erosivity values specific rains in catchment of Wadi El Malleh.
- The establishment of a network of runoff plots to estimate the C-factor value for all combinations of food crops grown in the watershed.
- The establishment of experimental plots with different soil conservation structures to determine the value of P-factor for the watershed.
- To optimize the watershed, we will still need to spatialize risks and model the liquid and solid flows. Remote sensing, simulation rain, GIS and indicators (cesium-137 and surface states) are modern techniques, but require local validation by land loss measurements at different scales.

Bibliography

Ahmed, R., Lamiae, K. I., Abdelkarim El, A., Ma, M., & Roberto, P. (2012). GIS-based model to assess erosion sensitivity in Northern Morocco. Laou watershed case study. *International Journal of Geosciences*.

Anik Bhaduri, C. R. (2015). Sustainability in the water–energy–food nexus, Water International, 40:5-6,723-732, DOI: 10.1080/02508060.2015.1096110.

Antoni, V., Le Bissonnais, Y., Thorette, J., Zaidi, N., Laroche, B., Barthes, S., et al. (2006). Modélisation des risques d'érosion des sols contexte méditerranéen avec un référentiel régional Pedologique au1/250 000 et Confrontation aux enjeux locaux. *Etude et Gestion des Sols, 13(3)*, 201-222.

Beasley, D. B., Huggins, L. F., & Monke, A. (1980). ANSWERS: A model for watershed planning. *Transactions of the ASAE, 23(4)*, 938-944.

Benchaabane, A. (1997). Impact de l'exploitation du prélèvement du bois de feu sur l'érosion du sol en haute montagne (cas du huat aTlas de Marrakech, Maroc). *8(4)*, 13-21.

Beniston, M. (2006). *A general overview and a focus on climatic change in the Alps.*

Biard, F., & Baret. (1997). Crop residue estimation using multiband reflectance. *Remote Sensing of Environment, 59(3)*, 530-536.

Bicknell, B. R., Imhoff, J. C., Kittle, J. L., Donigian, A. S., & Johanson, R. C. (1997). *Hydrological Simulation Program--Fortran: User's manual for version 11.* National Exposure Research. Athens: U.S.Environmental Protection Agency.

Black, C. (1965). *Methods of Soil Analysis* (Vol. 9). American Society of Agronomy.

Bleu, P. (2013). *Threats to Soils in Mediterranean Countries.* Plan Bleu.

Bodoque, J. M., Diez-Herrero, A., Martin-Duque, J. F., Rubiales, J. M., Godfery, A., Pedraza, J., et al. (2005). Sheet erosion rates determined by using dendrogeomorphological analysis of exposed tree roots: two examples from Central Spain. *Catena, 64(1)*, 81-102.

Bolline, A., & Rousseau, P. (1978). Erodibilité des sols de moyenne et haute Belgique. Utilisation d'une méthode de calcul du facteur K de l'équation universelle de perte en terrequation of soil loss. *Géographique de Liège, 4*, 127-140.

Bouraoui, F. G. (1997). A distributed physical approach for surface-subsurface water transport modeling in agricultural watersheds. *Hydrology*, 79-92.

Bouraoui, F., Vachaud, G., Haverkamp, R., & Normand, B. (1997). A distributed physical approach for surface-subsurface water transport modeling in agricultural watersheds. *Journal of Hydrology, 203(1)*, 79-92.

Bouslihim, Y. I., Bouslihim, Y., Kacimi, I., Brirhet, H., Khatati, M., Rochdi, A., et al. (2016). Hydrologic Modeling Using SWAT and GIS, Application to Subwatershed Bab-Merzouka (Sebou, Morocco). *Geographic Information System, 8(01)*, 20-27.

Brant, J. B., Myrold, D. D., & Sulzman, E. W. (2006). Root controls on soil microbial community structure in forest soils. *Oecologia, 148(8)*, 650-659.

Breiby, T. (2006). Assessment of Soil Erosion Risk within a Subwatershed using GIS and RUSLE with a Comparative Analysis of the use of STATSGO and SSURGO Soil Databases. *Papers in Resource Analysis, 8*.

Brittain, H. G. (2002). Particle-Size Distribution, Part III Determination by Analytical Sieving Harry G. Brittain. *Pharmaceutical Technology, 26(12)*, 56-64.

Brooks KN, F. P. (2003). *Hydrology and the management of watesheds.*

CÂRDEI, P. (2010). *The dimensional analysis of the USLE_MUSLE soil erosion model.* National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry (INMA).

Cerdan, O., Le Bissonnais, Y., Souchere, V., King, C., Antoni, V., Surdyk, N., et al. (2006). *Guide méthodologique pour un zonage départemental de l'érosion des sols.* Synthèse et recommandations générales.

Chalouan, A., Galindo-Zaldivar, J., Akil, M., Marin, C., Chabli, A., Ruano, P., et al. (2006). Tectonic wedge escape in the southwestern front of the Rif Cordillera (Morocco). *Tectonics of the Western Mediterranean and North Africa. Geological Society, London, Special Publications, 262(1)*, 101-118.

Comary, Y., & Masson, J. (1964). Etude de conservation des eaux et du sol au centre de recherches du génie rural de tunisie. In *Application à un projet-type de la formule de pertes de sols de Wischmeier* (Vol. 2, pp. 3-26). Tunisia: Cahiers ORSTOM.

Dabanga. (2015). Egypt, Sudan, Ethiopia to meet over Blue Nile waters in Khartoum. *Dabanga*, https://www.dabangasudan.org/en/all-news/article/egypt-sudan-ethiopia-to-meet-over-blue-nile-waters-in-khartoum.

Dahan, R., Boughlala, M., Mrabet, R., Laamari, A., Balaghi, R., & Lajouad, L. (2012). *A Review of Available Knowledge on Land Degradati on in Morocco.* OASIS Country Report.

De Pley, J., Auzet, A. V., & Sala, M. (1989). Soil erosion map of western Europe. *Cremlingen-Destedt (Allemangne de l'Ouest), Lawrence (Kansas): Catena Verlag*.

De Roo, A. (1996). Soil erosion assessment using GIS. In *Geographical information systems in hydrology* (pp. 339-356). Dordrecht; Boston: Kluwer Academic Publishers.

EAA. (1999a). *Environment in the European Union at the turn of the century. European Environment Agency.*

Ecology. (2016). *Water Quality Guide: Recommended Pollution Control Practices for Homeowners and Small Farm Operators.* No. 87-30 (Revised) November 1994 (Paper Version), Department of Ecology, Washington.

Eid, A. N., El Garouani, A., & Chabane, S. S. (2016). Opportunities in the water-energy-food security nexus: exploring novel ways to increase benefit and cooperation in the Eatern Nile Basin. *Communication in the International Conference: Water, Energy & Climate Change WECC2016. 1-4 June 2016.* Marrakesh, Morocco.

Eid, A. N., El Garouani, A., El Aroussi, O., & Chabane, S. S. (2016). Evaluation of soil erosion and deposition process bu using Geographical Information System and Remote Sensing in Wadi El Malleh watershed (Morocco). *Communication in the 5th International Symposium of Water and Climate Network, Organized by Sidi Mohamed Ben Abdellah University, University of Rouen and IRD, October 12- 13, 2016.* Fez, Morocco.

El Aroussi, O. (2013). *PhD thesis: Modelling and mapping of soil erosion on the Wadi El Malleh (Pre-Rif, Morocco) catchment using remote sensing and GIS.*

El Aroussi, O., El Garouani, A., & Jabrane, R. (2013). Modelling and mapping of soil erosion on the oued el malleh catchement using remote sensing and GIS. *Urban and Environmental Engineering*, 302-307.

El Garouani, A., Chen, H., Lewis, L., Tribak, A., & Abahrour, M. (2009). Cartographie de l'utilisation du sol et de l'érosion nette à partir d'images satellitaires et du SIG Idrisi au Nord-Est Marocain. *Télédétection, 8(3)*, 193-201.

El Garouani, A., Laurence, A. L., & Hao, C. (2007). Modelling soil erosion and deposition within a Mediterranean mountainous environment utilizing remote sensing and GIS – Wadi Tlata, Morocco. *J. of Modelling soil erosion and deposition*.

ENTRO. (2015). *Eastern Nile Technical Regional Office (ENTRO)*. Retrieved from http://entroportal.nilebasin.org/pages/about.aspx

Eriksson, N. (2003). Adaptation of the Agricultural Non-point SourcePollution Model to the Morsa Watershed.

ESRI. (2005, December 31). *Annual Report and Review of Research 2005.* Retrieved July 29, 2016, from The Economic and Social Research Institute: https://www.esri.ie/pubs/AnnualReport2005.pdf

FAO. (n.d.). *Irrigation Water Management: Irrigation methods*. Retrieved 2016, from FAO CORPORATE DOCUMENT RPOSIRTORY: http://www.fao.org/docrep/s8684e/s8684e0a.htm

FAO, (. (1990). *Conservation des sols et des eaux dans les zones semi-arides.* Rome: Bulletin pédologique.

FAOSTAT. (2014, October 23). *FAOSTAT Emissions database*. Retrieved from http://faostat.fao.org/site/698/default.aspx.

Feng, X., Wang, Y., Chen, L., Fu, B., & Bai, G. (2010). *Modelling soil erosion and its response to land-use change in hilly catchments of the Chinese Loess Plateau.*

Fournier. (1967). The erosion in research and soil conservation in the African continent. *African soil, 12(1)*, 53-96.

Gitas, I. Z., Douros, K., Minakou, C., Silleos, G. N., & Karydas, C. G. (2009). Multi-temporal soil erosion Risk assessment in N. Chaldiki using modified USLE raster model. *EARSel eProceedings, 8(1)*, 40-52.

Guosong Zhao, H. X. (2010). Assessment of ASTER GDEM Performance by Comparing with SRTM and ICESat/GLAS Data in Central China.

Heusch, B., Kalman, R., Duhamel, P. L., & Robert, P. (1970). Erosion, transport solide, sédimentation. *Etude sur l'erosion, 10*, 390.

Hickey, R., Burns, E., Bolte, J., & Walker, D. (2005). *Development of a statewide erosion vulnerability screening tool for Oregon.* Retrieved June 2016, from http//www.siue.edu/geography/online/Hickey05.pdf

Hjulstorm, F. (1935). The Morphological Activity of Rivers as illustrated by the River Fyris. *Inaugural Dissertation, 10*.

Igue, K., Farmer, W. J., Spencer, W. F., & Martin, J. P. (1972). Volatility of organochlorine insecticides from soil: Effect of relative humidity and sil water content on dieldrin volatility. *Soil Science Society of America Journal, 36(3)*, 447-450.

Jahn, R., Blume, H. P., Asio, V. B., Spaargaren, O., & Schad, P. (2006). *Guidelines for Soil Description.* Rome: FAO.

Jensen, M. E., Burman, R. D., & Allen, R. G. (1990). Evapotranspiration and irrigation water requirements. *ASCE*.

Johnson, A. I. (1963). *A Field Method for Measurement of Infiltration.* Washington: US Governemnt Priniting Office.

Jones, D. S., Kowalski, D. G., & Shaw, R. B. (1996). *Calculating revised universal soil loss equation (RUSLE) estimates on department of defense lands: A review of RUSLE factors and US army land condition-trend analysis (LCTA) data gaps.* Colorado State University, Forest Science. Fort Collins: Center for Ecological Management of Military Lands.

Kim, H. S. (2006). *Soil erosion modeling using RUSLE and GIS on the Imha watershed, South Korea (Doctoral dissertation).* Fort Collins, Colorado: Colorado State University.

Kinsel, W. G. (1980). *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural ManagementSystems. U.S.* Department of Agriculture.

Lahlou, A. (1994). *Envasement des barrages au Maroc.* SMD Wallada, Maroc.

Lai, J., & Ren, L. (2007). Assessing the size dependency of measured hydraoulic conductivity using double-ring infiltrometers and numerical simulation. *Soil Science Society of America Journal, 71(6)*, 1667-1675.

Lars, R. (2013). Water, food and energy security in shared river systems. *SDEWES 2013.* https://www.youtube.com/watch?feature=player_embedded&v=c7LIzh_BEgY.

Le Bissonnais, Y., Dubreuil, N., Daroussin, J., & Gorce, M. (2004). Modélisation et cartographie de l'aléa d'érosion des sols à l'échelle régionale. *Etude et Gestion des Sols, 11(3)*, 307–321.

Lewis, L. A., Verstraeten, G., & Zhu, H. (2005). RUSLE applied in a GIS framework: Calculating the LS factor and deriving homogeneous patches for estimating soil loss. *International Journal of Geographical Information Science, 19(7)*, 809-829.

Marko Keskinen, P. S. (2015). Water-Energy-Food Nexus in a Transboundary River Basin:The Case of Tonle Sap Lake, Mekong River Basin.

Martonne, E. (1942). New global map of the aridity index. *Journal of Geography, 51*, 242-250.

Matherne, A. M. (2006). *Effects of roads and well pads on erosion in the Large Canyon watershed.* New Mexico.

McArthur, J. M., Ravenscroft, P., Banerjee, D. M., Milsom, J., Hudson, Edwards, K. A., et al. (2008). How paleosols influence groundwater flow and arsenic pollution: a model from the Bengal Basin and its worldwide implication. *Water resources research, 44(11)*.

McKenzie, N., Jacquier, D., Isbell, R., & Brown, K. (2004). *Australian soils and landscapes: an illustrated compendium.* Collingwood, Victoria: CSIRO Publishing.

Melesse, A. M., & Jordan, J. D. (2002). A comparison of fuzzy vs. Augmented-ISODATA classification algorithms for cloud-shadow discrimination from Landsat images. *J of Photogrammetry Engineering and Remote Sensing, 68*, 905-911.

Merritt, W. S., Letcher, R. A., & Jakeman, A. J. (2003). A review of erosion and sediment transport models. *Environmental Modelling & Software, 18(8)*, 761-799.

Mohtar, R. H., & Daher, B. (2012). *Water, Energy, and Food: The Ultimate Nexus.* Food, and Biological Engineering. Encyclopedia of Agricultural.

Montier, C., Daroussin, J., King, D., & Le Bissonnais, Y. (1998). *Cartographie de l'aléa "Erosion des Sols" en France.* Orleans: INRA.

Moore, I. D., Grayson, R. B., & Ladson, A. R. (1991). Digital terrain modeling: A review of hydrological, geomorphological and biological applications. *Hydrological Processes, 5(1)*, 3-30.

MORGAN, J. N. (1998). THE EUROPEAN SOIL EROSION MODEL (EUROSEM): A DYNAMICAPPROACH FOR PREDICTING SEDIMENT TRANSPORT FROM. *Earth Surface Processes and Landforms*, 527–544.

Morgan, R. P. (1998). The EUROSEMmodel', in Boardman, J. B. and Favis-Mortlock, D. (Eds.) Global Change: modelling soil erosion by water, NATO ASI series, Series 1:. London.

Muhammad, K. T. (2013). Study of soil erosion in Chaqan watershed using Universal Soil Lose and Modified Musgrave Equations. *International Research Journal of Agricultural Science and Soil Science, 3(7)*, 275-282.

Mullan, D., Favis-Mortlock, D., & Fealy, R. (2012). Addressing key limitations associated with modelling soil erosion under the impacts of future climate change. *Agriculture and Forest Meteorology, 156*, 18-30.

Musgrave. (1947). The quantitive evaluation of factors in water erosion, a first approximation. *Soil and water conservation, 2(3)*, 133-138.

Nearing, M. (2001). Potential changes in rainfall erosivity in the U.S with climate change during the 21st century. *soil and water conservation*.

Nearing, M. A. (1997). A single, continuous function for slope steepness influence on soil loss. *Soil Science Society of America Journal, 61(3)*, 917-919.

Nearing, M. A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., et al. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. *Catena, 61(2)*, 131-154.

Nearing, M. A., Lane, L. J., & Lopes, V. L. (1994). Modeling soil erosion. *Soil erosion research methods, 2*, 127-156.

Nowak, D. J., & Greenfield, E. J. (2010). Evaluating the national land cover database tree canopy and imprevious cover estimates across the conterminous United States: a comparison with photo-interpreted estimates. *Environmental Management, 46*(3), 378-390.

Offermans, R. J., & De Roo, A. P. (1995). LISEM: a physically-based hydrological and soil erosion model for basin-scale water and sediemnt management. *Modelling and Management of Sustainable Basin-scale Water Resource Systems (Proceedings of a Boulder _, _ rt. 231*, pp. 399-408. IAHS Publ.

Oldeman, L. R., Hakkeling, R. T., & Sombroek, W. G. (1990). *world map of the status of human-induced soil degradation (GLASOD).* Nairobi: United Nations Environment Program and International Soil Reference and Information Centre (UNEP/ISRIC).

Oyedele, J. D. (1996). *Effects of Erosion on the Productivity of Selected Southwestern Nigerian Soils: [Dissertaion].* Department of Soil Science, Obafemi Awolowo University, Ile-Ife, Nigeria.

Pelton, J., Frazier, E., & Pickilingis, E. (2015). *Calculating Slope Length Factor (LS) in the Revised Universal Soil Loss Equation (RUSLE).* Retrieved March 26, 2016, from GIS 4 Geomorphology: http://gis4geomorphology.com/ls-factor-in-rusle/

Pieri, L., Bittelli, M., Wu, J. Q., Dun, S., Flanagan, D. C., Pisa, P. R., et al. (2007). Using the Water Erosion Prediction Project (WEPP) model to simulate field-observed runoff and erosion in the Apennines mountain range. *Journal of Hydrology, 336(1)*, 84-97.

Pitt, R. (2007). Erosion Mechanisms and the Revised Universal Soil Loss Equation (RUSLE). In R. Pitt, *Construction Site Erosion and Sediment Controls, Planning, Design and Performance.*

Quattara, T., Dubois, J.-M., & Hugh, J. (2003). Un nouveau modèle d'érosion hydrique pour les milieux semi-arides de forte énergie à partir d'images multi sources et de données auxiliaires. *Télédétection, 3*, 151-163.

Rahman, P. M. (2014). *The Geopolitics of Water in the Nile River Basin.*

Renard, K. G., Foster, G. R., Weesies, G. A., & Porter, J. P. (1991). RUSLE: revised universal soil loss equation. *Soil and Water Conservation, 46(1)*, 30-33.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)* (Vol. 703). Washington: U.S. Department of Agriculture.

Renschler, C. S. (2003). Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. *Hydrological processes, 17(5)*, 1005-1017.

Renschler, C. S., & Harbor, J. (2002). Soil erosion assessment tools from point to regional scales-the role of geomorphologists in land management research and implementation. *Geomorphology, 47(2)*, 189-209.

Ringler, C. (2015). *THE WATER ENERGY FOOD NEXUS*. Retrieved 12 1, 2015, from International Food Policy Research Institute: https://www.ifpri.org/project/water-energy-food-nexus

Roose, E. J. (1977). Use of the universal soil loss equation to predict erosion in West Africa. *Soil erosion: prediction and control, 21*, 60-74.

Schertz, D., Moldenhauer, W., Livingston, S., Weesies, G., & Hintz, E. (1989). Effect of past soil erosion on crop productivity in Indiana. *Soil and Water conservation, 44(6)*, 604-608.

Schmidt, J., Evans, I. S., & Brinkmann, J. (2003). Comparison of polynomial models for land surface curvature calculation. *International Journal of Geographical Information Science, 17(8)*, 797–814.

Sharma, K. D., & Correia, J. F. (1987). An upland soil erosion model derived from the basic principles. *Earth Surface Processes and Landforms, 12(2)*, 205-210.

Sharma, K. D., Menenti, M., Huygen, J., & Vich, A. (1996). Modeling spatial sediment delivery in an arid region using thematic mapper data and GIS. In *Transactions of the ASAE* (Vol. 39(2), pp. 551-557).

Shepherd, K. R. (1986). Planting, Site Preparation and Maintenance. *In plantation silviculture*, 162-200.

Shi, Z. H., Cai, C. F., Ding, S. W., Li, Z. X., Wang, T. W., & Sun, Z. C. (2002). Assessment of Erosion Risk with the RUSLE and GIS in the Middle and Lower Reaches of Hanjiang River. *12th ISCO.* Beijing, China.

Shi, Z. H., Cai, C. F., Ding, S. W., Wang, T. W., & Chow, T. L. (2004). Soil Conservation Planning at the Small Watershed Level Using RUSLE with GIS: a Case Study in the Three Gorge Area of China. *Catena, 55(1)*, 33–48.

Shrestha, B., Babel, M., Maskey, S., & Griensven, A. (2013). *Impact of climate change on sediment yield in the Mekong River basin: A case study of the Nam Ou basin.*

Smith, H. J. (1999). Application of Empirical Soil Loss Models in southern Africa: a review. *South African Journal of Plant and Soil*, 158-163.

Smith, S. J., Kissel, D. E., & Williams, J. R. (1980). *Nitrate production, uptake, and leaching.* U. S. Department of Agriculture. Science and Education Administration.

Sonneveld, B. G., & Dent, D. L. (2009). How good is GLASOD? *Environmental Management, 90(1)*, 274-283.

Tim, U. (1996). Emerging technologies for hydrologic and water quality modeling research. In *Transactions of the ASAE* (Vol. 39(2), pp. 465-476).

Tiwari, A. K., Risse, L. M., & Nearing, M. A. (2000). Evaluation of WEPP and its comparison with USLE and RUSLE. *Transactions of the ASAE, 43(5)*, 1129.

Valdiya, K. S. (1998). *Dynamic Himalaya.* Universities Press.

van der Krogt, H. J. (2014). Insights in the water-energy-food nexus in the Nile Basin with the new Eastern Nile Water Simulation Model. *International Conference Sustainability in the Water-Energy-Food Nexus.* Bonn.

Van Rompey, A., Bazzoffi, P., Jones, R., Montanarella, L., & Govers, G. (2003). *Validation of soil erosion, risk assessments in Italy.* Luxembourg: European Soil Bureau Research.

Vanoni, V. A. (1975). *Sedimentation Engineering: American Society of Civil Engineers.* Manuals and Reports on Engineering Practice.

Vasagar, J. (2004). *Storms lie ahead over future of Nile.*

Whiting, P. J., Bonniwell, E. C., & Matisoff, G. (2001). Depth and areal extent of sheet and rill erosion based on radonuclides in soils and suspended sediment. *Geology, 29(12)*, 1131-1134.

Williams. (1990). *The erosion-productivity impact calculator (EPIC) model: A case.*

Williams, B. (1972). *Sediment yield computed with universal equation.*

Williams, J., Nearingm, nicks, A., Skidmore, E., Valentin, C., King, K., et al. (1996). Using soil erosion models for global change studies. *Soil and Water Conservation, 51(5)*, 381-385.

Wischmeier and Smith, D. D. (1965). *Predicting rainfall-erosion losses from.*

Wischmeier, W. H. (1966). *Surface runoff in relation to physical and management factors.* Brazil: In Proc. First Pan Am. Soil Conserv. Congress Sao Paolo.

Wischmeier, W. H., & Smith, D. D. (1958). *Rainfall energy and its relationship to soil loss.* Transactions American Geophysical Union.

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses. In *A guide for conservation planning* (pp. 1-537). Washington: U.S. Department of Agriculture.

Wischmeier, W. H., Johonson, C. B., & Cross, B. V. (1971). Soil erodibility nomograph for farmland and construction sites. *Journal of soil and water conservation, 26*, 189-192.

Yang, D., Kanae, S., Oki, T., Koike, T., & Musiake, K. (2003). Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes, 17(14)*, 2913-2928.

Yassoglou, N., Montanarella, L., Govers, G., Van Lynden, G., Jones, R. J., Zdruli, P., et al. (1998). *Soil Erosion in Europe.* European Soil Bureau.

Yearke, L. W. (1971). River erosion due to chanel relocation. *Civil Engineering*.

Young, R. A., Onstad, C. A., Bosch, D. D., & Anderson, W. P. (1987). *AGNPS, Agricultural Non-Point-Source Pollution Model : a watershed analysis tool.* Washington: U.S. Dept. of Agriculture, Agricultural Research Service.

Zhang, L., O'Neill, A. L., & Lacey, S. (1996). Modelling approaches to the prediction of soil erosion in catchments. *Environmental Software, 11(1)*, 123-133.

Zhang, X., & Nearing, M. (2005). Impact of climate change on soil erosion, runoff and wheat productivity in central Oklahoma. *Catena, 61(2)*, 185-195.

Zhang, X., Srinivasan, R., Debele, B., & Hao, F. (2008). Runoff Simulation of the Headwaters of the yellow river using the SWAT model with three snowmelt Algorithms1. *The American Water Resources Association*, 48-61.