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Impact Evaluation of Sustainable Land Management (SLM) Options to Contribute to Land Degradation Neutrality in Rmel Catchment in Northeastern Tunisia

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ABSTRACT

Soil erosion is a natural process causing serious land degradation problems. In Tunisia, soil erosion represents a serious environmental problem. The Rmel watershed located in the Governorate of Zaghouan in north-eastern Tunisia and covering an area of 679 square kilometers, suffers from this problem. It was thus selected to estimate annual soil loss using the Revised Universal Soil Loss Equation (RUSLE), and geographic information system (GIS).

RUSLE model's parameters (R, K, LS, C, and P) were derived from digital elevation model (DEM), average annual precipitation, soil type map and land cover map. They were computed as raster layers in a GIS environment, then multiplied together to predict soil erosion rates, and to generate a soil erosion risk map.

Based on this study, the annual soil loss varies across the Rmel watershed from 0 to 186 ton ha^{-1} $year^{-1}$. The average and total annual soil loss potential of the study watershed was 2.18 ton ha^{-1} $year^{-1}$and 22.8 million ton $year^{-1}$, respectively. About 85% of the watershed was categorized low risk class, 9.5% moderate class and 5.5% high to severe erosion risk classes.

The predicted amount of soil loss and its spatial distribution could provide indications to plan sustainable land use and management, by showing where the potential erosion hotspots are.

The data generated by this project can contribute to improve current land management and related economic activities by making available an impact evaluation tool for sustainable land management (SLM) practices, to achieve sustainable economic development.

Sustainable Land Management (SLM) practices have been advocated by several worldwide partnerships – such as the CGIAR, the United Nations Convention to Combat Desertification (UNCCD) and Economics of Land Degradation (ELD) – but still selectively applied. This research has been conducted in the frame of the project "Impact Evaluation of SLM Options to Achieve Land Degradation Neutrality" a holistic, innovative initiative aiming at providing solid geoinformatics guidance for planning and impact evaluation of SLM practices.

Keywords: Soil erosion, Land degradation, Sustainable land management, RUSLE, GIS.

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LIST OF ACRONYMS AND ABBREVIATIONS

DEM	Digital Elevation Model
C	Cover-management factor
GeOC	Geo-Informatics Options by Context
FAO	Food and Agricultural Organization
GIS	Geographical information system
GPS	Global Positioning System
Ha	hectare
LWC	land water conservation
K	Soil erodibility factor
Km	kilometer
LDN	Land Degradation Neutrality
LS	Slope Length and Slope Steepness
m.a.s.l	meter above sea level
P	Conservation support practice factor
R	Rainfed erosivity factor
RUSLE	Revised Universal Soil Loss Equation
SLM	Sustainable Land Management
t/ha/yr.	tone per hectare per year
USDA	United State Department of Agriculture
USGS	United States Geological Survey
WEPP	Water Erosion Predictions Project
WOCAT	World Overview of Conservation Approaches and Technologies

INTRODUCTION

The loss of soil from land surfaces by erosion is globally widespread and reduces the productivity of natural ecosystems as well as agricultural, forest, and pasture ecosystems (Lal et al., 1990).

Soil erosion is a growing problem, in particular, in the agricultural areas where it not only leads to decreasing agricultural productivity but also reduces the availability of water.

In addition to the researchers' efforts and in order to protect their natural resources, many countries, mainly those threatened by this environmental problem, have adopted different prevention or mitigation strategies. In Tunisia, about 3 million ha are threatened by erosion of which 50% are seriously affected. For this reason, Tunisia has adopted two institutional strategies - the first during the period ranging from 1990 to 2001 and the second between 2002 and 2011- which main objective is to protect and to preserve soil and reduce erosion effects (DG/ACTA, 2002).

This study was conducted to quantify soil erosion in a representative watershed (Rmel Watershed). The revised universal soil loss equation methodology was adopted and implemented in a Geographical Information System (GIS) environment.

One of the objectives of this work is to provide a method for mapping areas at different erosion risk and illustrate the possibility to determine how a targeted change in soil occupation, could limit the process of soil degradation. The assessment of the soil erosion risk in the study area required mapping and analysis of the many factors involved in the erosive process: the rainfall erosivity, the slope and the slope length, the soil erodibility, vegetation cover and cropping practices. Each factor has a different spatial pattern in the study area. This has led to a multitude of data to map, store, structure, and process in a rational way.

Land Degradation Neutrality (LDN), defined as the use of land resources while maintaining their healthy and productive states so that there is no net land degradation, is critical for the achievement of the Sustainable Development Goals set by the United Nations. The high contextual diversity in drylands does not favor the design and application of "uniform blanket" policies. Therefore, Sustainable Land Management (SLM) options that fit specific social and ecological contexts are required to achieve LDN over large scales where a significant impact can be expected.

The project “Impact Evaluation of SLM Options to Achieve Land Degradation Neutrality”, funded by the German Federal Ministry for Economic Cooperation and Development (BMZ and coordinated by ICARDA intended to support this process by developing tools that allow to simulate the impacts of SLM practices at the landscape scale. The erosion modelling approach presented here is part of these tools.

Tunisia was selected by the project because:

- It is a dryland country facing a high risk of land degradation over more than 50% of its territory.
- Land and water conservation practices (LWC, CES in French) implemented throughout the country over decades are in need of impact assessment, to improve policies promoting SLM and to offer learning cases for the international community of SLM practices.

This report contains five chapter:

Chapter I; literature review; inventory and analysis of already related publications: thesis, reports, books, papers, etc.

Chapter II; Study area and the various data needed to analyze erosion;

Chapter III; Field work: sites visited and presentation of different soil and water conservation measures with descriptions and photos illustrative.

Chapter IV; Field inventory of Soil and water conservation measures using the standardized SLM options by context template.

Chapter V; Modelling (RUSLE model) and quantification of the erosion with GIS.

Chapter VI; Result discussion and classification of intervention zones according to the rate of erosion, choice of priority zones for implementation of soil and water conservation measures.

CHAPITRE I

LITERATURE REVIEW

1. Watershed

Watershed is the land area that drains into a particular watercourse (Hassan et al.,2005).

A watershed is a surface area from which runoff is drained and collected through a common outlet. Mostly, the term is similar to a drainage basin or catchment area. Hydrologically, it is an area from which the runoff drains through a particular point in the drainage system. It includes the natural resources of a catchment, especially soil, water and vegetative factors. Socioeconomically a watershed includes people, their farming system and interactions with land resources, economic and social activities and cropping strategies (Moard, 2005).

2. Land degradation

Land degradation is defined as a decline in the productive capacity of the land in relation to current or possible land uses (Berry, 2003).

It can be considered in terms of the loss of actual or potential productivity or utility because of natural or anthropic factors; it is the decline in land quality or reduction in its productivity. In the context of productivity, land degradation results from a mismatch between land quality and land use (Beinroth et al., 1994).

There are three categories of land degradation which are: - I) Physical land degradation such as water and wind erosion, crusting and sealing, compaction, waterlogging and reduced infiltration, - II) Chemical land degradation which includes acidification, salinization, nutrient depletion, pollution and III) Biological land degradation such as soil organic matter decline, and depletion of vegetation cover and soil fauna (FAO, 2001).

Land degradation, especially in ecosystems with arid and semi-arid conditions where rainfall is low, also brings about is a change in the land cover (the surface and sub-surface area) of drylands.

3. Erosion

The process of soil erosion by water starts from the detachment of soil particles by raindrop impact, followed by transportation by the force of flowing water. When the flowing water losses its energy deposition will occur (Foster and Meyer, 1977; Wischmeier and Smith, 1978).

Depending on the stage of progress in the erosion cycle and the position in the landscape, there are various forms of soil erosion by water. Splash, sheet, rill, and gully are the major ones (Mitiku, 2006). (Figure 1)

Rain splash erosion occurs when water falling directly on to the ground during rainstorms or intercepted by the canopy, impacts with the ground. It weakens the natural soil aggregates and breaks them down (Morgan, 1995).

Water that cannot infiltrate into the soil will generate the runoff. If the runoff does not concentrate, sheet erosion can occur. This, uniformly moves the productive topsoil particles detached by the rain-splashdown slope (Mitiku, 2006).

Rill erosion is result of concentrated runoff resulted from intensive rainstorms producing more observable features of linear erosion, this often happens on steep slopes and in depressions. It can form channels up to 50 cm deep or more (Nyssen et al., 2006).

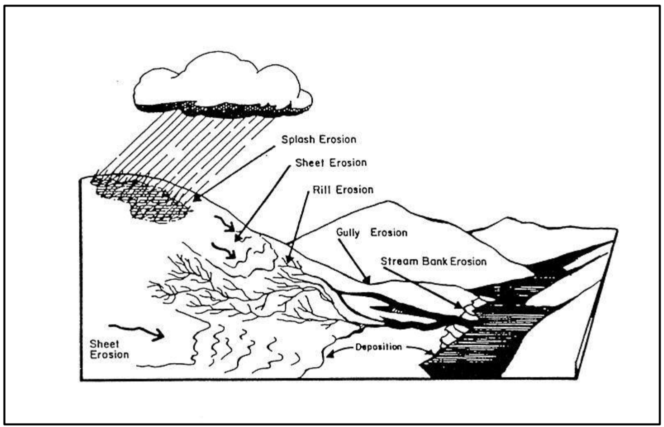

Figure 1: The mechanisms of soil erosion (USACE, 1985)

4. Factors affecting erosion :

Generally, there are five primary types of factors that affect soil erosion and that are dependent on each other. These are; the climatic factor, soil, topography, land use, and land cover. Natural and human disturbances dramatically increase erosion (Costick, 1996).

- **Climatic Factors**

Precipitation, temperature, humidity, wind, and solar radiation are Climatic attributes that affect erosion. Rainfall erosivity is a property of rainfall that quantifies the potential capacity of rain to cause erosion in a given circumstance (Saavedra, 2005).

- **Soil**

Due to of the effect of a range of soil properties such as soil texture, structure, soil moisture, organic matter content and chemical and biological characteristics, soils are different in their resistance to erosion (Vrieling, 2007). The susceptibility of soil to erosion agents is known as soil erodibility (Lal, 2001). Soil erodibility factors reflect the resistance of soil to both detachment and transport (Morgan, 1995). In general, soils having faster infiltration rates, higher levels of organic matter and better soil structure have a greater resistance to erosion (Saavedra, 2005).

In addition, as greater force is required to move them, larger particles are more resistant to transportation. The erodibility of soil with particle size less than 0.06 is instead low due to cohesiveness properties. Therefore, silt and fine sand are the particles that are less resistant to erosion (Petter, 1992).

- **Topography**

The effect of topography on erosion is complex. Slope length (L) describes the distance between the origin and termination of inter-rill processes. The local slope gradient (S) influences flow velocity and thus the rate of erosion (Renard et al., 1997). Increase in slope length and slope steepness will increase erosion as a result of respective increases in volume and velocity of surface runoff (Doere, 2005).

- **land cover/Land use**

The meaning of land use and land cover are different. According to FAO, (2000) Land use is “the arrangements, activities and inputs that people undertake on a certain land cover type". Land cover is defined as "the observed biophysical cover on the earth’s Surface”. In general land cover types refers to the vegetation of the area. Vegetation can reduce soil erosion by: increasing the degree of infiltration of water into the soil, protecting the soil versus the action of falling raindrops, reducing the speed of the surface runoff, binding the soil mechanically, maintaining the roughness of the soil surface, and improving the chemical, physical and biological soil properties (De Asis and Omasa, 2007).

- **Conservation Practice**

Soil covered by crop plants, cover crops, residues or mulches, would be protected from wind and water erosion. Infiltrations of water would be enhanced. Minimum tillage, cover cropping, managed grazing, strip cropping, crop rotation, contour planting, and control structures are some of the practices that protect soils from water erosion and maintain soil cover. These practices principally affect erosion by reducing the amount and rate of runoff and by modifying the flow pattern, grade, or direction of surface runoff (Renard and Foster, 1983).

Especially in agricultural areas, conservation practices such as contouring, strip cropping, or terracing, reduce soil losses. For instance, in areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery. The effectiveness of such practices is often analyzed with a support practice factor (P-factor) which is defined as the ratio of soil loss with the practice applied and up and down slope cultivation (Wischmeier and Smith, 1978; Renard et al., 1997). P-values have been assigned to land use classes using values ranges from 0 to 1 (Kaltenrieder, 2007).

5. Sustainable Land Management

Sustainable Land Management has been defined by the TerrAfrica initiative as: 'the adoption of land use systems that, through appropriate management practices, enables land users to maximize the social and economic benefits from the land while maintaining or enhancing the ecological support functions of the land resources'.

SLM is the combination of technologies, activities and policies aimed at integrating socio-economic principles with environmental concerns so as to simultaneously maintain or enhance production, reduce the level of production risk, prevent soil and water degradation and protect the potential of natural resources, being economically viable and socially acceptable (Dirk Kloss, Michael Kirk and Max Kasparek, 2004

SLM includes management of soil, water, vegetation and animal resources. It also includes ecological, economic and socio-cultural dimensions (Hurni, 1997). These three are not separate, but interconnected. They are also referred to as the '3 Es' of sustainable development - Equality, Economy, and Ecology (UNESCO, 2006)

- Ecologically, SLM technologies – in all their diversity – effectively combat land degradation. But a majority of agricultural land is still not sufficiently protected, and SLM needs to be spread further.
- Socially, SLM helps securing sustainable livelihoods by maintaining or increasing soil productivity, thus improving food security and reducing poverty, both at household and landscape levels.
- Economically, SLM pays back investments made by land users, communities or governments. Agricultural production is safeguarded and enhanced for small-scale subsistence and large-scale commercial farmers alike, as well as for livestock keepers. Furthermore, the considerable off-site benefits from SLM can often be an economic justification in themselves.

The World Overview of Conservation Approaches and Technologies (WOCAT) defines SLM as the use of land resources for the production of goods and services to meet changing human needs while simultaneously ensuring the long-term productive potential of land resources and the maintenance of their environmental functions (WOCAT 2007). However, the United

Nations Convention to Combat Desertification (UNCCD) defines SLM as “land managed in such a way as to maintain or improve ecosystem services for human well-being, as negotiated by all stakeholders” (Winslow et al. 2011).

6. Hydrologic models

To predict and evaluate soil erosion, several models have been developed which are a simplification of reality. Erosion modeling is the process of describing soil particle detachment, transport, and deposition mathematically on land surfaces. Erosion models are used as a tool: (1) to predict and assess soil loss for conservation planning, project planning, regulation, and for soil erosion inventories. (2) to predict where and when erosion is occurring and hence helping the conservation planner to target efforts to reduce erosion. (3) for understanding erosion processes and their interaction and for setting research priorities (Lal 1994).

Several models were developed for the assessment of soil loss and some of them are CREAMS, WEPP, SLEMSA, EUROSEM, GUESS, USLE, RUSLE, RMMF and MUSLE etc. In general, the models are categorized into three types: namely conceptual, empirical and physically based models (Saavedra, 2005).

- **Conceptual models** include only a general description of catchment processes, without including the details occurring in the complex process of interactions (Renschler 1996). This allows these models to provide an indication of the qualitative and quantitative effects of land use changes, without requiring a large amount of spatially and temporally distributed input data (Merritt et al., 2003).
- **Physically based models** include the laws of conservation of mass and energy, where energy can change form but total energy remains the same (Petter, 1992). They are based on the understanding of the physics of erosion processes
- **Empirical models** refer to a simplified representation of a system or phenomenon which is based on experience or experimentation. Examples of these models are SLEMSA, MUSLE, USLE, RUSLE etc... The computational and data requirements for such models are usually less than for conceptual and physically based models (Li et al., 1996). By considering its ease of implementation, reliability, and its relatively accurate results RUSLE was chosen and used for this study.

6.1. Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) was developed to incorporate new research and technology made available since the earlier USLE publication in 1978

(Wischmeier and Smith 1978). The basic form of the equation remained the same, but modifications to several of the factors were made.

The RUSLE has the ability to predict the long-term average annual rate of soil erosion on a field slope caused by rainfall pattern, soil type, topography, crop system and management practices (Renard et al., 1997). In a GIS environment, it can predict erosion potential on a cell-by-cell basis, to identify the spatial pattern of soil loss within a large watershed area (Shi et al., 2003). GIS tools can then be used to isolate and query locations to identify the role of individual variables in contributing to the observed erosion potential value (Saavedra, 2005)

RUSLE estimates the average annual soil loss from this equation below:

$$A = RxKxLSxCxP \qquad (1)$$

Where:

A is the computed soil loss (t $ha^{-1}yr^{-1}$)

R is the rainfall-runoff erosivity factor (MJ $mmha^{-1}h^{-1}yr^{-1}$)

K is the soil erodibility factor (t ha h $ha^{-1}MJ^{-1}mm^{-1}$)

L is the slope length factor (m), S is the slope steepness factor (%)

C is the cover management factor

P is the supporting practices factor.

RUSLE model calculates the average annual soil erosion loss by considering the five factors as defined in equation 1 (Renard et al., 1997).

- **R-factor:**

Rainfall erosivity is defined as the aggressiveness of the rain and it capacity to cause erosion (Lal 1990). The most common rainfall erosivity index is the R factor of USLE (Wischmeier and Smith 1965, 1978) and RUSLE (Lal 1990). The R factor for any given period is obtained by summing, for each rainstorm, the product of total storm energy (E) and the maximum 30-min intensity (I30). Since pluviograph and detailed rainstorm data are rarely available at standard meteorological stations, mean annual (Yu and Rosewell 1996a, b, c; Banasik and Gorski 1994; Renard and Freimund 1994) and monthly rainfall amount (Ferro et al., 1991) have been often used to estimate the R factor for the USLE. The formula proposed by Rango and Arnoldus (1987) was used in this study to estimate the R factor using monthly and annual rainfall data as shown in Eq. (2).

$$\log R = 1{,}74 * \log \sum_{j=1}^{12} \left(\frac{Pi^2}{P}\right) + 1{,}29 \qquad (2)$$

Where: Pi: monthly rainfall in mm, P: annual rainfall in mm

- **K-factor:**

The K-factor is a measure of the inherent erodibility of a given soil under the standard condition of the RUSLE unit plot maintained in continuous fallow. Values for K typically range from about 0.013 to 0.059 SI units, with high-sand and high clay content soils having the lower values and high-silt content soils having the higher values (Foster et al., 1981).

Soil erodibility plays a major role in the ability of water to detach and transport its particles. Some of the major soil properties that affect soil erosion include soil texture, soil organic matter, soil structure and permeability of the soil profile (Wischmeier et al., 1971; Renard et al., 1997). Since information on texture, organic matter, structure and permeability especially at large geographical coverage, are scarce, various studies attempted to estimate K-factor based on soil types (Veldkamp 2002; Roy et al., 2003; FAO 2004; Symeonakis and Drake 2004, 2010). The K-factor in this study was derived from the FAO-IIASA soil map (Fischer et al., 2002) and the translation of soil types into K-factor values (ton ha^{-1} yr^{-1}) was based on Folly (1997).

K factor values were derived based on:

$$K = \frac{(2.1 * M^{1.14}\ (10^{-4}) * (12 - OM)}{7.59} \qquad (3)$$

Where:

K = soil erodibility, OM = soil organic content (%),

M = ((% silt + % sand) *100 - % clay).

- **L and S factors:**

The slope length factor (L) and the steepness factor (S) account for the effects of topography on soil erosion modeling in RUSLE. In general, as slope length (L) increases, erosion increases due to a progressive accumulation of runoff in the downslope direction. As slope steepness (S) increases, soil erosion also increases as a result of the increase in velocity.

Slope length (L) is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient (steepness) decreases enough so that deposition begins or runoff becomes concentrated in a defined channel (Wischmeier and Smith 1978). Slope length (L) is also defined as the ratio of soil loss from the field slope length to that from a 72.6 ft length under otherwise identical conditions. Figure 2 presents the schematic profile of a slope. For cropping land, L is evaluated by the equations used in RUSLE (McCool et al., 1987; McCool et al., 1997; Renard et al., 1997):

$$L = \left(\frac{X_h}{72.6}\right)^m \qquad (4)$$

Where:

X_h: the horizontal slope length in ft

m: a variable slope length exponent

m is related to the ratio ε of rill erosion to interrill erosion by the following equation:

$$m = \frac{\varepsilon}{1+\varepsilon} \qquad (5)$$

ε is computed for conditions when the soil is moderately susceptible to both rill and interrill erosion using the following equation:

$$\varepsilon = \frac{\sin\theta}{0.0896*[3\,(\sin\theta)^{0.8}+0.56]} \qquad (6)$$

Where:

θ = the slope angle.

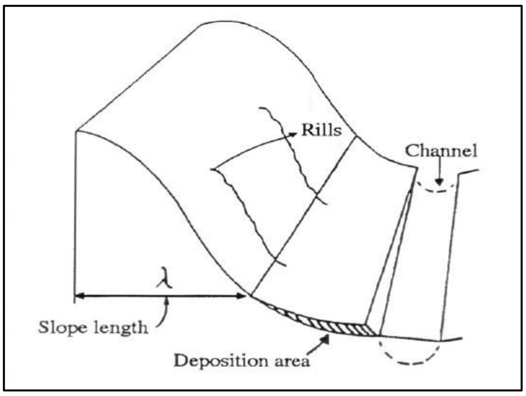

Figure 2: Schematic slope profiles of RUSLE applications (Renard et al., 1997)

The slope steepness (S) is defined as the ratio of soil loss from the field slope to that from a 9% slope under identical conditions. The RUSLE slope steepness equations are given by (McCool et al., 1987; McCool et al., 1997; Renard et al., 1997):

- S=10.8 * sinθ+0.03 $\sigma \leq 9\%$
- S=16.8 * sinθ−0.50 $\sigma > 9\%$

Where:

θ = the slope angle;

σ = the slope gradient in percentage.

- **Cover Management: C-factor:**

The cover and management factor is an index that indicates how crop management and land cover affect soil erodibility. It measures the effects of all interrelated cover and management variables (Renard et al., 1997).

It is used to express the combined effects (reduction of runoff velocity and protection of surface pores) of plants and soil cover as well as those of all other interrelated cover and management variables (Karaburun, A., 2010).

In this study the C factor was derived using remote sensing techniques. A land cover map layer was created from the results of the supervised classification method based on a Landsat 7 ETM satellite image with a 30-meter resolution. The land cover was classified adhering strictly to the Anderson Land Use Classification system (1977). A reclassification was done on the C-Factor layer to portray its sensitivity to erosion.

Surface cover affects erosion by reducing transport capacity of runoff water, by causing deposition in ponded areas, and by decreasing the surface area susceptible to raindrop impact. The surface cover includes crop residue, cryptograms, or other nonerodible material that are in direct contact with the soil surface (Simanton et al., 1984; Box, 1981; and Meyer et al., 1972).

- **P-factor:**

In RUSLE, compared to USLE, extensive data have been analyzed to evaluate the soil conservation effect of contouring. The results have been interpreted to give factor values for contouring as a function of ridge height, furrow grade, and climatic erosivity. New P-factor values for the effect of terracing are also considered in RUSLE that account for a grade along the terrace and for a broader array of strip cropping conditions. Finally, P factors in RUSLE have been developed to reflect conservation practices on rangelands such as pitting, ripping and root plowing. Evaluation of these practices requires estimates of surface roughness and runoff reduction. Some of the P-factor values are slope-dependent.

In RUSLE, the support practice factor is generally applied to lands affected by erosion and accounts for how much management practices such as contouring, terrace, and strip cropping are effective to reduce erosion. For areas where there are not support practices, the P factor is set to 1. (Simms 2003).

7. Geographic Information Systems

Geographic Information Systems are databases that have a spatial component for the storage and processing of the data. So that, they have the potential to store and create maps. It has also the potential for performing multiple analyses or evaluations of scenarios such as model simulations (Maidment and Djokic, 2000).

A Geographic Information System (GIS) is an arrangement of computer hardware, software, geographic data and people that interact to integrate, analyze, and visualize data; identify relationships, patterns, and trends; and find solutions to problems. The system is designed to capture, store, update, manipulate, analyze, and display studied data and used to perform analyses (ESRI, 2005). GIS have been used in various environmental applications since the 1970s; however, extensive application of GIS to hydrologic and hydraulic modeling and flood mapping and management did not begin until the early 1990s (Moore et al., 1991; Vieux and Gauer, 1994; Maidment and Djokic, 2000). The ability to represent elevation in terms of topographic surfaces is central to geomorphological analyses and thus to the importance of representing topography using DEM. It is through the distribution of soil that the land surface changes over the long term and so the ability to link sediment transfer with DEM changes (Schmidt et al., 2000). The redistribution of sediment will drive the long-term landscape change, which in turn will affect the hydrological processes acting within and over individual hillslopes (Brooks and McDonnell, 2000).

Soil erosion is affected by the spatial topography, vegetation, soil properties, and land use. A GIS is a very useful tool to deal with a large number of spatial data and the relationship from various sources in the erosion modeling process. Obtaining different variables important for watershed studies was difficult to do from paper maps and aerial photographs as it was subject to errors related to manual operations and time-consuming. Mapping soil erosion using GIS allows to easily identify areas that are at potential risk of erosion and provide information on the estimated value of soil loss at various locations in the watershed (Shi et al., 2003). In addition to this, the capabilities of modern GIS for modeling and visualization, offer new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds (Jain and Goel, 2002).

There are several advantages of linking soil erosion models with a GIS, such as:

1) The possibility of rapidly producing input data to simulate different scenarios. A GIS provides important spatial/analytical functions to develop the model input data at various spatial scales (Sharma et al., 1996).

2) The ability to simulate very large catchments with many pixels, so the catchment can be simulated with more detail (De Roo, 1996).

3) The facility of displaying the model outputs. Visualization can be used to display an animated sequences of model output images across time and space. Therefore, visualization enables objects to be viewed from various external perspectives (Tim, 1996).

CHAPTER II

SITE DESCRIPTION AND DATA SET

1. Introduction:

This chapter describes briefly the Rmel watershed site, along with the various data needed to analyze erosion in the Rmel watershed; topography, soil types, land-use types, runoff, and precipitation are illustrated for the application of soil erosion modeling. Precipitation data will be used to estimate the rainfall-runoff erosivity factor, soil and land use type data will be used to predict the soil erodibility factor and cover management factor, respectively. In order to calculate the slope length and slope steepness factor, digital elevation model will be used.

2. Overview of the study area:

2.1.Location :

The Rmel river basin is selected as the case study area, which is mainly fallling in the Governorate of Zaghouan in northeastern Tunisia. It lays between 36°15' and 36°35 latitude North, and 10°05' and 10°25' longitude East. It covers an area of 679 km^2 and drains into the Rmel reservoir. It extends over 17 local territorial units and four governorates (70% in Zaghouan, 19% in Sousse, 8% in Nabeul and 3% in Ben Arous). Several administrative departments are included in the Rmel watershed: four in Zaghouan (Zriba, Zaghouan Saouaf and Bir Mchergua), one in Sousse (Bouficha), another at Nabeul (Hammamet) and the last one in Ben Arous (Mornag). (Figure 3)

Rmel catchment discharges to a 22 million m^3 capacity dam built in 1999. This reservoir is intended mainly for irrigation in Zaghouan (500 ha) and Enfidha (5900 ha). In addition to the dam, already described, 22 additional hill lakes were built on the Rmel watershed. The basin also includes 370 surface wells, 104 wells and 13 natural springs.

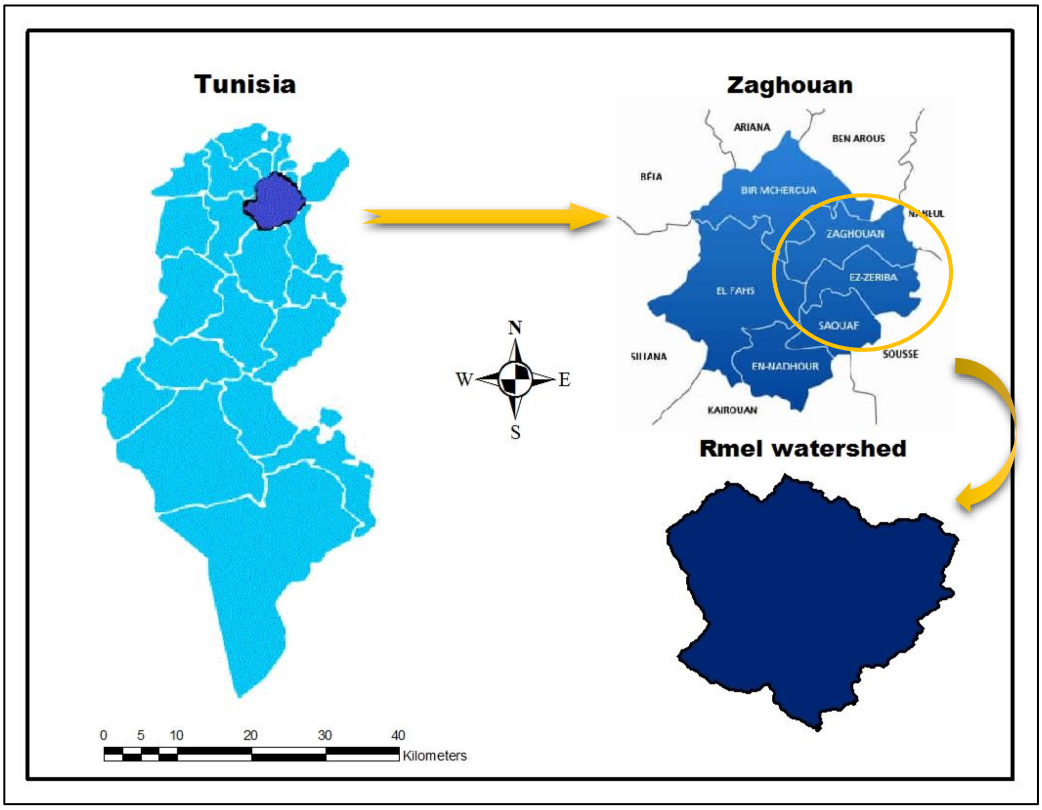

Figure 3: Boundary and location of the study area

2.2.Climat :

The climate of Rmel watershed is classified as semi-arid according to the UNEP aridity index (UNEP 1992), characterized by mild, rainy winters and hot, dry summers. The watershed is subjected to the influence of the Mediterranean Sea and to the continental effects of the inland mountains. Average annual temperature is 19°C and average annual rainfall is 470 mm.

The monthly data for temperature and precipitation data are shown respectively in table 2.

Table 1:Monthly temperature in the Rmel watershed

Station	Sept	Oct	Nov	Dec	Jan	Febr	March	April	May	June	July	Aug
Zaghouan	24	19,5	14,6	10,9	9,6	10,5	12,8	15,6	19,4	23,8	27	27,1
Saouaf	24,7	20,7	15,1	11,9	10,1	11,3	13,4	16	19,6	24,7	27,5	27,6
Bir M'cherga	24,4	19	14,3	11,2	9,5	10,4	12,5	14,5	18,9	24	26,4	27,2

(Source: The regional commissioner for agricultural development of Zaghouan, 2011)

2.3.Population :

The total population in Rmel watershed was estimated in 2014 at about 135 438 inhabitants, with about 46% living in urban areas and 54% in rural areas. The distribution of the population in the basin is closely related to water resources. Indeed, valleys, wadis (rivers and streams), small lakes and groundwater (aquifers and springs) are among the factors influencing settlement location in the basin.

3. Data Set of the study area:

3.1. Digital Elevation Model :

The digital elevation model (DEM) of the Rmel basin (Figure 4) with a spatial resolution of 30 m x 30 m is available from The United States Geological Survey (USGS).

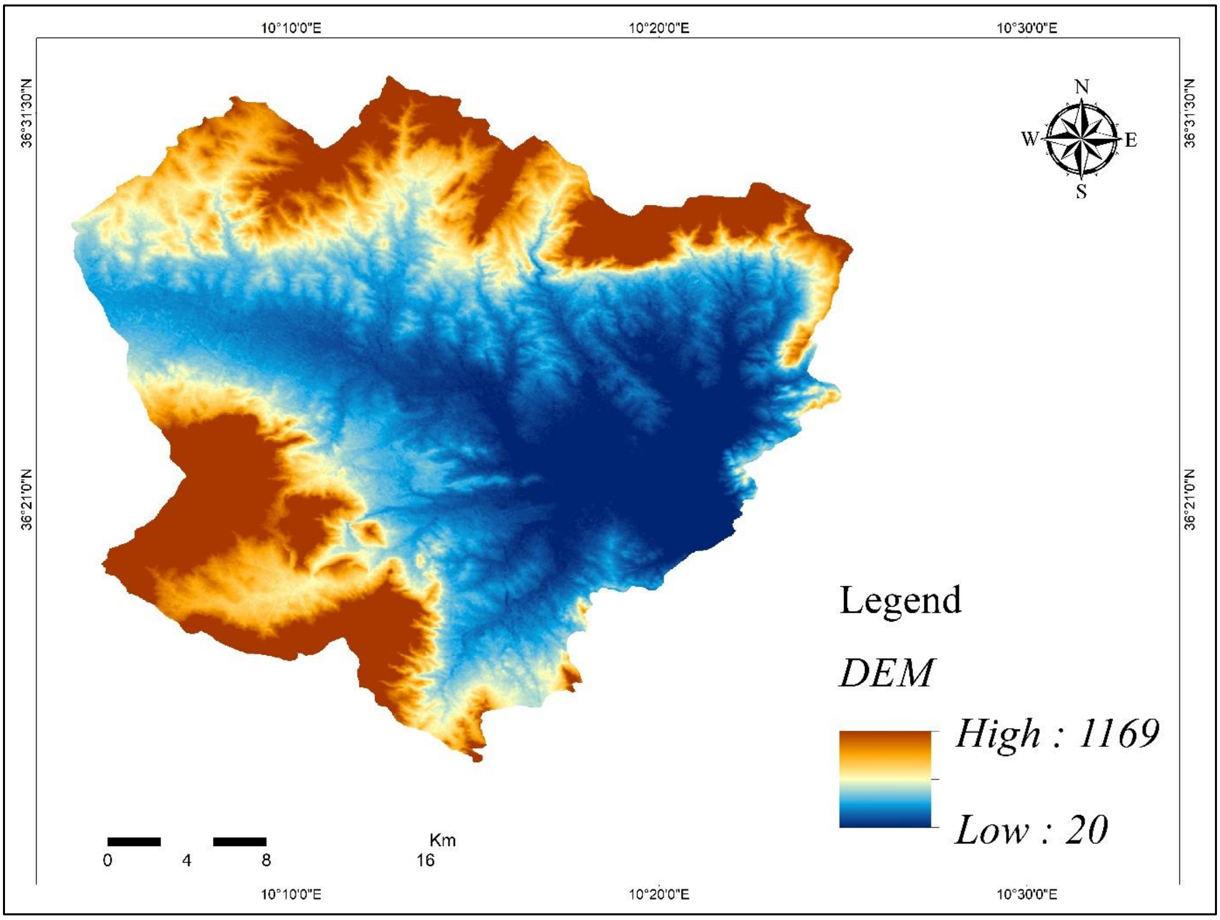

Figure 4: Digital Elevation Model map of the Rmel watershed

According to DEM map, the Rmel basin has an irregular terrain ranging from 20 meters to 1169 meters above sea level, with an average elevation of 205 meters. Several basin and stream features can be determined from the DEM such as elevation, slope, slope steepness and slope length factors of the RUSLE model. The center of the watershed is characterized by low elevation and the edges of the watershed are characterized by higher elevation due to presence of mountains.

3.2.Slope classification :

The Slope map was generated from 30m*30m resolution DEM using ArcGIS 10.4.

The average slope of Rmel watershed is estimated as 5%. The slope was sliced based on FAO slope classes namely 0 - 2, 2 - 10, 10 - 15, 15 - 30 and more than 30 percent slope.

According to the slope map, large portion of the study area fall in the gently flat to undulating terrain (54%) slope class.

Table 2: Slope range of the area in percent

SLOPE (%)	Class name	Area (km2)	Area (%)
0 - 2	Flat to almost flat terrain	70,1	10%
2 - 10	Gently flat to undulating terrain	364,5	54%
10 - 15	Rolling terrain	107,3	16%
15 - 30	Hilly terrain	110,5	16%
>30	Steep dissected to mountainous terrain	26,8	4%
Total Area		679.2	100%

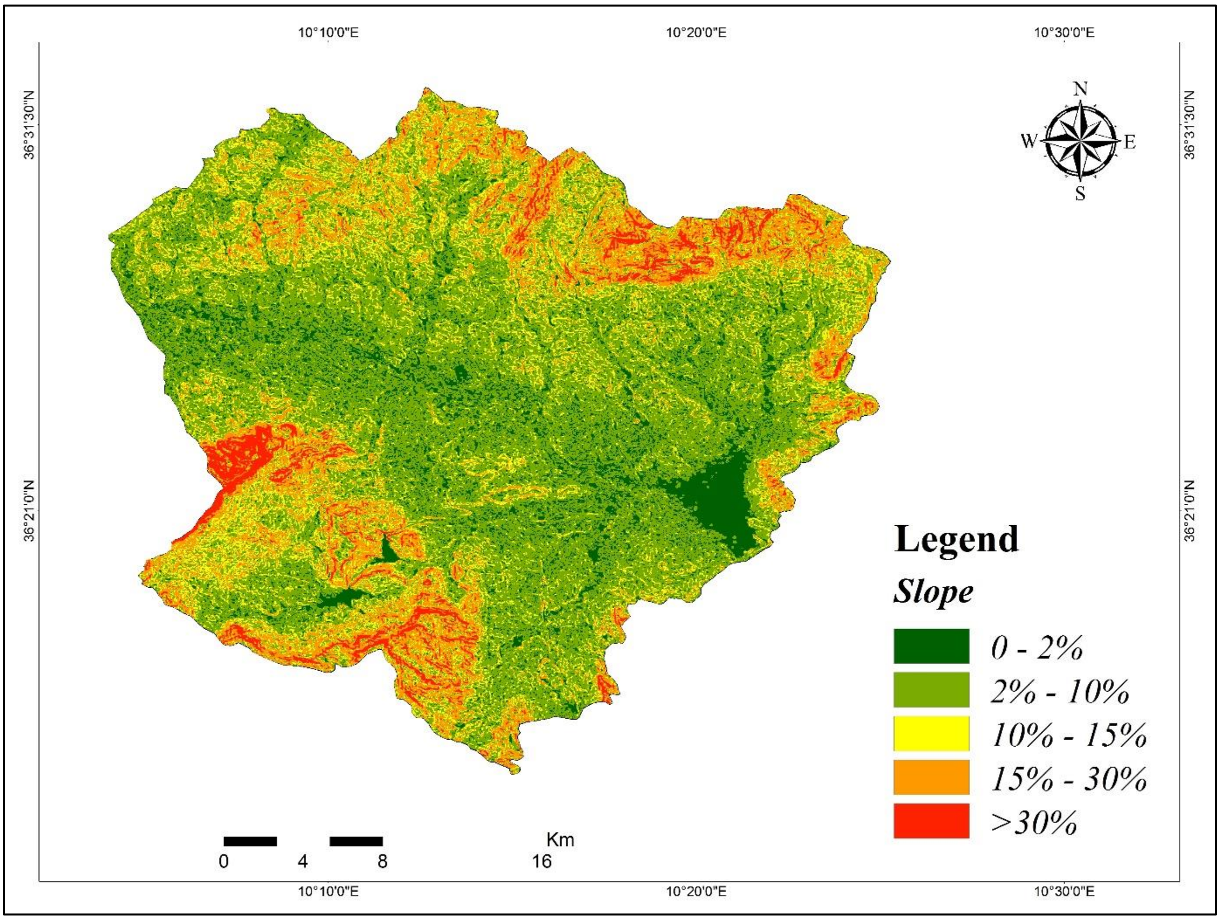

Figure 5: Slope classification map of the Rmel watershed

3.3.Soil Classification :

The soil map of the Rmel watershed obtained from the agricultural map 2000 also based on a more detailed pedological study of Zaghouan (Ben Ayed, 1966),) includes 11 principal soil types as shown in the map (Figure 5).

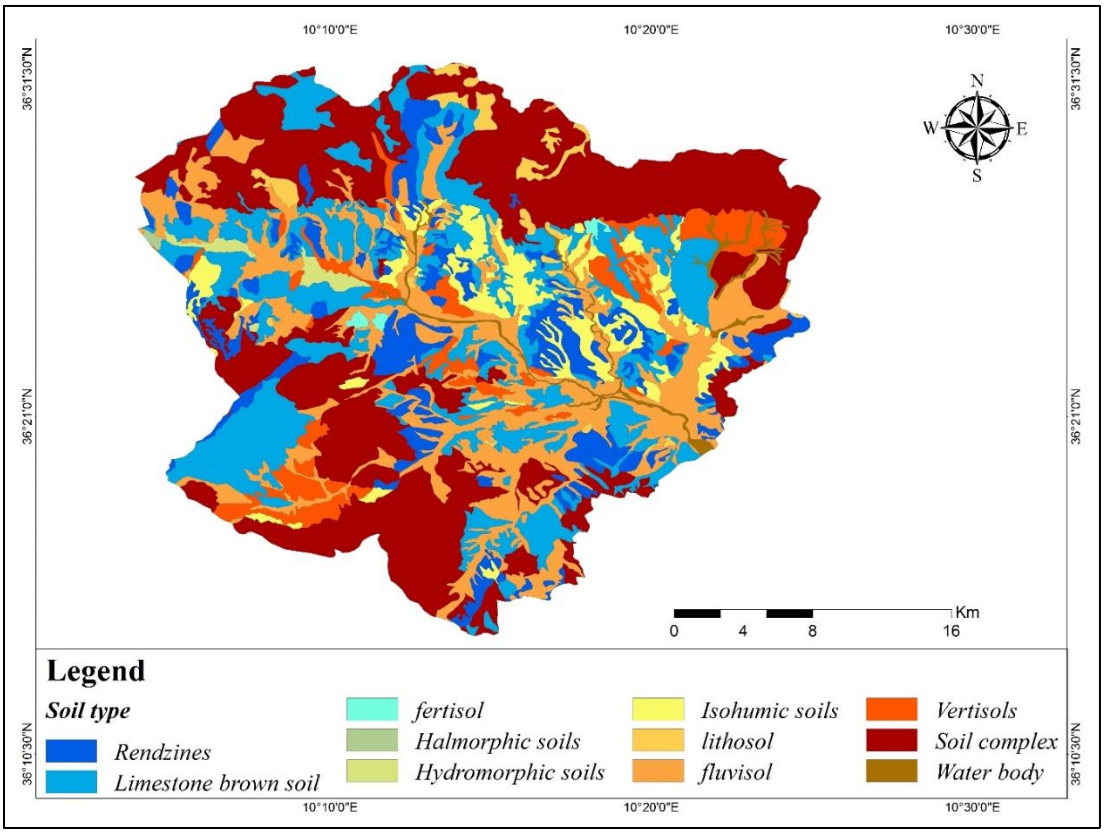

Figure 6: Soil classification map of the Rmel watershed

Table 4 gives information about soil classification and soil texture and soil units area in square kilometer and in percent.

Table 3: Soil type range of the area in percent

Soil type	Clay %	Silt %	Sand %	Area (km2)	Area (%)
Soil complex	42	35	23	243	34,5
vertisol	46	31	33	39,8	5,9
fluvisol	37	24	39	128	18,7
lithosol	48	32	20	13,6	2
Isohumic soils	28	37	35	40,2	5,9
Hydromorphic soils	59	23	18	5,3	0,8
Halmorphic soils	59	23	18	0,5	0,1
fertisol	35	35	25	2	0,3
Limestone brown soil	35	40	25	138,8	20,4
rendzines	35	35	30	68,4	10,1
Water body	0	0	0	8,7	1,3
Total				**679, 3**	**100 %**

3.4.Land Use :

The land use was extracted from the agricultural map data based on satellite images (Landsat 2000 with a resolution of 20 m), and recent data digitized from Google Earth.

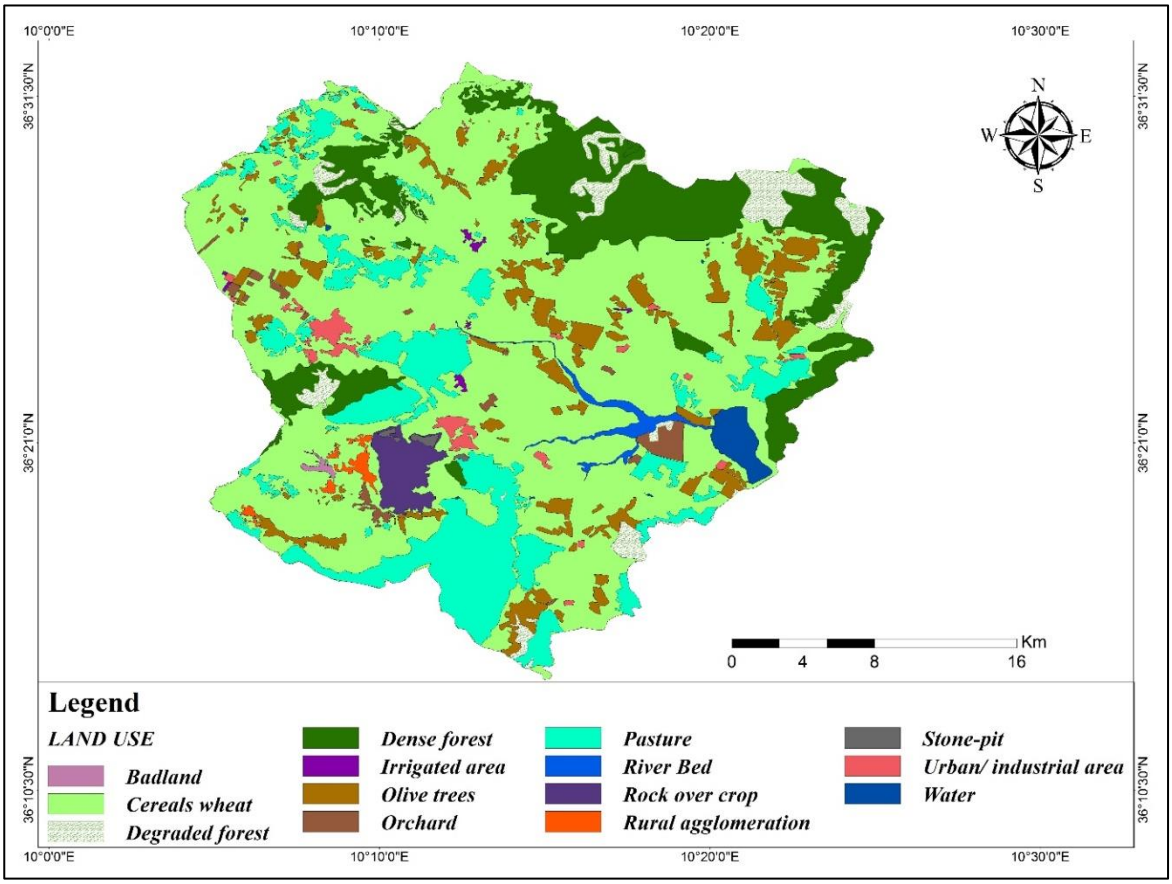

Figure 7: Land use map of the Rmel watershed in 2016

The role of land use has been important particularly in estimating the cover factor C.

From identified fourteen land use types which is indicated in Table 5, the largest portion of the study area is covered by cereals wheat (55,5%), then pasture (14,5%) and dense forest (14%).

Table 4: Repartition of Land-use land-cover types

Land Use	Area (km2)	Area (%)
Rural agglomeration	2,05	0,3
Orchard	2,80	0,5
Water	6	0,7
Stone pit	1,05	0,2
Irrigated area	0,46	0,3
Degraded Forest	23,50	4
Dense Forest	99	14
Cereals wheat	377	55,5
River bed	6,10	0,6
Rock over crop	10	1
Olive trees	50	7,5
Pasture	94	14,5
Industrial zone	1,10	0,1
Urban area	6,90	0,8
Total	**679,7**	**100 %**

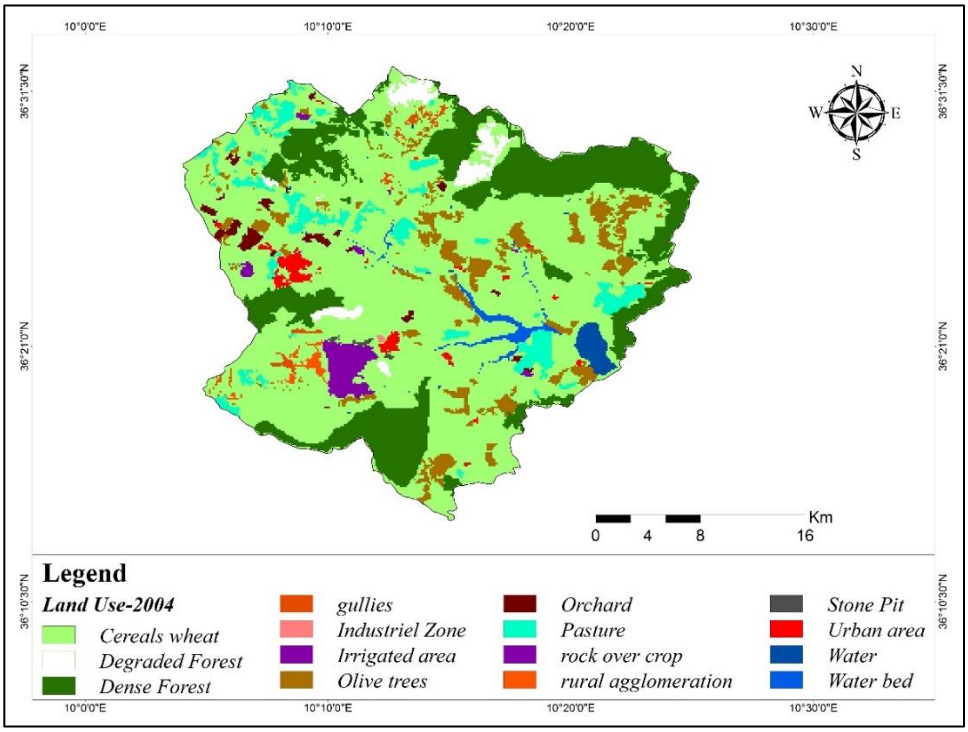

Figure 8: Land use maps in 2004

Two historical land cover maps were also produced to observe the evolution of land cover over years.

Comparison between land use map 2016 and land use maps of 2004 and 2010 shows that pasture areas increased, whereas degraded forest areas decreased.

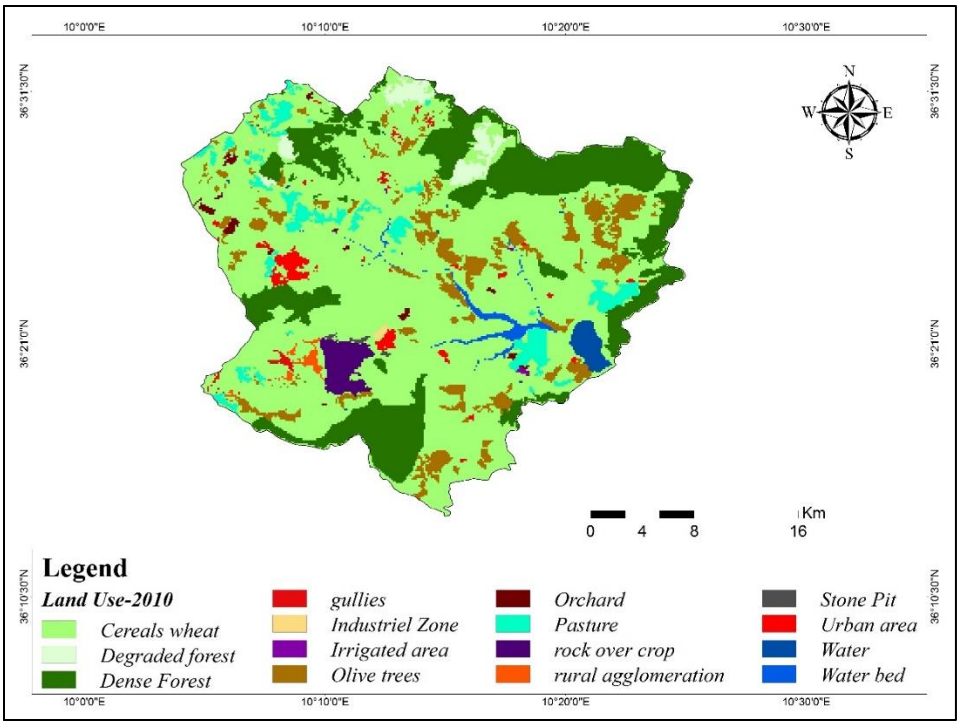

Figure 9: Land use maps in 2010

3.5.Water and soil conservation measures:

Existing water and soil conservation measures were mapped based on filed observations and google Earth imagery to enable the quantification of the RUSLE support practice (P factor).

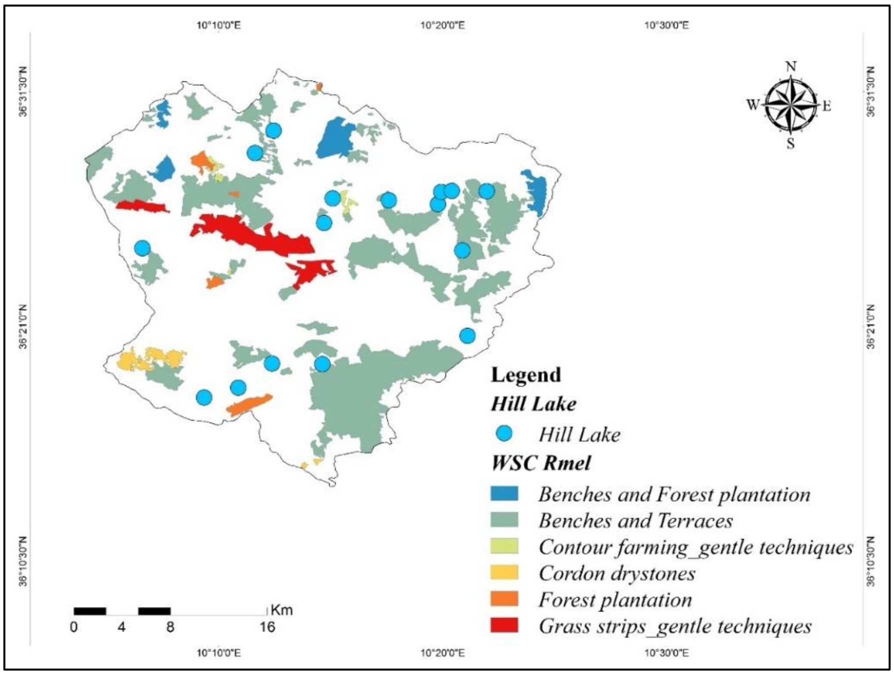

Figure 10: SWC measures of Rmel watershed in 2016

The main SWC techniques used in Rmel watershed are bench terraces, grass strips, stone bunds and forest plantation. All together they cover 27,2 % of the total area of Rmel basin. It will be take into account in the next chapter in erosion estimation that only 184 square kilometers of Rmel basin are protected.

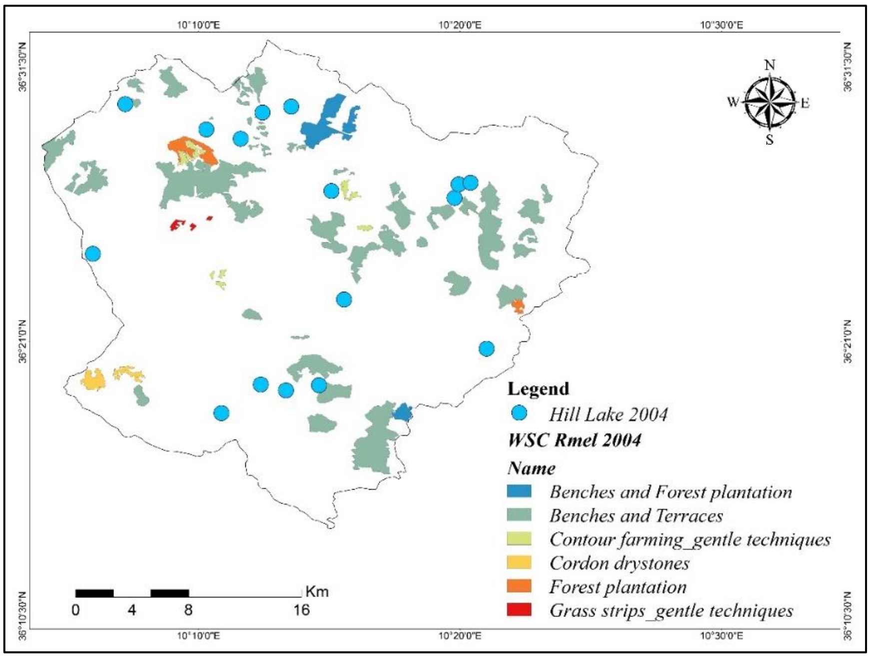

Figure 11: SWC measures of 2004

Soil and water conservation practices maps were produced for two dates; 2004 (Figure 11) and 2010 (Figure 12), to show the evolution of the conservation practices and their influence on erosion over years to enable multi-temporal simulation.

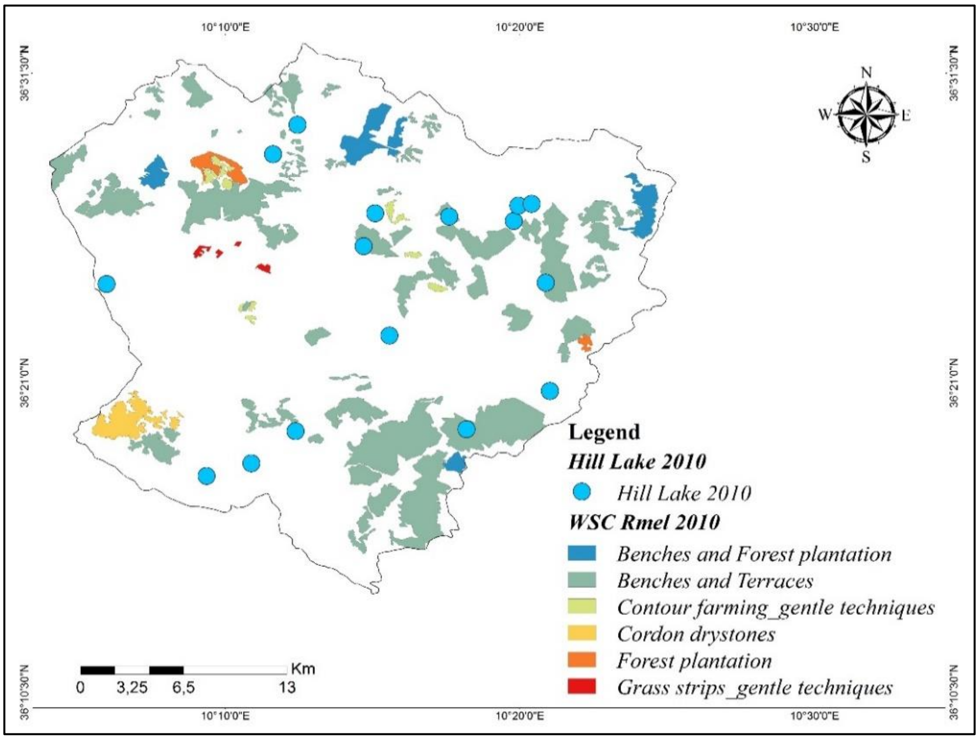

Figure 12: SWC measures of 2010

4. Summary

This chapter describes the study area and the datasets available for the study: climate, topography, soil types, land use, land cover and conservation techniques. These data are the input for the soil erosion modeling with the RUSLE equation. Chapter 5 will present the use of DEM data to compute the slope length – slope steepness; factor (LS) map, the development of the rainfall-runoff erosivity; factor (R) map from the average annual precipitation, the derivation of the soil erodibility factor (K) map from the soil type map and the land cover classification map to predict the cover management factor (C), the deduction of factor P from SWC and slope maps.

CHAPITRE III

FIELD OBSERVATIONS

1. Introduction

Field observations were conducted in the study area to understand soil erosion processes and to document soil and water conservation measures implemented in the watershed, their characteristics and effects on farmlands. It can give us unique information, because we don't have to rely on other's verbal interpretations of situations, but we can see it by ourselves. Thanks to our field observation was; we obtained a valuable knowledge base for our project.

In order to achieve these objectives, site visits, interviews and meetings with stakeholders, data collection and reviews of reports, were carried out from 21st March 2017 to 20 April 2017.

The field team was comprised of the following members:

-Dr. Taoufik Hermassi from the National Research Institute of Rural Engineering, Water and Forests (INRGREF).

-Mr. Bachir Tarchi, from the Regional Commissariat of Agricultural Development of Zaghouan.

-Mr. Monji ben Neji from the Regional Commissariat of Agricultural Development of Zaghouan.

-Dr. Badabate Diwediga, Geo-informatics and Multi-functional Landscape Ecology, iMMAP consultant.

-Ms. Fajr Fradi, Dryland Resources Management, Project Officer, c/o ICARDA.

The selection of sites to visit was indicated by the team of the Regional Commissariat of Agricultural Development of Zaghouan, based on their direct knowledge.

The team adopted two types of approaches: direct observation of various soil and water management structures in their natural setting, and a thorough descriptive analysis supported by literature analysis. Both approaches create new datasets useful for model implementation.

2. Major SWC Technologies observed in Rmel watershed:

Soil and water conservation (SWC) technologies are measure taken to protect the soil of the agricultural and forestry land from dangers such as erosion or degradation, and to conserve water resources.

All the technologies that could be observed during the field visit are listed below. Some information about how and why they are practiced, is also given below, based on direct field observation, interviews with farmers and experts, and on archives reviews.

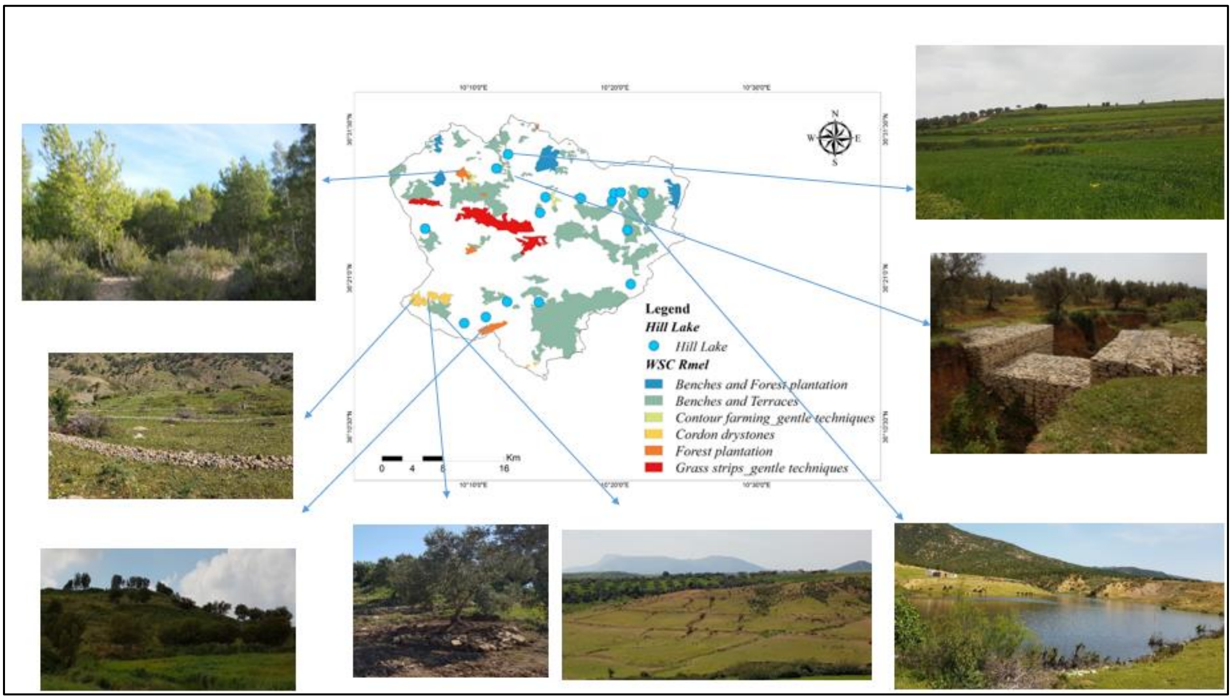

Figure 13: Examples of SWC T measures in Rmel watershed

<u>Mechanical bench terraces</u>

This technique has been used extensively in Zaghouan; it is a sustainable technology for small farmers because it can improve their income by increasing water harvesting and reducing soil loss.

It consists of an earth embankment placed just downhill of a channel dug, following the contour line. This embankment (Figure 15) is made with earthmoving machines that dig the channel, move the earth, and shape the benches. This technology is recommended for slopes with an angle below 25%. The channel of the benches is about 6 m wide, the height of the bench is about 1.5 m. There should always be several bunds next to each other, whereas the distance between them depends on the slope and the soil type of the field.

The purposes of this SLM Technology are to decrease slope length, slow down and infiltrate water runoff generated from rainfall, and improve soil quality and soil moisture retention, also retaining soil nutrients on-site. The structure requires regular maintenance since the embankments are made of soil, which is not stable.

An advantage of mechanical bench terraces is that they allow the cultivation of several crops or fodder between the bunds (Figure 14). When they are designed correctly, there is no loss of runoff out of the system. However, this technique is not suitable for uneven terrains.

Their construction and maintenance are expensive but they are simple. It is important that the primary construction is done carefully and solidly to limit maintenance to a minimum. Grass growing on bunds can further enhance stability as grass roots fix the soil. It should therefore not be removed. They have a high reliability if construction and maintenance are done correctly.

Figure 14: managed lands with mechanical bench terraces for cereal cropping in the Sbaihia watershed (Zaghouan). Field photo, 22/03/2017.

Figure 15: managed lands with mechanical bench terraces for olive trees land in Sbaihia watershed (Zaghouan). Field photo, 22/03/2017.

<u>Manual bench terraces</u>

The manual bench terraces (Figure 16), are found on hill slopes with deep soils. They are terraces, aligned by eye - and done manually using hand hoes, which are constructed by digging ditches, and heaping the soil on the upper sides to form the bunds. The bund has a height of 0.5 m and a base width of 0.5 to 1 m, spacing between bunds is according to slope and soil depth. Construction by hand takes around 60 days per hectare.

Manual bench terraces serve the functions of stopping downslope soil and water runoff and also have the advantage of providing a flat surface for the planting of crops, increased soil water retention, preserve and enhance soil fertility and reduced soil erosion to increase crop productivity.

Bench terraces require regular care and maintenance especially in the first two to three years' period. Grasses and weeds should be removed from the benches. If a small break is neglected, a large-scale damage will result. A list of maintenance works has to be carried out after heavy storms and cropping, and after crops harvesting.

The major advantage of this technique is that design and construction are easy and can be done without much-specialized knowledge. However, failure in respecting the contour lines in its construction would lead to loss of soil.

Figure 16: managed lands with manual bench terraces for olive trees land in Oued el khirat watershed, (Zaghouan). Field photo, 23/03/2017.

<u>Stone bund terraces</u>

This structure is an obstacle to runoff constructed by accumulating dry stones aligned according to contour lines. The establishment is made by laying out contour lines, digging the foundation, and placing stones in a manner to interlock to each other (Figure 17). The bunds should be about 30 to 50 cm high from the ground and spaced about 20 to 50 m apart, depending on the inclination of the terrain. They form a barrier that slows down runoff and spreads it more evenly over the land. By slowing the flow water can seep into the soil more easily preventing the loss of rainwater. The bunds also act as a filter, trapping fine waterborne particles of soil and manure, resulting in a build-up of sediment. When rainfall is erratic, the stone bunds contribute to conserving more moisture in the soil for longer, which helps to alleviate water stress during dry spells. In order to optimize the positive effects of stone bunds, it is important to ensure that they are constructed closely following the natural contour of the land and in accordance with the established technical standards.

There is evidence that bunds have positive effects on yields. A minimum amount of maintenance is required, which essentially involves replacing stones dislodged by animals or water flow. The lifespan of a stone bund is 5 to 10 years. There is a progressive build-up of sediment behind the bunds, resulting in the formation of terraces. Although the capacity of the bunds to retain water declines as the sediment builds up, soil infiltration capacity increases, thanks to improved soil structure, and the slope becomes gentler thanks to the terracing effect. The best results are achieved when stone bunds are used in combination with biological measures (planting of grass, trees, and hedges) (Figure 18).

Stone bunds are largely practiced in Rmel watershed provided that there are stones on individual farms; it might be difficult to import stones from other farms as the exercise may require a lot of work and money. The local governorate has taken a lead role in encouraging farmers to adopt this technology, especially farms that have many stones by offering them labor. Nevertheless, the cost of transporting stones shall be borne by those who have no stones in their farms.

Figure 17: Stone bund terraces in land recently planted by olive trees in Jouf (Zaghouan). Field photo, 23/03/2017.

Figure 18: Managed Land with Stone bund terraces in order to improve olive production in Ain Ansarin (Zaghouan). Field photo, 23/03/2017.

<u>Semi-circular bunds</u>

Semi-circlar bunds (Figure 19) are used as soil and water harvesting structures to improve the productivity of trees, especially olive trees, on steep slopes. These are small-scale earth structures, with diameters between 2 to 4 m, established to catch rainfall and runoff from small micro-catchments covering relatively short slopes. This type of system is suitable for fields where trees are distributed in a regular pattern. Stones are in some cases mined from rock outcrops and transported to the slopes using tractors. Then the stones are set out manually in a semi-circle (crescent) around the downside of the tree. Their role is to consolidate the earth bund. The semi-circle bunds are about 40 cm high with a base width of 30 to 40 cm. It is also important to leave free spaces between the bunds in order to enable excess water to run off.

This technology is used to reduce losses of soil and nutrients and capture runoff water, which helps to rehabilitate degraded land and improves the yield.

The technology makes the mechanized tillage difficult because of the layout of the structures. This reduces the number of tillage operations and hence reduces erosion since tillage is one of the main causes of soil erosion under these conditions. The structures also reduce runoff velocity, which increases water availability for the plant roots (water harvesting) and also allows for more sedimentation around the trees and less transportation of soil particles and nutrients outside the field (soil conservation).

The establishment of large semicircular earth bunds involves the collection of stones, alignment of the semi-circle with the contour line, excavation of a foundation, construction of the embankment and digging of planting pits and runoff harvesting ditches. The maintenance includes re-enforcing the embankment and dredging sediment from the runoff harvesting ditches during the dry season. Semicircular bunds are recommended as a quick and easy method of improving agriculture in semi-arid areas.

Figure 19: managed lands with semicircular bunds for olive trees land in Jouf watershed, (Zaghouan). Field photo, 25/03/2017.

<u>Hill reservoirs</u>

A hill reservoir is a hydraulic structure of medium size, that can contain ten thousand to few millions m3 of water collected from watersheds covering areas from few hectares to some km2.

The size depends on the slope of the stream and the soil and climate of the region. Its installation also depends on hydrogeology and topography. Reservoirs are integrated in a natural way within the landscape and do not create any particular pollution problems. Their construction has several objectives: protection of downstream infrastructures against floods and erosion, assuring availability of water at several places in the landscape for domestic needs and

livestock drinking, micro-irrigation, and water harvesting for replenishing shallow groundwater reserves. They can support the creation of new agricultural areas, the development of new economic activities, tourism, and improvement of the environment. The land interested by this technique are mainly of agricultural use. The technology minimizes greatly the risk of crop failure and improves the livelihood of the land users. The implementation of the lake requires several previous studies with regard to its location, safety, design, and budget.
There are some photos taken in Rmel watershed of hill reservoir.

Figure 20: Hill Lake, oued Lachguef, Sidi zid Zaghouan governorate (Tunisia). Field photo, 11/04/2017.

Figure 21: Hill lake Gattar2, Sbaihia. (Zaghouan). Field photo, 22/03/2017.

Figure 22: Hill Lake, Oued Melah, Bir mchergua, (Zaghouan). Field photo, 28/03/2017.

Figure 23: Hill Lake, Oued Reziyen, Sidi Zid, (Zaghouan). Field photo, 17/04/2017.

<u>Gabion threshold</u>

Gabions consist of rectangular steel wire mesh baskets, filled with small rocks, used to form a section, or a man-made wall, across a waterway. A gabion is a cage with a cubic shape filled with stony material of suitable diameter keep the stones together and stops them from moving under the pressure of water. The average height of a gabion varies from 2 to 4 m and its length is a function of the width of the water way to be treated. Dozens of gabions can be locked together and stacked upon each other. In this way they create a barrier to delay and slow down water flow. The stones must be carefully arranged so that the structure is stable. They can be used in gullies (Figure 24), and small watercourses (Figure 25) to stabilize the slope and the tearing edges. These structures are also used for groundwater recharge, especially when the soils in the wadi beds are permeable. In order to slow down the water flow and improve infiltration into deeper soil layers and geologic formations, thresholds can be constructed with gabions across ephemeral river beds.

Figure 24: Gabion threshold installed on the wadi bed in Sbaihia, (Zaghouan) to protect the land against the lateral landslides and improve olive production. Field photo, 23/03/2017. landslides and improve olive production. Field photo, 23/03/2017.

Figure 25: Gabion threshold in order to slow down the water flow in the wadi courses and improve its infiltration into the deeper soil in Sidi zid, (Zaghouan). Field photo, 23/03/2017.

<u>Gullies restoration</u>

Gully restoration is done by using vegetation to provide protection to soil and reduce flow velocity, or by controlling gully heads through the construction of stone thresholds (Figure 26). Gullies are formed by increased surface run-off, which acts as a cutting agent and can generate deep channels. The main physical factors affecting the rate and amount of surface run-off are precipitation, topography, soil properties, and vegetative cover. Gullies are formed also because of man's misuse of the land. A number of initiatives have been undertaken in Zaghouan to prevent and mitigate gully development. For gully control, the following three methods must be applied according to the order given:

1- Improvement of gully catchments to reduce and regulate the run-off rates (peak flows);

2- Diversion of surface water upslope the gully area;

3- Stabilization of gullies by structural measures and accompanying vegetation (mechanical and biological restoration).

Restoration design features including the width, depth, and shape of structures are dependent on catchment size, shape, slope and surface condition.

The aim is to reduce gully formation, protect the fertile agricultural land and minimize the impact of erosion. Plugging gullies with stone dams may reduce flow and allow sediment accumulation on flatter shallow areas. Stone will be needed with individual stones laid lengthways along the channel.

Restoration of gullies must be carried out in combination with the blocking of smaller grips upstream and re-vegetation of bare peat (Figure 27).

The main effect of these restoration techniques will be to reduce water flow to enable the trapping of sediment in the base and to prevent peat sides of the gullies from drying out, cracking and collapsing.

Prevention is more convenient because structural measures are considerably more expensive than preventive measures. If incipient gullies are not stabilized, they become longer, larger and deeper.

Stone threshold

Figure 26: Stone thershold in Sbaihia, (Zaghouan) in order to stop down the gullies formation. Field photo, 29/03/2017.

Biological restoration of gullies

Figure 27: Biological restoration of gullies in rangeland in Sbaihia, (Zaghouan) by trees and shrub plantation. Field photo, 28/03/2017.

Reforestation

Reforestation is one of the key approaches to address the fragility of ecosystems: it provides protection against erosion and enhanced use of rainfall in order to maintain the sustainability of agricultural systems, particularly when implemented in degraded lands.

Reforestation has had a great importance in the context of combating desertification in Zaghouan, to achieve rehabilitation of vegetation cover, meet energy and forage needs, and in developing agrosilvopastoral systems. Besides this, it has undoubtedly contributed to a significant modification of the landscape in Zaghouan watershed. The main species used in Zaghouan are Atriplex spp, Eucalyptus spp (Figure 29), and Pinus halepensis (70%) (Figure 28). Its main purposes were to combat desertification, rehabilitate degraded drylands, restore the original forest-steppe ecosystem and protect biodiversity.

Figure 28: Plantation with Pin d'Alep trees (Pinus halepensis) in Oued Zit (Zaghouan). Field photo, 05/04/2017

Figure 29: Eucalyptus plantation at the bottom of the hil in Oued Zit, (Zaghouan). Field photo, 05/04/2017.

Plantation of forage species

This technique consists in planting forage shrubs species on pasturelands that have reached a severe degradation state. Fodder species contains important feed items (nutrients) that grasses sometimes do not have.

The purpose is to complement the annual deficit of forage resources, or to preserve livestock in case of drought or food shortage, and conserve soil and water improving soil fertility by enriching it with nitrogen and organic matter.

Species are used that give high feed yields all year round, every year. The selection of the right fodder species requires consideration of the needs of livestock. There is a range of indigenous species and shrubs that are of value to livestock such as cactus (Opuntia ficus indica) and sulla (Figure 30). It is possible to integrate fodder production into fields with minimal reduction in the production of other crops. Many of the species (Figure 31, 32) that are planted as sources of fodder also make ideal windbreaks; modify the microclimates beneath their canopies; reduce water loss from the soil, and soil erosion. This technology is supposed to promote natural afforestation with native species thanks to natural seed dispersal. The Livestock and Pasture Office is in charge for bringing the seedlings and providing subsidies to the beneficiary who is responsible for all maintenance and protection operations.

Figure 30: Plantation of Sulla (Hedysarum coronarium) for livestock needs in Jouf, (Zaghouan).

<u>Rangeland improvement</u>

Rangeland improvement has the aim of preventing and mitigating degradation of soils and

Figure 31: Cactus pear cultivar for forage production in Jouf, (Zaghouan). Field photo, 29/04/2017.

Figure 32: Cactus plantation in combination with native species in order to convert marginal soils and poor vegetative cover to productive lands in Bir Mchergua, (Zaghouan). Field photo, 29/04/2017.

meeting the needs of livestock by planting desirable forage species.

Rangeland suffer from degradation and overgrazing due to the continuous growth of livestock number. This technique consists in introducing pastoral species and forage trees (e.g., Atriplex spp (Figure 33), Acacia spp (Figure 34), luzerne..).

However, the absence of long term monitoring of rangeland resources (soil and vegetation) does not allow a coherent assessment of the effectiveness of the interventions done. Nevertheless, the free access to collective rangelands and the trends in terms of rangeland areas and livestock numbers suggest that rangeland natural resources are submitted to strong pressure and are in process of degradation.

Figure 33: Atriplex plantation in degraded land in Jouf, (Zaghouan). Field photo, 03/04/2017.

Figure 34: Plantation of Acacia for consolidating the mechanized terraces in Saouaf, (Zagouana). Field photo, 24/03/2017.

3. Summary

Land degradation in Rmel watershed is a regional issue with local solutions. Therefore, the concerted effort on the development agenda should also include the many promising sustainable land management technologies and approaches that are already applied. This would help the community learn from each other and help build resilience at the local, national and regional levels. The goal was to combat erosion, contribute to the mobilization of water resources, and protect infrastructure and cities against floods.

The specific aim of the field visit is to present and discuss the major soil and water conservations developments and theirs social and economic effects in the agricultural field.

CHAPTER IV

Documentation of SWC measures using a standardized SLM template

1. The SLM Template

The project "Impact Evaluation of SLM Options to Achieve Land Degradation Neutrality" aimed at supporting the implementation of sustainable land management (SLM) practices.
This project, in synergy with other projects and initiatives led by ICARDA has developed a set of SLM tools. One of these tools is a standardized template to document SLM techniques, which was developed by building on internationally accepted frameworks such as WOCAT. The template can be used both on-line and off-line, as a document in spreadsheet format. In this study, the template was used to document technically the soil and water conservation measures observed in the Rmel watershed.
This off-line CRP-DS/ICARDA template of SLM technology description is partly adapted from those of WOCAT, however with major modifications and additions. It has six (6) main parts.

- General information
- Description of the SLM technology
- SLM purpose and classification
- Geographic locations, extents and socio-ecological context/environment
- Technical specifications, inputs and costs
- Impacts, influencing factors

2. General information

This section includes name and location of the documented implementation, along with information about the person filling the template (Appendices 2).

- Name of the SLM technology
- Documentors
- Co-Documentors

- Date and Place of filling the sheet
- Resources persons
- Information sources

3. Description of SLM technology

This section requires more detailed technical information on the SLM technology (Appendices 3).

- Definition of the SLM technology
- Illustrative photos
- Years of implementation

4. SLM Purpose and Classification

This section defines the purpose, type and technical features of the SLM technology (Appendices 4).

- Purposes of the SLM technology
- Type of the SLM technology
- Measures comprising the SLM technology: Agronomic, Vegetative, Structural, and Management measures

5. Geographic Locations, Extents and Socio-Ecological context/Environment

This section requires defining the context and the extent of the SLM technology (Appendices 5).

- Regions/locations where the SLM technology has been applied
- Socio-ecological context/environment variables: Bio-physical conditions, Physical and institutional accessibilities, Population dynamics and pressure, National economic development status, Socio-ecological context similarity
- Performance/impact indicators: Productivity and Water Use Efficiency, Pessure on land's carrying capacity, Affected population
- Environment variables filled by the documentors: Biophysical conditions, Socio-economic conditions, Accessibilities to services and infrastructure

6. Technical Specifications, Inputs and Costs

This section defines technical specifications and costs of the SLM technology (Appendices 6).

- ✓ Labor: How many workers are required to establish and upkeep the SLM technology? What is the cost per worker?

- ✓ Equipment: Which tools are needed to establish and upkeep the SLM technology? What is the cost per tool?
- ✓ Plant materials: Which plants are needed to establish and upkeep the SLM technology? What is the cost per plant?
- ✓ Fertilizers and biocides: Which fertilizers and biocides are needed to establish and upkeep the SLM technology? What is the cost per fertilizer or biocide?
- ✓ Construction materials: Which construction materials are needed to establish and upkeep the SLM technology? What is the cost per material?
- ✓ Other inputs: Any other need can be registered in this sub-section.
- ✓ Costs: The total cost is automatically calculated.

7. Impacts, Influencing Factors

This section highlights the expected impact of the technology Appendices (7), from several perspectives:

- ✓ On-site impact: divided into three categories 1) socio-economic, 2) socio-cultural, 3) ecological impacts.
- ✓ Off-site impact: in particular, risk reduction in the neighbor fields and areas.
- ✓ Exposure and sensitivity of the SLM technology to gradual climate change and climate-related extremes and disasters: How does the SLM technology cope with 1) gradual climate changes and 2) extremes disasters (e.g. climatological, hydrological, and biological)?
- ✓ Cost-Benefit analysis from land-user's perspectives: in particular, are costs of establishment and upkeep balanced by the benefits for the land users?
- ✓ Adoption of the SLM technology: How much this SLM technology, where and how?
- ✓ Adaptation of the SLM technology: How does the SLM technology cope with generic potential changes?
- ✓ Strengths, advantages and opportunities of using SLM technology: these are discussed from the perspective of 1) land users, 2) SLM experts, 3) documenters and other observes, 4) policy-makers and third parties.
- ✓ Weaknesses, disadvantages of the SLM Technology and ways to overcome them: these are discussed from the perspective of 1) land users, 2) SLM experts, 3) documenters and other observes, 4) policy-makers and third parties.

8. Summary

The SLM Template developed by ICARDA, was used to document technically the soil and water conservation measures observed in the Rmel watershed. It can be used both on-line and off-line, as a document in spreadsheet format. In order to ease the process of the filling.

The offline process can be done by downloading a template of SLM, it is an excel sheet where onecan find the same fields as the online sheet, filling this template and importing to the GeOC system. The Global Geo-Informatics Context and Options (GeCO) is a new web-based GIS tool that enables its users to co-create knowledge and learning on relevant Sustainable Land Management (SLM) options that match the social-ecological context at global, regional and national scales. The GeOC tool aims to support the implementation of SLM practices by the local international communities by providing them with context-specific information that is required to make sound investment decisions for agricultural and rural development. It is designed to provide land users, development projects or programs, and policy decision-makers with plausible, robust extrapolation domains for guiding decisions on the selection and use of SLM options, and an open platform for docking different disciplinary projects into integrative/holistic and converging actions for promoting SLM at scale.

CHAPITRE V

PARAMETER ESTIMATION AND MODELLING RESULTS

1. Introduction:

This chapter describes the basic concepts, the procedure of the RUSLE model, in addition to the methods used to estimate five RUSLE parameters. Based on the rainfall storm events, DEM, soil type map, land cover map and soil and water conservation measures map.

2. Rainfall erosivity factor (R):

Rainfall data collected for 12 years for six weather stations distributed over the watershed (Appendices), were used to calculate R-values based on the equation proposed by Rango and Arnoldus (1987), already discussed.
The equation of Rango and Arnoldus 1987 used to compute R-values.
In terms of GIS layers, each weather station was represented by a point. The Inverse Distance Weighted (IDW) interpolation method in GIS was used to generate a raster map for R factor.

Table 5: Station location and Rainfall erosivity factor

Station name	X	Y	R
SBAIHIA	608193.94	4039075.3	92
MOGRANE	597730.25	4031956	113
OUED EZZIT	617175.51	4030502.4	89
SAOUAF	603609.28	4010943.9	84
ZAGHOUAN	601150.94	4031224.2	98
ZRIBA	608795.28	4023458.7	104

Table 6, figure 43 and 44 illustrate the computed rainfall erosivity (R) values using data from six weather stations across the Rmel watershed (and one additional station close to the upper part of the watershed).

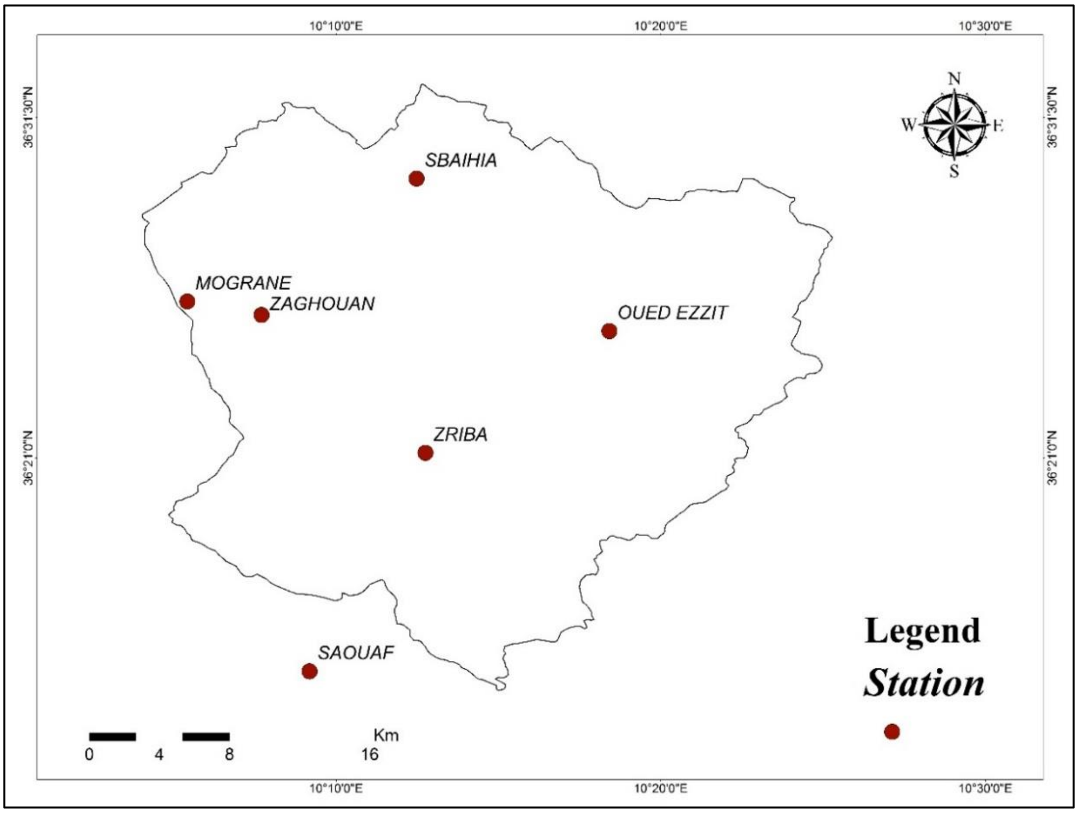

Figure 35: Location of the rainfall stations in Rmel watershed

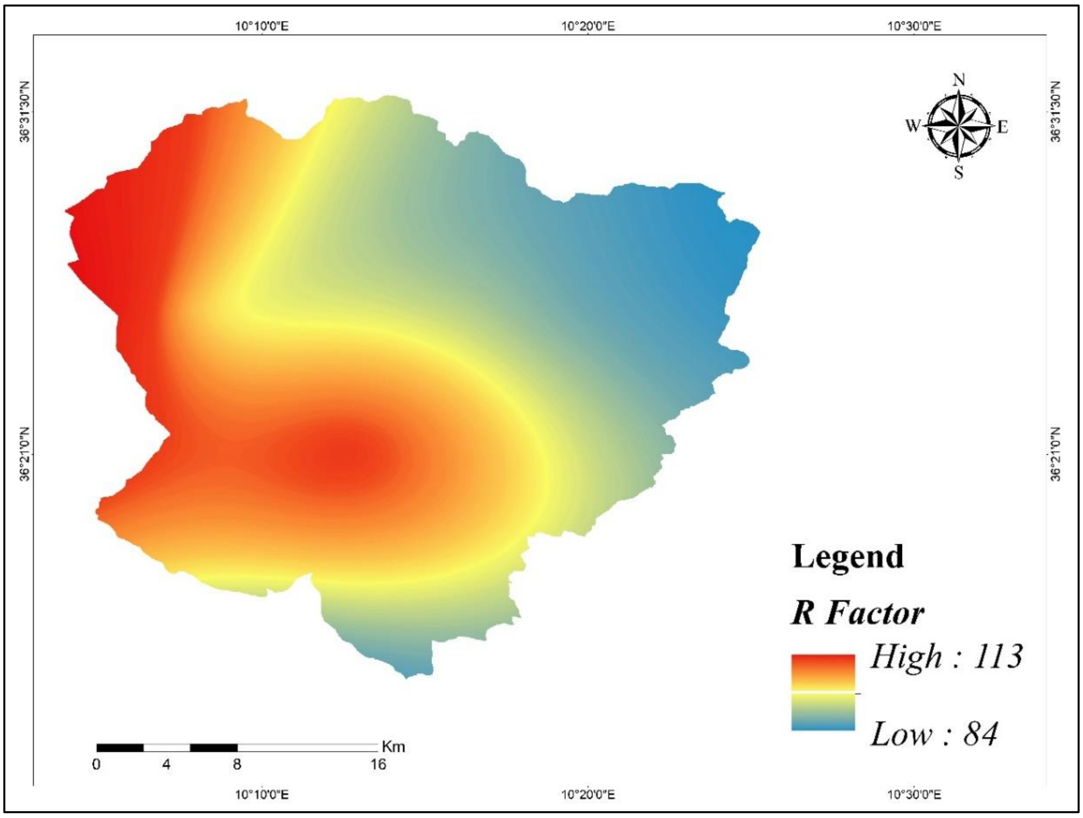

Figure 36: R factor map of the Rmel watershed

The value of R factor ranges from 84 to 113. The highest values which found in the lower part of the study area showing high rainfall erosivity. Thus based on R-factor value it is more vulnerable to erosion. The lowest values of R-factor found in the upper part of the study area indicates that this part of the watershed is less vulnerable to erosion.

Generally, Areas with low slope degree have low erosivity R-values which imply that flat areas would increase the water ponding on the surface, thus protecting soil particles from being eroded by rain drops.

3. Soil Erodibility Factor (K):

The K factor expresses the vulnerability of the soil to be eroded by the rain.

To create the soil erodibility map, a lookup table was created to link soil type unis to the corresponding K values. Based on this, a K map was generated in raster format with a cell size of 30 m.

The K values of each soil type have been deduced from the literature (Zante et al., 2003, Collinet et al., 2001, Dangler et al., 1976, Masson, 1971, Dumas, 1965, Hermassi et al., 2014).

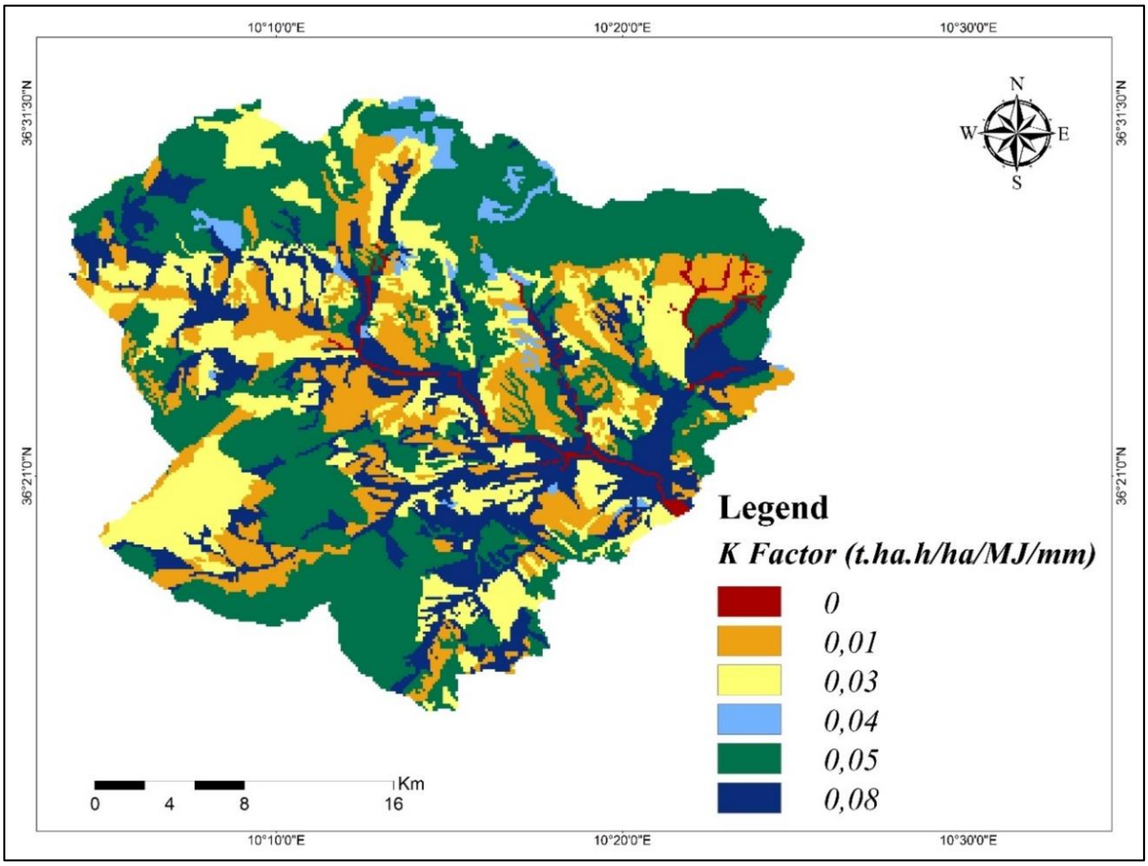

Figure 37 : K-factor map of the Rmel watershed

The value of k factor in the study area ranges from 0 to 0.08 expressed in t.ha.h/ha/MJ/mm. The high k factor values indicate more vulnerable soil types to erosion and the smaller values shows less vulnerable soil type to erosion. K factor is depending on the percentage of clay, sand and silt available in the study area. Generally, soils have low erodibility if the silt content is low. As it is shown in map, the high k-factor value is shown in Fluvisol (19% of surface area) and Soil Complex (40%). Low values are associated to the Vertisol (17%).

Table 6: Distribution of K Factor in the watershed

Soil Type	K Factor	Area (km^2)	Area (%)
Water body	0.00	8.7	1
Vertisol	0.01	115.7	17
Lime stone brown soil	0.03	138.8	20
Lithosol	0.04	13.5	2
Soil Complex	0.05	273.2	40
Fluvisol	0.08	129.5	19
Total		**679.3**	**100**

4. Cover-management factor (C):

The cover management factor (C) represents the effects of vegetation cover on soil loss. It expresses the protection of soil by cover-type and density. C is thus a relation between erosion on bare soil and erosion observed under a cropping system.

Based on the bibliographic literature of the works elaborated in Tunisia Collinet et al., (2001), Zante et al., (2003), a corresponding C value was assigned to each land-cover/use class, ranging from 0 to 0.9. The large value shows more vulnerable land use to erosion and on the other hand, the lower value shows less vulnerable land use for erosion, so an increase in the cover factor indicates a decrease in exposed soil, and thus an increase in potential soil loss. From the result Rock outcrop have the largest value of C factor (0.9) which is highly vulnerable to erosion. Next to Rock over crop, Cereals (0.65) are more vulnerable than others crops, pastures, and forests which have the C factor values of 0.4, 0.25 and 0.05 respectively.

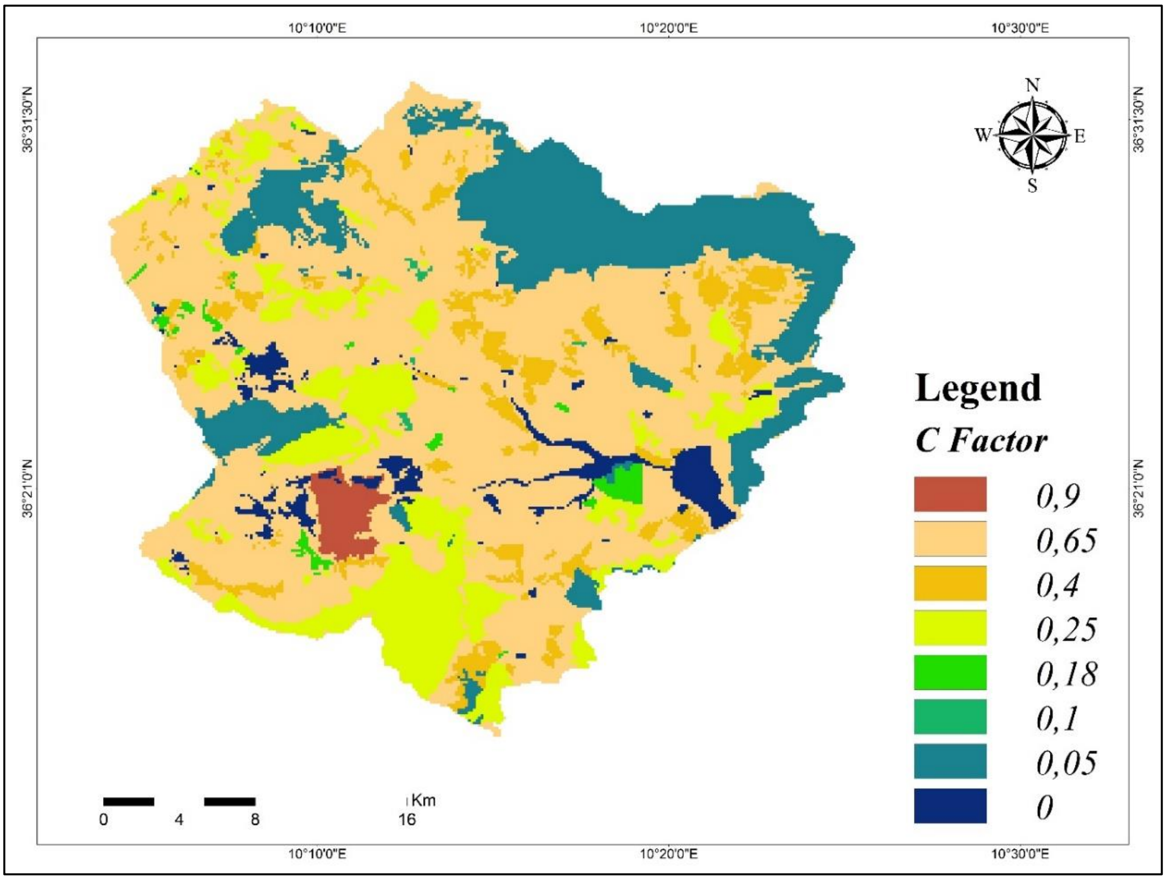

Figure 38: C factor map of the Rmel watershed in 2016

Table 7: Distribution of C Factor in the watershed

C Factor	Area (km2)	Area (%)
0.00	24.56	3.6
0.05	122.55	18
0.10	1.2	0.2
0.18	6.78	1
0.25	92.99	13.7
0.40	49.95	7.4
0.65	371.18	54.7
0.9	10	1.5
Total	**697.2**	**100 %**

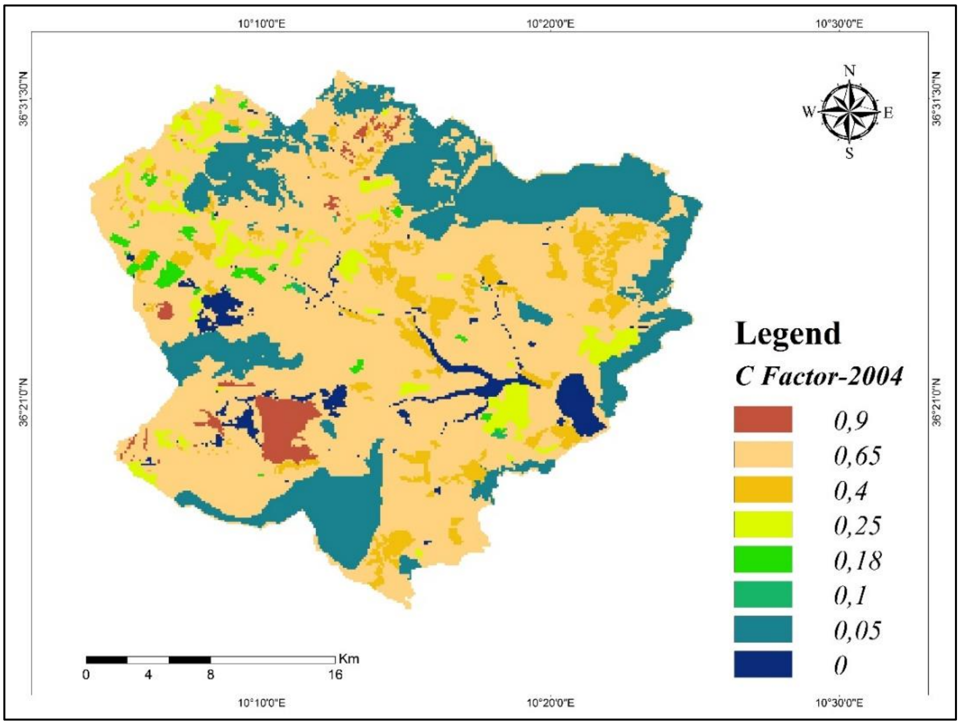

Figure 39: C Factor map of the Rmel watershed in 2004

To notice the evolution of land use of the Rmel watershed, land use map of 2004 (Figure 47) and 2010 (Figure 48) were generated. Comparison between actual land use map and previous land use of the Rmel watershed shows that pasture areas increased gaining areas from degraded forest areas.

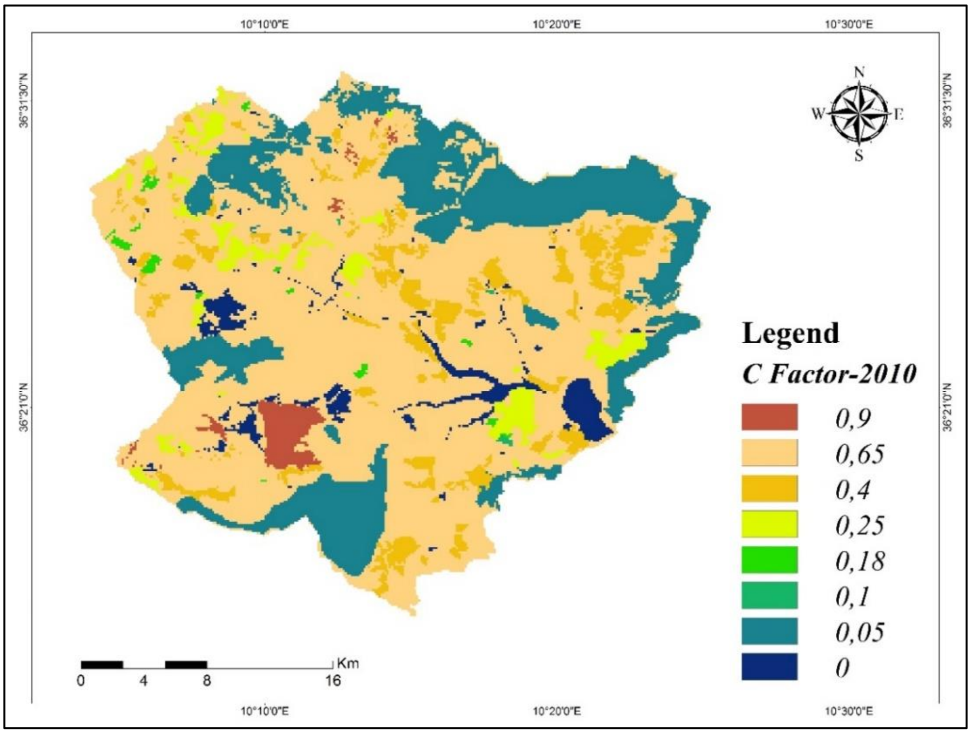

Figure 40: C Factor map of the Rmel watershed in 2010

5. **Topographic factors (LS):**

The RUSLE LS factor (topographic factor) accounts for the effect of topography on erosion that depends on slope length (L) and the slope steepness (S). For this study L is measured in meter and S in percent units.

For computing the LS factor, using the above-mentioned Digital Elevation Model (DEM) at 30-meter resolution, we generate the Flow direction map then the flow accumulation map, and the slope degree map. Slope length and slope gradient factors were calculated using this equation below:

The slope length factor was calculated by applying equations developed by Weischmeier and Smith (1978), Foster et al., (1977) and McCool et al., (1989).

The slope steepness factor is evaluated with the equation proposed by McCool et al., (1987).

These equations above were used in the map calculator to produce the raster maps for L factor and S factor, which were multiplied with each other to obtain the LS factor map.

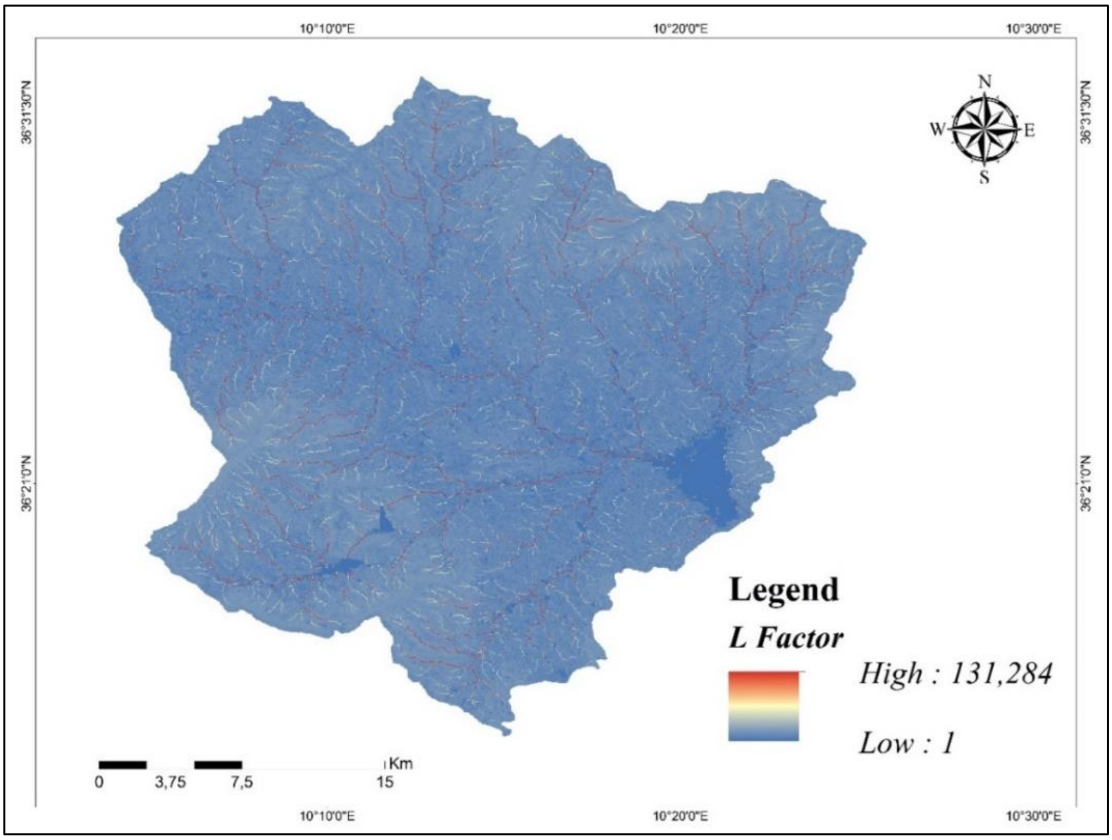

Figure 41: Slope Length factor map

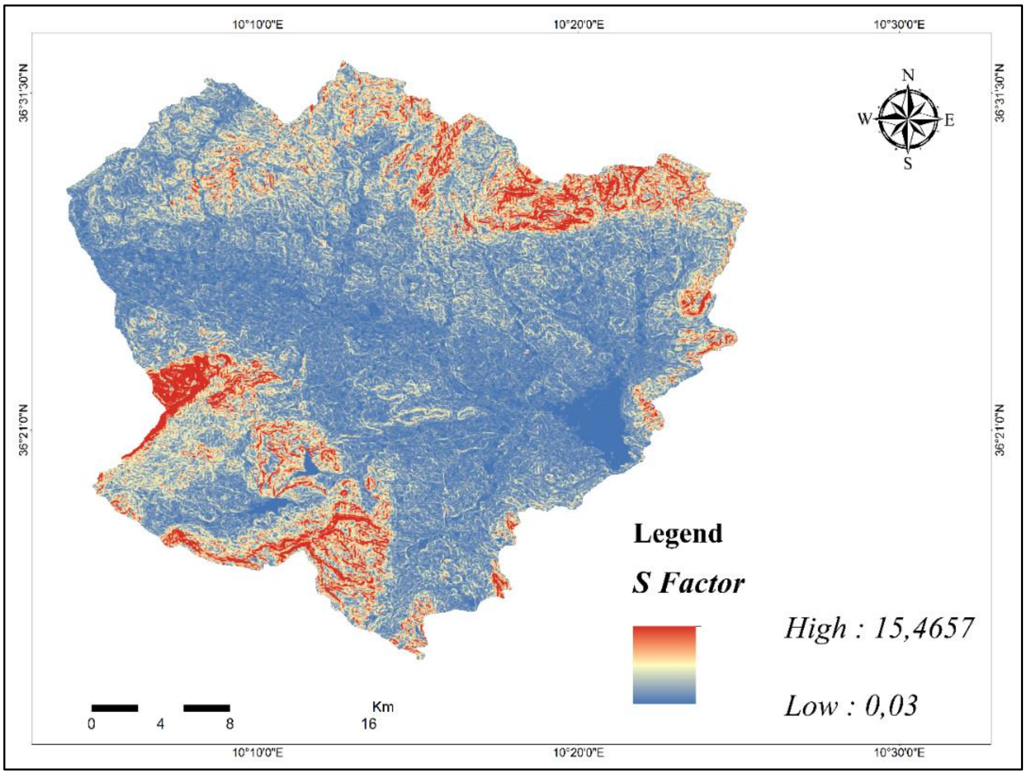

Figure 42: Slope Steepness factor map

Slope length and slope steepness maps were multiplied to obtain the LS factor map (Figure 51)

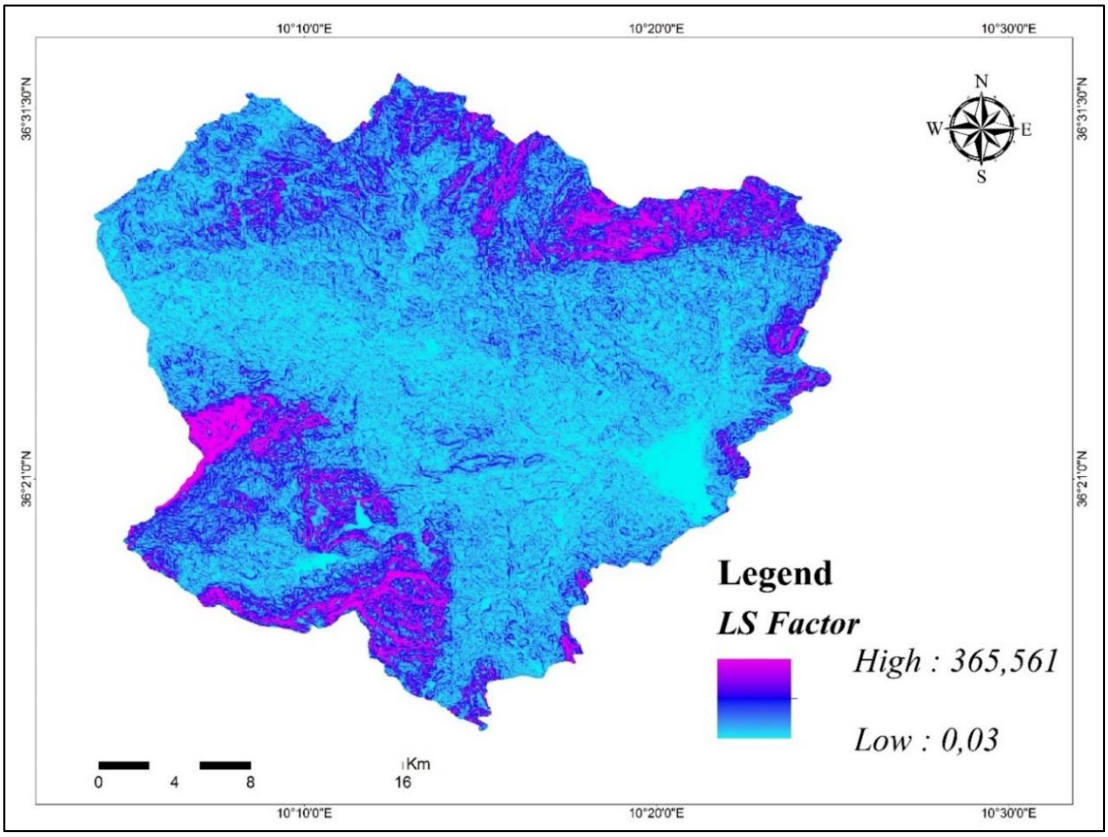

Figure 43 : LS factor map of the Rmel watershed

The LS factor of the watershed varies from low (0.03) to high (365.561). The areas with high LS values are more vulnerable to soil erosion and those with less value are relatively less vulnerable.

6. Conservation support practice factor (P):

The P factor map generated is used for understanding the conservation practices being taken up in the study area. It considers the control practices, which reduce the eroding power of rainfall and runoff by their impact on drainage patterns, runoff concentration, and runoff velocity.

The value of P factor depends on the soil management measures, and on the slope. In this study, a P value of 1 was attributed to areas without erosion control practices. For the areas under protection, where SWC measures are implemented, values were assigned according to the slope class, as follows: 0.1 with (0-5%) slope, 0.12 with (5-10%) slope, 0.14 with (10-20%) slope, 0.19 with (20-30%) slope, 0.25 with (30-50%) slope and 0.33 with (50-100%) slope.

A raster map of P factor (Figure 52) was produced accordingly, by combining the SWC and the slope Maps.

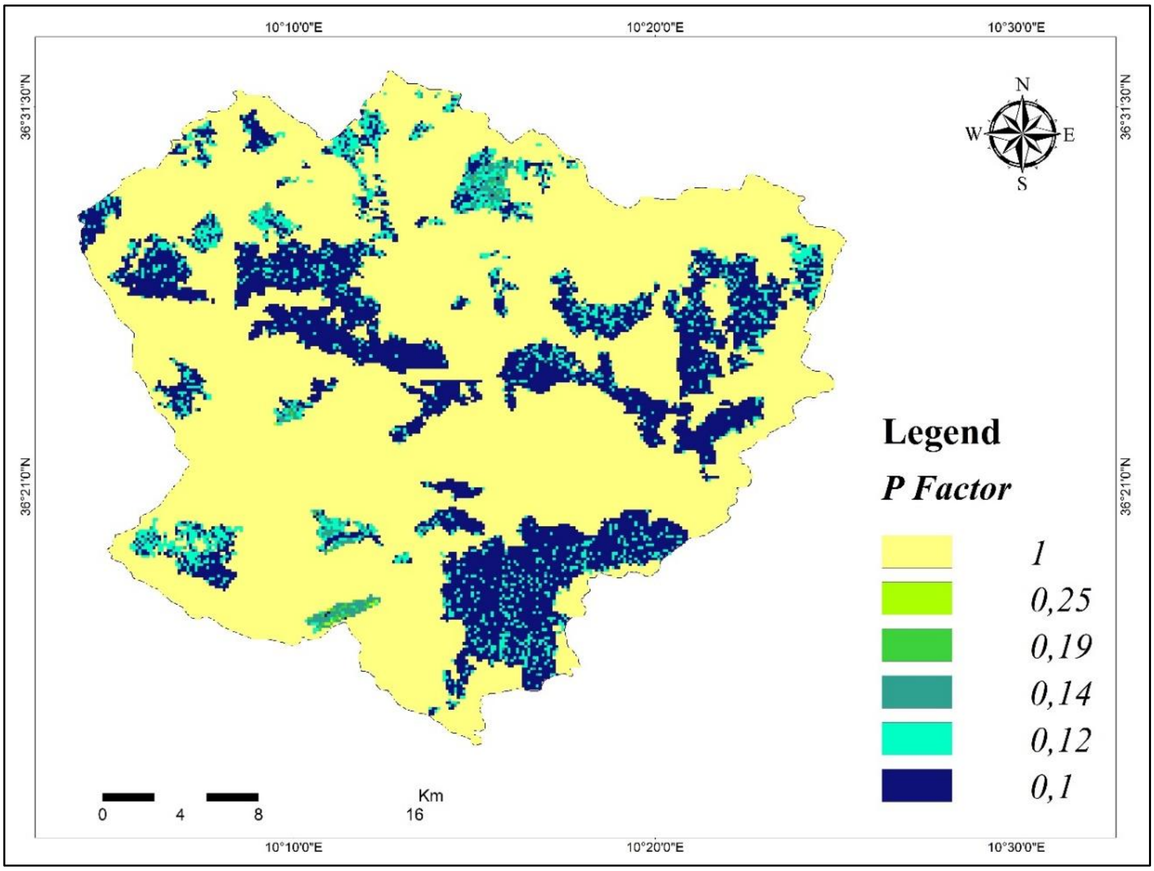

Figure 44: P Factor map of the Rmel watershed

Table 8:Distribution of P Factor in the watershed

Area	Slope (%)	P factor	Area (km^2)	Area (%)
with erosion control practice	0-5	0.1	135	20
	5-10	0.12	41	6
	10-20	0.14	7.2	1
	20-30	0.19	0,8	0.18
	>30	0.25	0.2	0.02
Without erosion control practice	all	1	495	72.8
Total			**679.2**	**100%**

The P factor decrease where slope decreases. It ranges from 0.1 to 1 in the watershed. Since anti-erosion practices cover only 27% (184, 2 km^2) of the total watershed area, a P value of 1 was assigned to 73% basin area (Table 9).

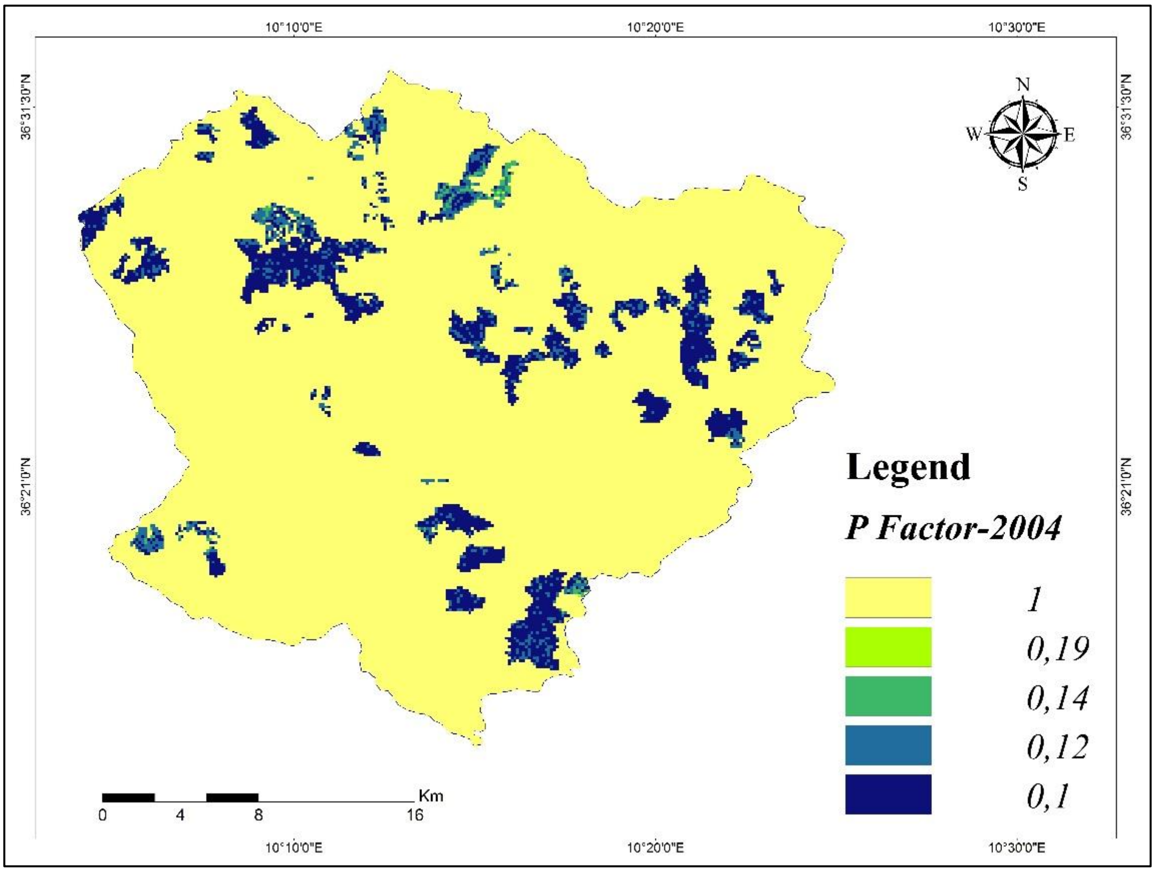

Figure 45: P Factor map of the Rmel watershed in 2004

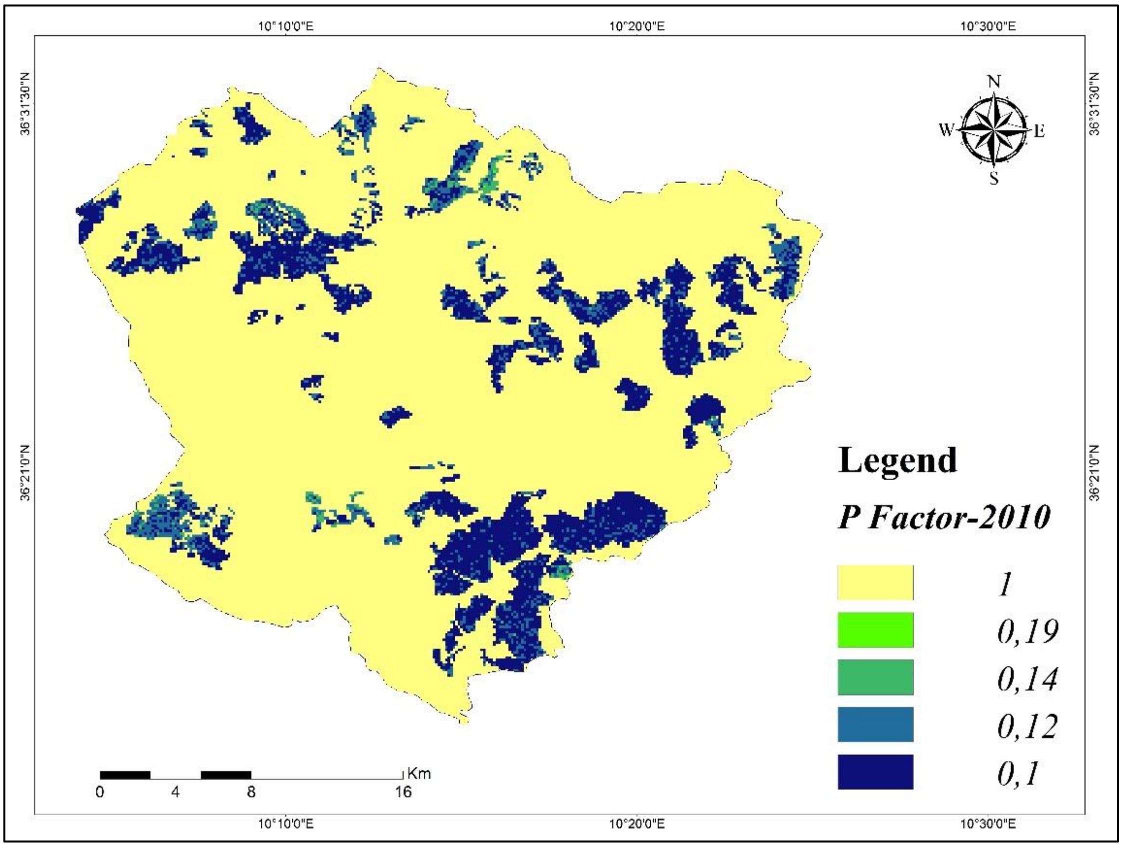

Figure 46: P Factor map of the Rmel watershed in 2010

To compare the erosion effect of previous dates with the current erosion, P factor maps of 2004 (Figure 53) and 2010 (Figure 54) were generate. The area protected by practices management was increased.

7. Soil Erosion Rate Estimates

The final map showing the annual soil loss rate of the watershed was produced by overlaying the five RUSLE factors (erosivity (R), erodibility (K), topographic(LS), cover management (C) and conservation support practice (P) factor) using RUSLE equation and raster calculator geo-processing tools in Arc GIS 10.4 (Figure 55).

The map shows the average rate of soil erosion on every point of the watershed.

For clarity reasons, we classified the areas affected by erosion into five classes following the system defined by SOTER (FAO, 1995). Indeed, the map that we obtained has pointed out the existence of different zones and each one is characterized by an erosive potential.

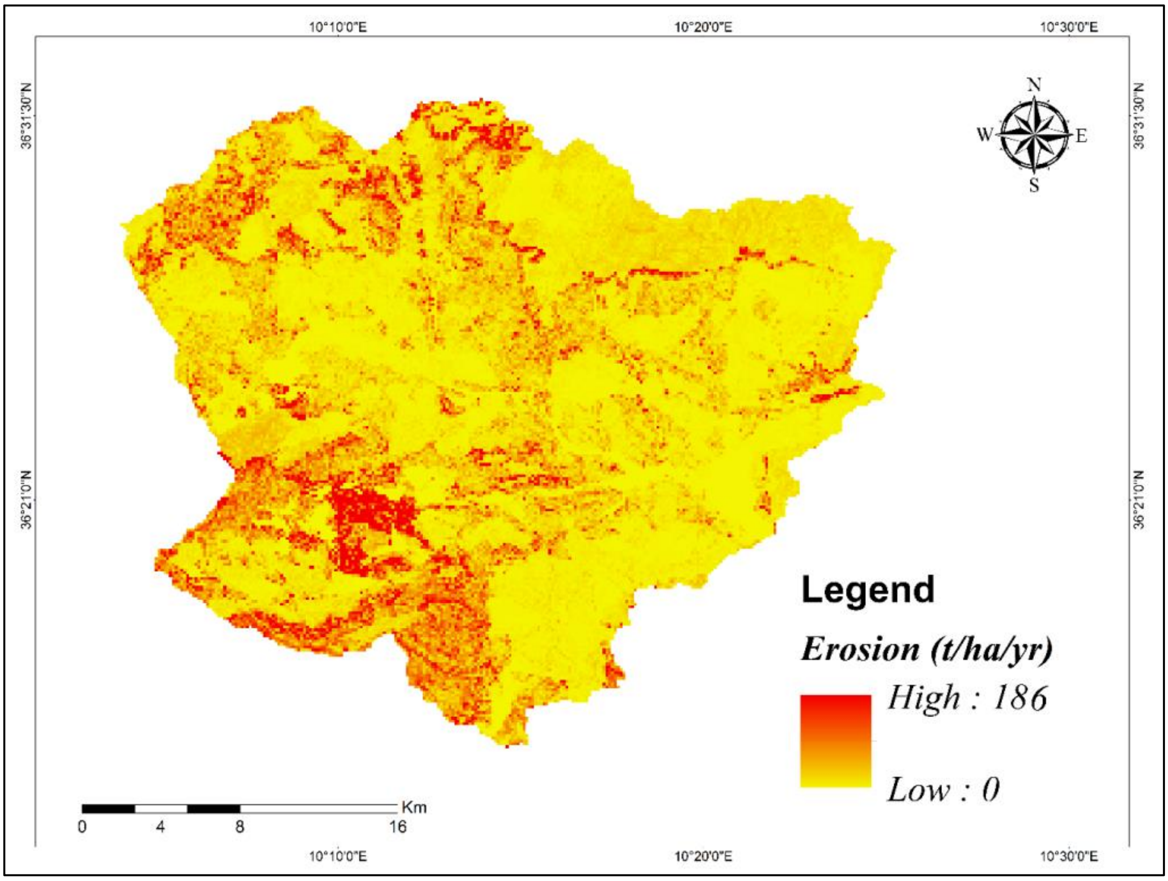

Figure 47: Soil erosion of the watershed

The area and proportion of soil erosion classes are illustrated in Table 10.

Table 9: Land area of each potential soil erosion class

Numeric range of soil loss (ton /hectare/year)	Potential soil erosion risk class	Area (km2)	Area (%)
0-5	Slight	567	85
5-10	Moderate	64.7	9.5
10-25	Severe	33	4.7
25-50	Very severe	3.6	0.7
>50	Extreme	0.2	0.1

The largest portion of Rmel watershed (85%) is classified as subjected to slight potential erosion risk, about 9.5% has moderate potential risk, 4.7% and 0.7% respectively have severe and very severe potential risk, and finally only 0.1% has extreme risk.

The annual soil loss of the Rmel watershed ranges from 0 to 186 ton ha^{-1} $year^{-1}$ with an annual average soil loss rate of 2.18 ton ha^{-1} $year^{-1}$, (2.5 ton ha^{-1} $year^{-1}$ in 2004 and 2.3 ton $ha^{-1}year^{-1}$ in 2010). The total annual soil loss in the watershed was estimated to 22.8 million tons/year, (36.8 million tons/year in 2004 and 24.5 million tons/year in 2010).

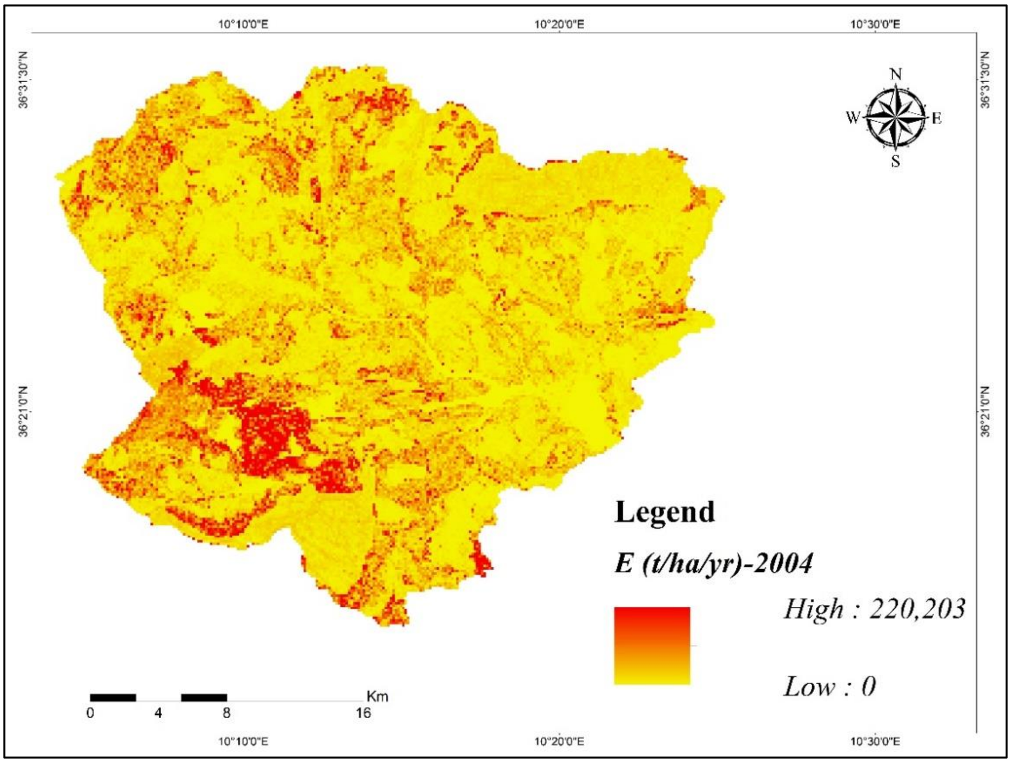

Figure 48: Soil erosion map of the watershed in 2004

The two soil erosion maps were produced to enable multi-temporal simulation and to compare soil loss rate in different period.

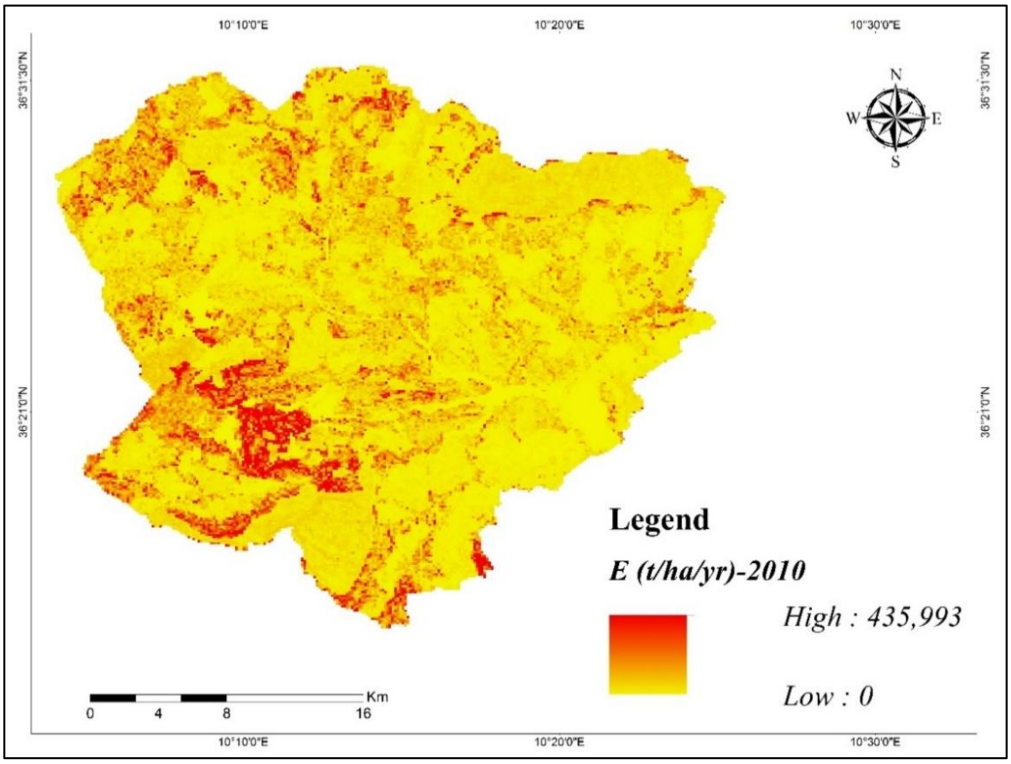

Figure 49: Soil erosion map of the watershed in 2010

8. Summary

Chapter 5 presents the procedure and methodology for the estimation of the RUSLE parameters (rainfall erosivity (R), soil erodibility (K), slope length and steepnees (LS), cover management (C), and support practice factor (P)) and of the potential soil erosion risk.

In the Rmel watershed, the annual average R-values ranged from 84 to 113 based on the location of rainfall stations; Mograne rainfall station located in the northwestern part of the watershed had the maximum R-value of 113. The soil erodibility factor (K) varied from 0 to 0.08. Slope length and steepness (LS) ranged from 0.03 to 365.56. The cover management factor (C) ranged from 0 to 0.9. The support practice factor (P) ranged from 0.1 to 1. The annual soil loss of Rmel watershed range from 0 to 186 ton ha^{-1} $year^{-1}$ with an annual average soil loss rate of 2,18 ton ha^{-1} $year^{-1}$.

CHAPTER VI

DISCUSSION

The results of this study show that it is possible to use a modelling approach–the RUSLE method–to conduct a detailed assessment of the spatial distribution of erosion risk across an entire basin using geographical information systems, generating useful information for decision-making about the watershed.

In the study case, the mean annual rate of soil loss in the watershed was large enough to degrade the area. Clearly, surface erosion can vary spatially due to rainfall variability, topographic and morphological changes, different soil types and characteristics, and human-induced disturbances.

Rain intensity is the main factor at play. The higher the rain intensity, the more the effect of threshing of the soil is pronounced. The rainfall erosivity factor (R) for six weather stations ranged from 84 to 113 $MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}$. The distribution of R-values varies and consistent with annual precipitation across the watershed. The highest R-values prevailed in the lower part of the watershed and the lowest occurred in the upper part.

The K-factor values are high especially where Fluvisoils and Lithosols are dominant, and where landslide complexes characterized the clay marly and marly limestone geological formations are present. Smaller values for Vertisols and Rendzine indicates less vulnerable soil type to erosion.

The slope of Rmel watershed has high variability. The LS factor in the watershed varies from 0.03 to 365.56. Area with high LS values are more vulnerable to soil erosion and those with less value are relatively less vulnerable.

Flow accumulation of the area was used as slope length and this has proved quite interesting in accounting for the direction of water movement. Slope and flow accumulation were then combined and the results further elaborated the adverse effect of the topography on soil erosion.

High values of C factor were related to low amount of vegetation cover. This indicates that the bare or sparsely vegetation soils are exposed to the direct impact of raindrop. On the other hand, low C values were mapped in presence of good vegetation cover.

The management practice factor P indicates the effect of conservation practices on soil erosion. Cultivation practices affect erosion by modifying the flow pattern and direction of runoff and by reducing the amount of runoff. Factor P in Rmel watershed range from 0 to 1, area with P equal to 1 are more vulnerable to soil erosion than area with regular maintenance.

The result of the overall potential soil loss risk should therefore be seen as a function of the above factors. High erosion losses were observed on the steepest lands despite appreciable vegetation cover indicating the considerably high effect of topography.

The highest average values of soil loss are essentially due to higher values of LS factor and R factor; and to the scarcity of vegetation cover which is proved by the high value of C factor. In addition, conservation practices are not widespread and for this reason P value is 1 for the majority area of the watershed. Therefore, high potential soil loss can occur particularly in areas with steep slope, poor vegetation, and no water and soil conservation practices.

Generally, the conservation practices have positive effect in controlling soil erosion. The RUSLE model brings an important help for the decision-makers, because it allows to simulate scenarios for anti-erosive practices and plan the interventions to control erosion, as shown in the next section. It also allows detecting sites presenting a priority, which are the most sensitive, and the most affected erosion. Therefore, this research allows disentangling the utility of the RUSLE model to manage and preserve land.

1. **Proposed scenario of anti-erosive practice:**

After superposing the erosion map with the Land cover map and the existing water and soil conservation map of the Rmel watershed, we simulated the effect of building additional bench terraces in areas with high risk of erosion. They were distributed as indicated the figure 58.

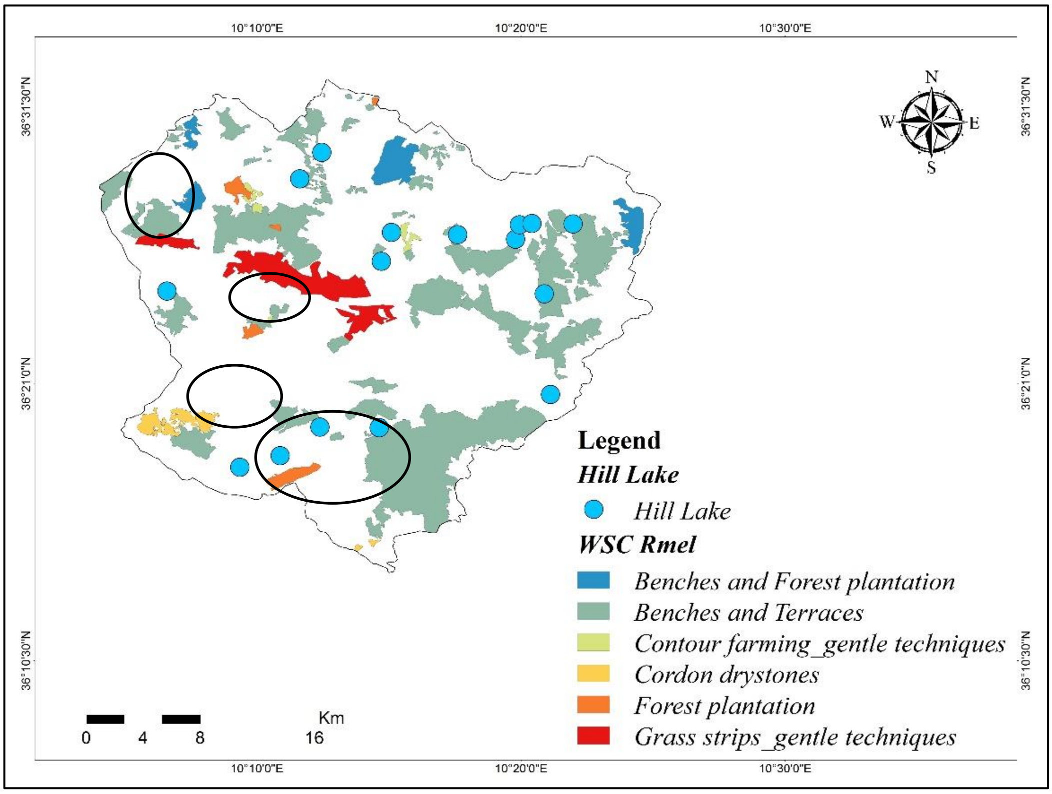

Figure 50: Location of the simulated bench terraces

By summing the existing SWC areas with the simulated ones, the overall area covered with anti-erosive practice increased to 38% (Figure 59).

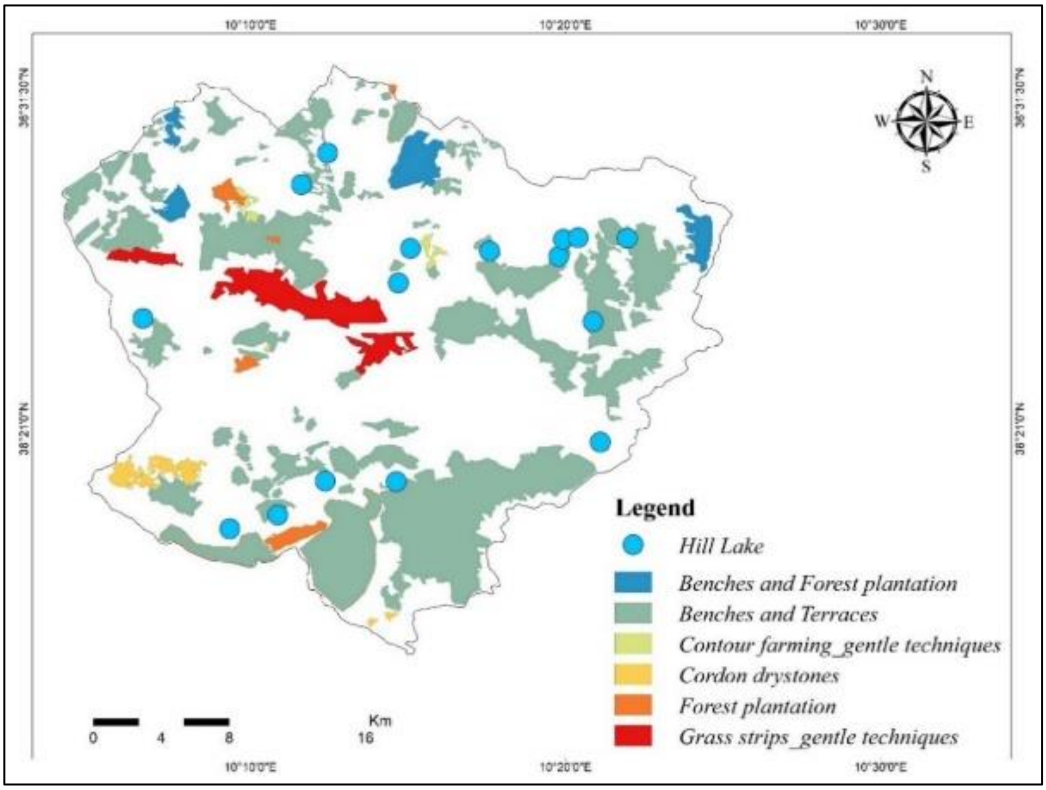

Figure 51: Proposed scenario of SWC Rmel watershed

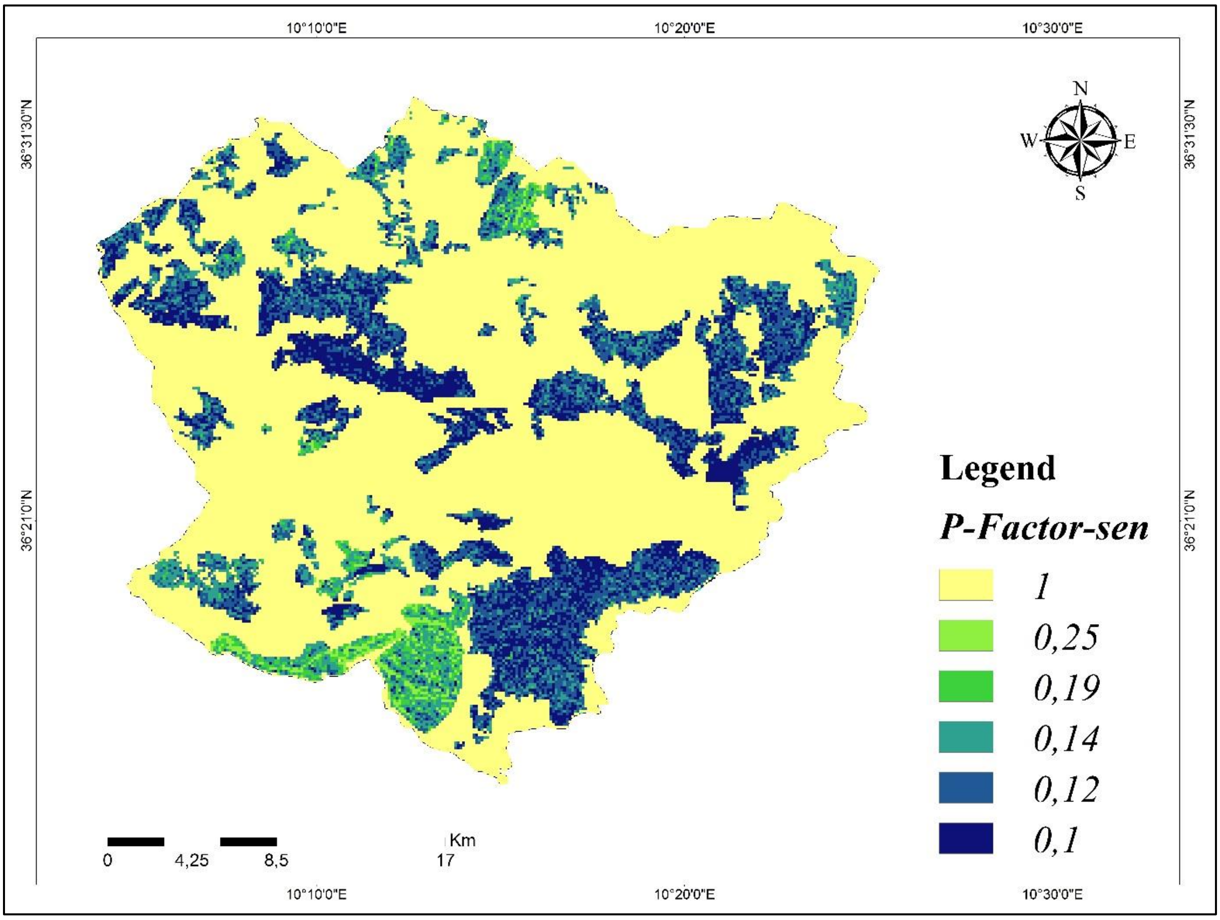

Figure 52: spatial repartition of factor P

In the same way as before, the new P-factor map was created based on the slope map (Figure 5) and the new SWC techniques map (Figure 59).

2. New Soil Erosion Rate Estimates

Based on the new P map (Figure 60), a new erosion map was then produced (Figure 61), along with a new table (Table 11) with the classification of the erosion following the classification defined by SOTER (FAO, 1995).

Table 10 : Classification of soil erosion

Numeric range of soil loss (ton /hectare/year)	Soil erosion risk class	Area (km2)	Area (%)
0-5	Slight	569	85
5-10	Moderate	67.4	10
10-25	Severe	32.6	4.3
25-50	Very severe	3.4	0.6
>50	Extreme	0.2	0.1

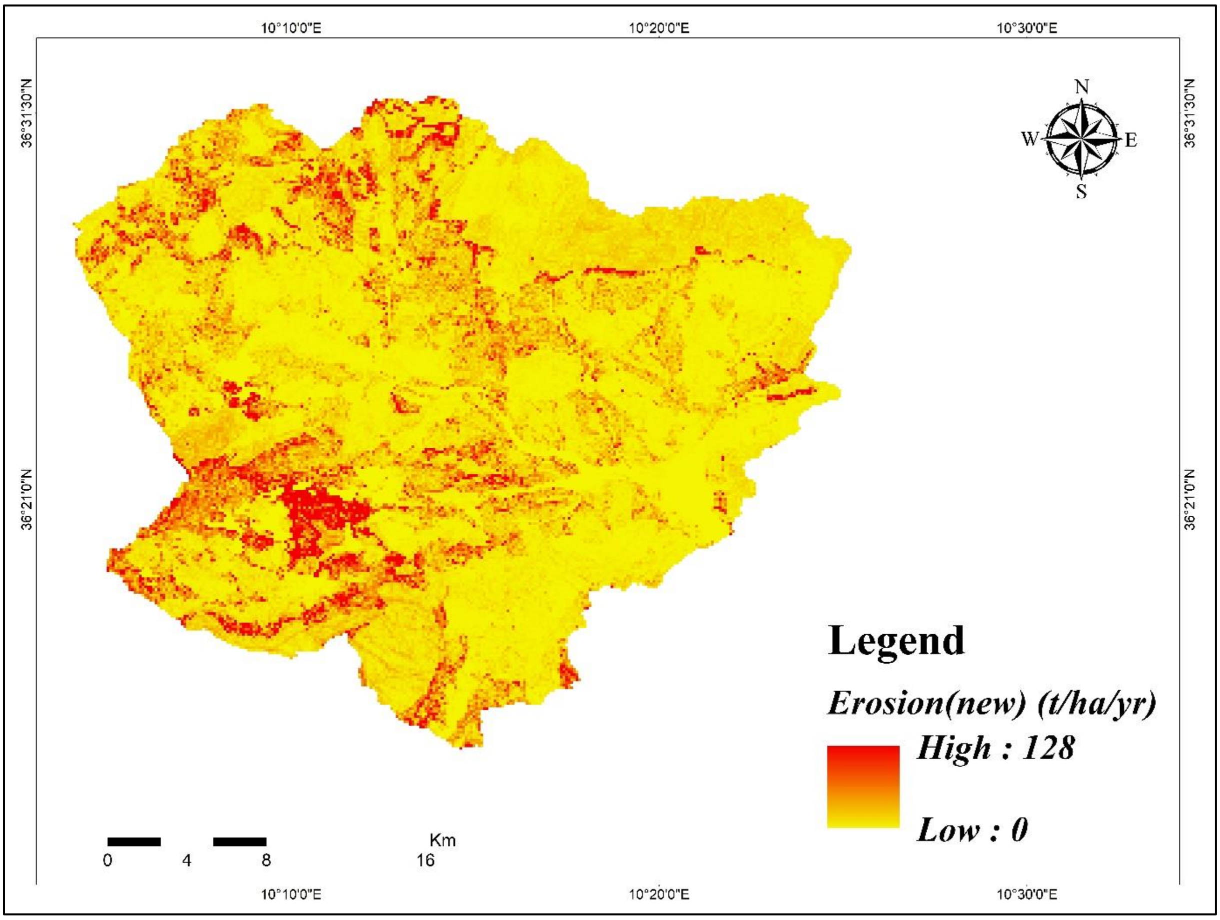

Figure 53: new Soil erosion classes of the watershed

The results show that the modification of the P factor has an effect on erosion.

The addition of mechanical bench terraces resulted in a decrease in the total annual losses of the basin, especially in areas with severe and very severe erosion.

The new annual soil loss of Rmel watershed ranges from 0 to 128 ton ha-1 year- 1 with an annual average soil loss rate of 1.9 ton ha-1 year- 1. A 15% reduction of soil loss compared to initial scenario.

The primary objective of proposed scenario was to investigate the effect of conservation practices on land productivity and land neutrality using multiple observations in various date. This helped compare lands with conservations measures (treated) and lands without conservation measures (non-treated).

CONCLUSION

The major objective of this study was to identify the soil erosion rate of Rmel watershed, which is located in the northeastern of Tunisia and compare this rate with a simulated scenario of enhanced SLM technologies to show the potentially big effect of the supporting practices factor (P) on land neutrality. This study demonstrates that the RUSLE model combined with GIS provides great advantage to analyze multi-layer of data spatially and estimates soil loss rate over large areas by utilizing information on rainfall erosivity (R) using interpolation of rainfall data, soil erodibility (K) using soil map, vegetation cover (C) using satellite images, topography (LS) using Digital Elevation Model (DEM) and conservation practices (P) using satellite images. Based on the analysis, the average and total annual soil loss potential of the study watershed was 2, 18 ton/ha/year and 22, 8 million tons/year, respectively. About 567 km2 (85%) of the watershed was categorized slight class which under soil loss tolerance (SLT) values ranging from 5 to 11 tons ha-1 year-1, whereas moderate to high soil loss potential covered about 108 km2 (15,2%) and the rest of watershed covered by severe to extreme class.
The predicted amount of soil loss and its spatial distribution could facilitate sustainable land use and management for the watershed and the method can be applied in similar watershed of the country. However, the accuracy of results obtained is largely a function of the accuracy of input data such as topography, support practices, and cover parameters, which are location specific and need to be calibrated. Areas characterized by moderate to high soil loss should be given special priority to reduce or control the rate of soil erosion by means of conservation planning.

In this study some of the data were interpolated using spatial interpolation, others are extracted from digital elevation models and remotely sensed data. On the other hand, the digital elevation model of the area, which was provided with an acceptable level of accuracy, was employed in this study to derive hydrological parameters with better confidence.

The result of this study indicate that high potential soil loss area is an area with severe slope, poor vegetation, and no water and soil conservation practices. Therefore, this combination of RUSLE and GIS can be useful for decision makers to establish appropriate strategies of soil and water conservation.

The ‘Impact evaluation of SLM options’-project aims to value current land use strategies and feasible alternatives in economic terms, in order to promote more sustainable land management that is also in line with national development goals. Therefore, the projects aim to develop a user-friendly, interoperable online GeoCOs (Global Geoinformatics Context and Options) tool to enable stakeholders to query SLM options in different context in order to assess potential impact for applying options in time and space. The tool requires a country-specific, accessible knowledge base of standardized, geo-referenced SLM options-by-context. This database will be established by identifying, describing and analyzing existing, tested and adopted SLM options versus different socio-ecological contexts by meta-analysis of the state-of-the art literature and of systematically reviewing and cataloguing existing and completed projects in target countries having an impact in terms of SLM options and lessons learned. Hence, the dataset and impact assessment of the tested SLMs can be embedded in the web-based GeoCOs tool. In times of rapid development of multi-dimensionally, multi-scale, timely updated socio-ecological geo-date, the options-by-context knowledge database and online impact assessment tool will enable the assessment of potential impacts of SLM in time and space. Via the web-based GeoCOs (Global Geoinformatics Context and Options) platform, effective decision-making of stakeholders involved with food production systems is encouraged. The platform allows NARS to acquire knowledge and tools to set standards and approaches to achieve land degradation neutrality and allows stakeholders at country level able to plan strategic interventions and steer foreign aid based on historical and current data of interventions.

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APPENDICES (1)

Oued Ezzit station

Year	September	October	November	December	January	February	March	April	May	June	July	Aout	R
1995	40,5	43,0	18,7	2,4	74,0	0,0	29,1	34,3	0,0	10,6	0,0	13,5	**63**
1996	120,6	21,3	62,8	54,5	84,0	221,8	35,5	51,2	51,1	33,4	1,0	12,8	**131**
1997	35,7	33,5	7,5	20,7	107,9	28,5	2,9	46,4	0,0	2,8	0,0	14,9	**79**
1998	92,1	49,2	47,4	69,6	4,5	7,0	29,6	16,5	13,2	2,0	0,0	14,7	**77**
1999	128,1	87,9	14,2	37,5	207,3	16,0	24,0	0,9	18,1	6,7	0,0	9,8	**141**
2000	14,9	3,0	121,8	44,0	3,1	15,0	62,0	41,5	55,6	7,8	0,0	0,0	**90**
2001	36,7	65,7	23,7	46,9	22,4	45,0	10,0	20,7	23,0	0,0	0,0	1,0	**60**
2002	61,9	1,6	27,8	18,5	6,1	5,4	7,0	44,9	33,7	4,7	30,3	17,0	**55**
2003	13,9	42,1	65,0	32,5	168,9	69,9	32,7	42,7	9,4	5,5	0,0	0,0	**109**
2004	120,1	78,7	22,8	159,0	21,6	16,5	74,1	20,4	12,0	43,3	0,0	8,0	**114**
2005	58,0	14,7	85,5	37,2	57,7	85,1	15,5	34,2	5,4	34,0	1,7	21,6	**78**
2006	2,4	21,2	33,1	91,6	184,5	21,0	24,0	9,8	41,1	7,7	0,0	0,0	**124**
						R.moy							**91**

Saouaf station

YEAR	September	October	November	December	January	February	March	April	May	June	July	Aout	R
1995	40,5	33,0	14,0	3,0	43,5	0,0	11,0	24,0	0,0	30,0	2,0	34,0	50
1996	182,0	33,5	72,0	102,0	107,0	151,5	25,5	67,5	62,0	25,5	0,0	42,5	127
1997	46,0	9,0	6,0	31,0	62,0	28,5	3,0	45,5	3,0	10,0	0,0	42,5	60
1998	111,5	70,0	34,0	46,0	29,0	7,0	30,0	16,0	52,0	8,0	0,0	25,0	81
1999	27,0	46,0	3,3	53,0	168,0	20,0	62,0	13,5	10,0		11,5	7,0	110
2000	32,0	18,0	131,0	25,0	10,0	16,0	29,0	35,0	55,0	8,5	0,0	0,0	89
2001	31,5	60,0	44,0	41,0	41,0	34,5	6,0	23,0	25,0	0,0	5,0	1,5	58
2002	29,0	2,0	39,0	17,0	6,0	8,5	20,5	53,0	46,5	3,5	21,0	20,5	52
2003	17,5	23,5	79,0	47,5	175,0	94,0	24,0	94,5	10,0	6,5	1,0	1,5	120
2004	100,5	103,0	20,5	135,0	22,0	23,0	72,0	38,0	8,0	27,0	2,0	8,0	105
2005	55,0	15,0	51,0	41,0	45,0	66,0	11,0	25,0	8,0	45,0	0,0	25,0	64
2006	3,0	59,0	17,0	63,0	156,0	16,0	16,0	11,0	34,0	10,0	33,0	4,0	103
					R.moy								**84**

Zaghouan station

YEAR	September	October	November	December	January	February	March	April	May	June	July	Aout	R
1995	33,3	54,5	10,4	5,0	61,2	0,0	36,5	21,3	0,0	15,5	0,0	19,0	59
1996	118,1	18,4	62,5	131,5	112,0	155,3	39,3	91,3	73,5	13,0	9,5	37,0	121
1997	30,3	15,4	7,0	22,7	76,8	21,5	10,5	56,7	0,0	3,5	0,0	35,1	65
1998	103,3	64,3	67,2	77,0	23,6	18,0	19,3	22,5	17,6	4,9	0,0	14,0	84
1999	57,2	102,3	36,6	52,0	257,8	22,5	46,8	3,5	21,6	11,8	6,0	1,5	153
2000	47,0	8,7	236,0	47,8	12,5	17,0	26,0	36,2	71,0	0,0	0,0	0,0	148
2001	59,5	116,0	23,0	60,6	49,0	19,0	9,0	20,5	28,0	0,0	0,0	0,0	86
2002	29,8	7,5	40,0	44,0	6,7	8,5	15,0	45,0	40,0	4,0	31,0	23,8	52
2003	18,3	24,1	87,5	45,5	187,5	81,0	34,0	88,8	7,0	17,5	0,0	0,0	122
2004	216,5	76,5	22,5	176,5	32,5	40,5	101,0	34,0	19,2	59,0	0,0	19,5	143
2005	66,0	19,4	39,7	55,5	54,1	111,5	20,5	55,5	6,5	21,0	6,5	29,5	81
2006	29,3	14,0	27,2	102,2	257,5	45,0	24,5	17,5	26,5	7,0	0,0	2,0	159
					R.moy								**98**

Mograne station

YEAR	September	October	November	December	January	February	March	April	May	June	July	Aout	R
1995	33,8	46,2	9,6	9,7	68,4	0,7	33,8	21,6	0,0	20,3	0,4	14,7	59
1996	83,0	24,7	53,1	140,4	90,5	155,7	40,0	88,6	63,0	19,8	12,2	39,8	115
1997	29,3	10,5	8,0	23,6	72,7	22,5	13,5	51,6	1,1	1,8	0,7	28,3	61
1998	105,6	65,6	58,8	76,9	25,8	28,7	20,1	19,7	18,3	8,1	0,0	12,9	83
1999	60,5	100,6	41,7	49,9	264,1	26,5	48,0	7,0	26,3	15,7	4,7	3,1	153
2000	56,9	12,2	129,1	59,5	15,9	20,7	3,8	25,1	1001,0	8,0	0,0	0,0	552
2001	48,7	119,7	20,5	59,9	51,8	20,4	12,4	21,2	35,8	0,2	0,3	0,0	86
2002	21,6	16,9	29,1	39,0	10,3	8,8	14,2	57,9	42,8	5,5	13,9	17,8	51
2003	29,3	28,6	82,1	46,8	184,5	75,0	28,4	98,0	9,7	15,9	0,6	0,0	120
2004	171,7	57,9	34,4	151,2	29,6	33,5	95,7	31,3	13,8	61,5	0,0	24,6	122
2005	59,1	17,2	72,9	73,6	51,6	104,1	23,7	48,6	8,0	21,4	5,6	21,0	83
2006	30,8	15,2	40,0	8,2	260,6	48,6	26,4	2,2	27,0	5,4	0,6	4,9	167
						R.moy							**113**

Zeriba station

YEAR	September	October	November	December	January	February	March	April	May	June	July	Aout	R
1995	44,7	46,0	24,5	3,0	63,0	0,0	26,5	47,5	0,0	37,0	0,0	38,0	63
1996	186,0	21,5	72,0	142,0	90,0	208,5	40,5	87,6	41,5	61,0	10,0	14,0	144
1997	73,0	23,5	11,5	28,5	79,5	25,0	6,2	57,5	0,5	8,5	0,0	31,0	73
1998	163,0	54,0	54,0	92,5	29,0	0,7	22,5	21,0	23,0	3,0	0,0	10,0	111
1999	43,5	117,0	27,0	52,0	228,0	26,0	45,0	4,0	18,1	6,7	0,0	19,0	141
2000	33,0	6,0	224,0	27,0	6,0	19,0	18,0	34,0	41,0	1,5	0,0	0,0	149
2001	54,0	174,0	21,0	99,0	37,0	30,0	9,0	26,0	23,0	0,0	0,0	1,0	117
2002	30,0	6,0	56,0	47,0	4,0	10,0	18,0	45,0	40,0	0,0	27,0	25,0	57
2003	26,0	38,0	63,0	49,0	164,0	92,5	43,0	71,5	14,0	3,0	0,0	0,0	109
2004	153,5	100,5	15,0	146,0	27,5	19,0	93,5	32,0	15,5	42,5	0,0	18,0	121
2005	60,5	17,0	87,5	33,2	38,6	103,5	26,5	46,5	5,0	22,0	1,0	17,0	83
2006	4,7	39,5	46,3	70,5	208,0	19,0	28,5	5,5	54,0	10,0	2,0	4,0	130
					R.moy								**97**

Sbaihia station

YEAR	September	October	November	December	January	February	March	April	May	June	July	Aout	R
1995	11,0	42,5	25,5	6,5	52,0	0,5	38,0	18,0	1,0	14,5	0,5	11,5	52
1996	69,0	27,5	51,0	105,5	102,5	166,5	37,0	70,0	71,0	25,0	4,5	22,0	112
1997	39,5	47,0	15,0	29,5	103,7	36,8	13,5	36,5	0,0	3,0	0,0	11,5	76
1998	111,7	66,3	23,5	75,5	19,5	14,5	26,5	35,0	15,0	4,5	0,0	18,5	84
1999	53,0	72,0	34,5	52,0	176,0	27,0	56,5	3,5	11,0	3,5	6,5	15,0	111
2000	17,0	3,5	139,0	45,5	23,5	15,5	25,5	37,0	52,5	13,5	0,0	0,0	94
2001	91,5	160,0	26,0	104,5	84,0	36,0	16,0	33,0	22,0	0,0	1,5	1,0	115
2002	39,0	23,0	30,5	40,0	12,0	14,0	24,5	46,5	43,5	5,0	24,0	15,5	51
2003	17,0	31,5	37,5	0,0	0,0	48,0	34,5	89,5	10,5	19,7	0,0	0,0	71
2004	0,0	43,0	43,0	24,5	89,5	89,0	68,5	30,5	232,5	24,5	33,5	102,0	134
2005	36,5	7,0	76,0	12,0	2,0	32,0	27,0	44,5	24,5	0,0	112,0	32,0	82
2006	40,0	25,0	34,2	101,8	196,0	29,0	1,0	27,5	6,2	5,3	8,0	6,5	129
					R.moy								**92**

APPENDICES (2)

	Field of information	Your input Note: please fill in the lined boxes, with the use of the provided formats or information lists if you are asked in the Note column.
	PART 1: GENERAL INFORMATION	
	1.1. Name of the SLM Technology	
1.1.1	Name *:	
	1.1.2 Locally used name:	
	1.1.3 Subject keywords (max. 3) * :	
	Subject Language	
	1.2 Documentors and Resouces Persons/Information	
	1.2.1. Are you the main documentor? (I Yes, please fill below) *	
	Name (first name + last name):	
	Sex (Male/Female):	
	Name of institution:	
	Address of institution	
	Postal Code:	
	City:	
	State or District and country:	
	Tel.:	
	Fax:	
	E-mail:	
	Field of expertise 1:	
	Field of expertise 2 (if any):	
	Field of expertise 3 (if any):	
	1.2.3. Date of filling this form *:	
	1.2.4. Place of filling this form *:	
	1.2.5. Is there any Resouce Person (if different from the Documentor(s)) *	
	Name (first name + last name	
	Sex (Male/Female) :	
	Name of institution:	
	Address:	
	Tel.:	
	Fax:	
	E-mail:	
	Stakeholder type:	
	Field of expertise:	
	If there is more Resource Persons, please insert rows similar to the above	
	1.2.6. Information sources (Projects that implemented the Technology/Related Articles/Report/Project-Program websites) *	
	Information Source 1:	
	Information Source 2:	
	Information Source 3:	
	Information Source 4:	
	Information Source 5:	
	If there is more Information Resource, please insert additional rows	

APPENDICES (3)

Field of information	Your input Note: please fill in the lined boxes, with the use of the provided formats or information lists if you are asked in the Note column.	
PART 2: DESCRIPTION OF SLM TECHNOLOGY		
2.1. Definition of the SLM Technology * WOCAT:		
2.2 Detailded description of the SLM Technology * WOCAT:		
2.3 Illustrative photos WOCAT (please insert up to 3 photos, including the technical sketch if possible) * :		
Illustrative photo 1:		
Caption of photo 1		
Illustrative photo 2:		
Caption of photo 2		
2.4. Size of the site		Please specify the size in km2
2.5 Years of implementation (year - year) * WOCAT		
2.6 Year of evaluation/documentation *		
2.7 Mode of introduction of the SLM Technology WOCAT (multiple choices possible) *		

APPENDICES (4)

Field of information	Your input Note: please fill in the lined boxes, with the use of the provided formats or information lists if you are asked in the Note
PART 3: PURPOSE AND CLASSIFICATION	
3.1 Purposes of the SLM Technology (max. 3 most important purposes) * WOCAT **:**	
3.1.1 The 1st most important purpose	
If the main purose was selected as "Other ...", please specify:	
3.1.2 The 2nd most important purpose	
If the main purose was selected as "Other ...", please specify:	
3.1.3 The 3rd most important purpose	
If the main purose was selected as "Other ...", please specify:	
3.2 Type of the SLM Technology (max. 3 most relevant SLM types) * MW **:**	
3.2.1 The 1st most relevant SLM type:	
If the SLM type was selected as "Other ...", please specify:	
3.2.2 The 2nd most relevant SLM type:	
If the SLM type was selected as "Other ...", please specify:	
3.2.3 The 3nd most relevant SLM type:	
If the SLM type was selected as "Other ...", please specify:	
3.2.4 Relevant SLM types (formula is used, please do not delete it):	
3.3 SLM measures comprising the SLM Technology * MW **:**	
3.3.1a Type of Agronomic measures (1st):	
Concrete Agronomic measures (1st):	
3.3.1b Type of Agronomic measures (2nd):	
Concrete Agronomic measures (2nd):	
3.3.2a Type of Vegetative measures (1st):	
Concrete Vegetative measures (1st):	
3.3.2b Type of Vegetative measures (2nd):	
Concrete Vegetative measures (2nd):	
3.3.3a Type of Structural measures (1st):	
Concrete Structural measures (1st):	
3.3.3b Type of Structural measures (2nd):	
Concrete Structural measures (2nd):	
3.3.4a Type of Management measures (1st):	
Concrete Management measures (1st):	
3.3.4b Type of Management measures (2nd):	
Concrete Management measures (2nd):	
3.3.5 Combination of SLM measures (formula is used, please do not delete it):	[] + [] + [] + [] + [] + [] + [] + []

APPENDICES (5)

Field of information	Your input Note: please fill in the lined boxes, with the use of the provided formats or information lists if you are asked in the Note column.
PART 4: GEOGRAPHIC LOCATIONS, EXTENTS AND SOCIO-ECOLOGICAL CONTEXT/ENVIRONMENT	
4.1 Regions/locations where the SLM Technology has been applied MW:	
4.1.1 Region *	
4.1.2 Sub-Region *	
4.1.3 Country (usually only one, max 2 if well-bordered) *	
4.1.4 Province:	
4.1.5 District	
4.1.6 Total area the SLM Technology applied WOCAT:	
4.1.7 Area/Site ID	
4.2 Socio-ecological context/environment variables automatically extracted from the GIS Context Database (in specific for georeferenced Site 1, 2, etc.)	Documentor(s) do not fill the below boxes!
	Reference site <site ID>
Bio-physical conditions	
4.2.1 ARIDITY: Main class of aridity index	
4.2.2 PRECIPITATION: Mean annual precipitation (mm/yr)	
4.2.3 PRECIP-TREND: Long-term trend of annual precipitation (trend coefficient)	
4.2.4 WATER- PROXIMITY: Proximity to water body (m)	
4.2.5 BROAD-COVER: Broad class of land cover - Level 1 of LCCS (nominal codes)	
4.2.6 TREE-DEN: Tree density (trees/km2)	
4.2.7 SLOPE: Surface slope (degree)	
4.2.8 ELEVATION: Mean elevation above sea level (m a.s.l)	
4.2.9 SOIL-CONSTRAINT: Soil combined quality constraint (ordinary code)	
4.2.9.1 SQC1-NUTAVA: Soil quality constraint regarding nutrient availability	
4.2.9.2 SQC2-NUTRCAP: Soil quality constraint regarding nutrient retention capacity	
4.2.9.3 SQC3-ROOTCOD: Soil quality constraint regarding root condition	
4.2.9.4 SQC4-OXYGEN: Soil quality constraint regarding soil oxygen	
4.2.9.5 SQC5-SALT: Soil quality constraint regarding salinity	
4.2.9.6 SQC6-TOXICITY: Soil quality constraint regarding toxicity	
4.2.9.7 SQC7-WORKCAP: Soil quality constraint regarding work capacity	
4.2.10 BED-ROCK: Bedrock type (nominal code)	
4.2.11 SOIL-TYPE: Predicted dominant soil type - ISRIC (nominal code) (link to ISRIC Soil Grid: http://www.soilgrids.org/)	
Physical and institutional accessibilities	
4.2.12 DIST-ROAD: Distance to main road (km)	
4.2.13 DIST-TOWN: Distance to district capital (km)	
4.2.14 PROTECT: Protected area (ordinary code)	
4.2.15 TENURE-SEC: Tenure security level (ordinary code)	
Population dynamics and pressure	
4.2.16 POP-DENSITY: Average population density (persons/km2)	
4.2.17 RURAL-POP: Rural population / total population (ratio)	
4.2.18 POPDEN-CHANGE: Change in population density over the period 1990-2015 (persons/km2)	
National economic development status	
4.2.19 GDP-CAPITA: Average GDP per capita ($US/person/yr)	
4.2.20 GDP-GROWTH: Mean growth rate of annual GDP during 2000-2015 (%)	
4.2.21 POVERTY: Poverty index = proportion of population that is below the poverty line (%)	
4.2.22 FOOD-SECURITY: Food security index	
Socio-ecological context similarity	
4.2.23 SES-TYPE: Socio-ecological context type (nominal code)	
4.2.24 GLS-ASSELEN: Global Land System (nominal code)	
4.2.25 LSA: Land System Archetypes (nominal code)	

4.3 Performance/impact indicators automatically extracted from the GIS Performance/Impact Database **(in specific for georeferenced Area/Site 1, 2, etc.)**	Documentor(s) do not fill the below boxes!	
	Reference site <site ID>	
Productivity and Water Use Efficiency		
4.3.1 PROD-DEG: Biomass productivity-based land degradation		
4.3.2 PROD-IMP: Biomass productivity-based land improvement		
4.3.3 RUE: Rain use efficiency = ratio of NPP / annual rainfall (g C/mm rainfall)		
Pressure on land's carrying capacity		
4.3.4 HANPP: Human appropriation of NPP = NPP used by human activities x 100 / total NPP (% of total		
4.3.5 NPP-GAPPC: Gap between actual and potential Net Primary Production (NPP)"		
Affected population		
4.3.6 AFFECTED-POP: Approximate population affected by land degradation (affected persons/km2)		
4.3.7 AFFECTED-RPOP: Approximate rural population benefited by land improvement (benefited		
4.4 Environment variables filled by the Documentors (in specific for georeferenced Site 1, 2, etc.)		
	Reference site <site ID>	**Source**
Biophysical conditions		
4.4.1 Average elevation a.s.l (m) WOCAT		
4.4.2 Average slope (%) WOCAT		
4.4.3 Average Annual Precipitation (mm) * WOCAT		
4.4.4 Average Annual Temperature (^{o}C) *		
4.4.5 Land use main type - BEFORE the SLM Technology applied * MW (max 2 choices)		
4.4.6 Land use subtype-practice - BEFORE the SLM Technology applied MW (max 2 choices)		
4.4.7 CURRENT land use main type * MW (max 2 choices)		
4.4.8 CURRENT land use subtype-practice MW (max 2 choices)		
4.4.9 Local bedrock - major FAO class (max 2 choices)		
4.4.10 Local bedrock - FAO group (under the major class selected above) (max 2 choices)		
4.4.11 Local bedrock - FAO type (under the group selected above) (only if relevant)		
4.4.12 Landform type WOCAT (max 2 choices)		
4.4.13 Soil type WOCAT (syntax: name/classification system)		
4.4.14 Soil depth WOCAT (max 2 choices)		
4.4.15 Topsoil texture (0-20 cm depth) WOCAT (max 2 choices)		
4.4.16 Soil texture below 20 cm depth WOCAT (max 2 choices)		
4.4.17 Topsoil organic matter WOCAT (max 2 choices)		
4.4.18 Soil pH (USDA 1993) MW (max 2 choices)		
4.4.19 Soil salt class based on soil electrical conductivity (EC) (FAO 2006) MW (max 2 choices)		
4.4.20 Soil % in rock fragments (FAO 2006) MW (max 2 choices)		
4.4.21 Water supply type * (max 2 choices)		
4.4.22 Ground water table depth WOCAT (max 2 choices)		
4.4.23 Surface water availability WOCAT (max 2 choices)		
4.4.24 Water quality (untreated) WOCAT (max 2 choices)		
Socio-economic conditions		
Characteristics of the average/typical land users who are practicing the SLM Technology		
4.4.25 Sedentary or nomadic household (type) WOCAT		
4.4.26 Market orientation of the production system (type) * WOCAT		
4.4.27 Share of off-farm income (i.e. not based on agriculture or forestry) (class) WOCAT		
4.4.28 Relative level of wealth (in according to local standard/perception) (class) WOCAT		
4.4.29 Implementation entity of the SLM technology (type) * WOCAT		
4.4.30 If the implementators are not individuals, please indicate the name(s) of the entity WOCAT (if available)		
4.4.31 Level of mechanization (class) WOCAT		
4.4.32 Gender aspect in the decision to adoption of SLM (class) MW		
4.4.33 Gender aspect in the operational practice of SLM: Agronomic activities MW (the concrete activity as what filled in part 3.3 ; if there is no activity of this kind please keep blank) (class)		
4.4.34 Gender aspect in the operational practice of SLM: Vegetative activities MW (the concrete activity as what filled in part 3.3 ; if there is no activity of this kind please keep blank) (class)		
4.4.35 Gender aspect in the operational practice of SLM: Structural activities MW (the concrete activity as what filled in part 3.3 ; if there is no activity of this kind please keep blank) (class)		
4.4.36 Gender aspect in the operational practice of SLM: Management activities MW (the concrete activity as what filled in part 3.3 ; if there is no activity of this kind please keep blank) (class)		
4.4.37 Age of land users (class) - the most common * MW		
4.4.38 Age of land users (class) - the second common MW		
4.4.39 Average household/family size (no. of persons in the family/household)		
4.4.40 Education level of land users (class) - the most common *		
4.4.41 Education level of land users (class) - the second common		
4.4.42 Average size of household land (farm size) (class) *		
4.4.43 Average size of fields on which the SLM has been applied (class) * WOCAT		
4.4.44 Land Tenure: Land ownership (type) * WOCAT		
4.4.45 Land Tenure: Rights of land use (type) * WOCAT		
4.4.46 Land Tenure: Rights of access (type) *	others	

APPENDICES (6)

PART 5: TECHNICAL SPECIFICATION, INPUTS AND COSTS		
5.1 Technical specification [MW]		
5.2 Costs of inputs needed for the <u>establishment</u> of the SLM [WOCAT].		
Input (unit)	Quantity	Cost/unit (in USD)
5.2.1 Labor:		
<Specify 2................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.2.2 Equipment:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.2.3 Plant materials:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.2.4 Fertilizers and biocides:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.2.5 Construction materials:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.2.6 Other inputs		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.2.7 Total cost		
5.2.8. Additional remarks regarding costs for establishments (Please be explicitly point-by-point, use ALT-ENTER to enter a new point):	Narrative remarks on the establishment costs: 1. ... 2. ... 3. ... 4. ...	
5.3 Costs of inputs and recurrent activities needed for the <u>maintenance</u> of the SLM (per year) [WOCAT].		
Input (unit)	Quantity	Cost/unit
5.3.1 Labor:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.3.2 Equipment:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.3.3 Plant materials:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.3.4 Fertilizers and biocides:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.3.5 Construction materials:		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.3.6 Other inputs		
<Specify 1................>:		
<Specify 2................>:		
<Specify 3................>:		
<Specify 4................>:		
5.3.7 Total cost		
5.3.8 Additional remarks regarding costs for maintenance (Please be explicitly point-by-point, use ALT-ENTER to enter a new point):	Narrative remarks on the maintenance costs: 1. ... 2. ... 3. ... 4. ...	

APPENDICES (7)

PART 6: IMPACTS, INFULENCING FACTORS		
6.1 On-site impacts that the SLM Technology has shown (please evaluate the aspects if they are applicable)	Note: in the scale: negative and positive are understood in the view of expectation.	
	Reference site <site ID>	Source
6.1.1 Socio-economic impacts WOCAT		
Production WOCAT		
crop production		
crop quality		
fodder production		
fodder quality		
animal production		
wood production		
forest/ woodland quality		
non-wood forest production		
reduced risk of production failure		
product diversity		
reduced expansion of cultivation areas		
improved land management		
energy generation(e.g. hydro, bio)		
Water availability and quality WOCAT		
drinking water availability		
drinking water quality		
water availability for livestock		
water quality for livestock		
irrigation water availability		
irrigation water quality		
improved irrigation water use efficiency		
Income and costs WOCAT		
improved agricultural inputs used efficiency		
farm income		
diversity of income sources		
economic disparities		
reduced workload		
6.1.2 Socio-cultural impacts WOCAT		
food security/ self-sufficiency		
health situation		
land use/ water rights		
cultural opportunities (spiritual, religious, aesthetic etc.)		
recreational opportunities		
community institutions		
national institutions		
SLM/ land degradation knowledge		
conflict mitigation		
situation of socially and economically disadvantaged groups (gender, age, status, ethnicity etc.)		
6.1.3 Ecological impacts WOCAT		
Water cycle/run-off WOCAT		
water quantity		
water quality		
harvesting/ collection of water (runoff, dew, snow, etc.)		
reduced surface runoff		
excess water drainage		
groundwater table/ aquifer		
reduced water loss by evaporation		
Soil WOCAT		
soil moisture		
soil cover		
reduced soil loss		
soil deposition		
reduced soil crusting/ sealin		
reduced soil compaction		
nutrient cycling/ recharge		
reduced salinity		
soil organic matter/ below ground C		
reduced acidity		
Biodiversity WOCAT		
vegetation cover		
biomass/ above ground C		
plant diversity		
reduced invasive alien species occurrence		
animal diversity		
beneficial species (predators, earthworms, pollinators)		
reduced of harmful species occurrance (e.g. mosquitoes)		
habitat diversity		
reduced pests/ diseases		
Climate and disaster risk reduction WOCAT		
reduced damages by flooding		
reduced landslides/ debris flows		
reduced damages by drought		
reduced damages by cyclones, rain storms		
reduced emission of carbon and greenhouse gases		
reduced fire risk		
reduced wind velocity		
favorable micro-climate		