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Decision-Support tools for assessing land degradation and realising sustainable land management, Study Case of El Mkhachbiya Catchment, Northwest of Tunisia

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Abstract

Land degradation is intrinsically complex and involves decisions by many agencies and individuals, land degradation mapping should be used as a learning tool through which managers, experts and stakeholders can re-examine their views within a wider semantic context. In this paper, we introduce an analytical framework for mapping land degradation, developed by World Overview for Conservation Approaches and technologies (WOCAT) programmes, which aims to develop some thematic maps that serve as an useful tool and including effective information on land degradation and conservation status. Consequently, this methodology would provide an important background for decision-making in order to launch rehabilitation/remediation actions in high-priority intervention areas. As land degradation mapping is a problem-solving task that aims to provide clear information, this study entails the implementation of WOCAT mapping tool, which integrate a set of indicators to appraise the severity of land degradation across a representative watershed. So this work focuses on the use of the most relevant indicators for measuring impacts of different degradation processes in El Mkhachbiya catchment, situated in Northwest of Tunisia and those actions taken to deal with them based on the analysis of operating modes and issues of degradation in different land use systems. This study aims to provide a database for surveillance and monitoring of land degradation, in order to support stakeholders in making appropriate choices and judge guidelines and possible suitable recommendations to remedy the situation in order to promote sustainable development. The approach is illustrated through a case study of an urban watershed in Northwest of Tunisia. Results showed that the main land degradation drivers in the study area were related to natural processes, which were exacerbated by human activities. So the output of this analytical framework enabled a better communication of land degradation issues and concerns in a way relevant for policymakers.

Introduction

The problem of the natural resources degradation, particularly land resources, water resources and vegetation, pose several questions about the effectiveness of current management. These resources are increasingly degraded and have several impacts affecting agronomy, socio-economic and environment.

Land degradation is a major obstacle to any potential improvement (especially agricultural) of arid and semi-arid areas of Tunisia. With the development of many competing sectors (agriculture, industry, tourism) and increasing food demand, natural resources are inevitably overexploited. All these events will certainly lead to land degradation that involves physical processes (soil structure changes), chemical (salinity, leaching and reduced fertility) and organic (biomass reduction and biodiversity) (Eswaran et *al.,* 2001).

However, despite several efforts, desertification and land degradation persist following the overuse of these resources.

According to Millennium Ecosystem (MEA, 2005), 10-20% of drylands are degraded and more than 250 million people are directly affected by desertification (Schwilch, 2009).

Therefore land degradation assessment and monitoring and land use systems vulnerability becomes more and more important in recent decades (Stocking and Murnaghan, 2001; Dregne 2002; Nachtergaele and Licona-Manzur, 2008), not only by governments but also by research organizations to develop tools in order to help make decisions (Engelen, 2003) for sustainable land management (Hurni et *al,* 2006;. IAASTD, 2008).

Several studies and research should be conducted by multidisciplinary teams where collaboration between scientists, researchers, land users, development workers and members of the security community, are needed (Seely and Moser 2004, Stringer et *al*, 2007. IAASTD, 2008). Indeed, it is to improve the assessment and monitoring of land degradation problems and explore solutions for Sustainable Land Management (SLM) and in order to help decision makers (Dougill et *al* ., 2006, Stringer et *al*, 2009).

This study focus on mapping land degradation and sustainable land management in a representative watershed in Northwest of Tunisia, called El Mkhachbiya. It required the collaboration of the international project, LADA, which focused on the assessment of land degradation and land management, based on WOCAT which aims to support innovation and making decision approach for SLM.

These two approaches are complementary improving their synergy to prepare and streamline methods for mapping land degradation and improvement at the local, national and global level in a single common way (Liniger et al., 2008).

This paper attempts the application of WOCAT tools to, first, assess land degradation in Mkhachbiya catchment and then determine the different pressures on the study area and their impact on natural and human resources. It is also to analyze the human activities related to the use of natural resources.

This first stage determines the degradation extent and identifies environmental indicators and agronomic risks at the study site, which will give an idea about the distribution and land degradation / conservation characteristics and SLM activities.

An on-line WOCAT mapping database tool for monitoring, mapping of degradation and conservation, will be established. After results development, this tool can be an effective attempt for making decision and ensure the sustainable land management and ecosystem services development.

Material and Method

1- Description of the study area

The watershed of El Mkhachbiya is located in the south of the delegation of South Beja, Governorate Beja, Northwest of Tunisia. Administratively, El Mkhachbiya is limited by El Menchar area in the north, Sidi Salem barrage in the south, Sidi Amer area in the east and Hamem Sayala and Maagoula sectors in the West.

The study site covers an area of 8900 hectares; with 900 hectares are eroded lands, 1,042 ha of forests, 300 ha of natural meadows and 6960 ha of UAA which represent 78% of the total area.

The UAA is distributed as follows: 310 ha of Arboriculture, 4200 ha of cereals, 1400 ha of forage and 1050 ha of legumes.

El Mkhachbiya area is a natural rich region, characterized by a lower variant semi-arid climate with mild winters.

The annual rainfall average is about 396 mm, number of rainy days is estimated at 71 days knowing that maximum rainfall is recorded during the month of January with an average of 57 mm and the minimum rainfall is recorded during the month of August with an average of approximately 6 mm. (Regional Directorate ODESYPANO, 2014).

Winter and fall, and the period early spring (usually early October until the end of April) are considered as the rainiest seasons.

The maximum temperatures degrees recorded at the end of July, where they vary between 38°C and 44°C. Minimum temperatures degrees recorded at the end of December, where they are between 6°C and 8°C.

Cereal is the most dominant land use system in the study area. Most soils are threatened by water erosion, which is trained by land topography, 60% of soils with high to steep slope and 40% of soil with moderate slope. Concerning its soil type, this area is characterized by the dominance of red soils in Guitouni, Bechouk and El Mahfoura region and brown calcareous soils in north of the sector of the region of El Araybiya, Sidi Rzig and Zwabi.

The most dominant erosion types are those of splash and mass flow, which are more present in southern sector; the region of Douar El Mahfoura, Awled Bni Ali, Bechouk and Sidi Rzig.

The main existing waterways in El Mkhachbiya area are located on the following areas: Wadi Om Ftayer, and Wadi Ajil and Wadi Madjerda. These wadi are permanent and the majority of their borders are grown by natural trees such tamarisk, oleander and Acacia…

2- Land Use Systems (LUS)

For the mapping exercise WOCAT-LADA-DESIRE, the system of land use (LUS) is considered as the basic unit of assessment (Nachtergaele et *al*, 2007). A world map of land use systems is available, but it needs to be refined and adjusted at the national level to provide adequate national units in which degradation and land conservation can be described and assessed. These basic units LUS contain several information (biophysical and socioeconomic) associated with land use and practices which are the main causes of land degradation.

The LUS units in combination with administrative units allow user to evaluate trends and changes over time of land degradation and conservation practices.

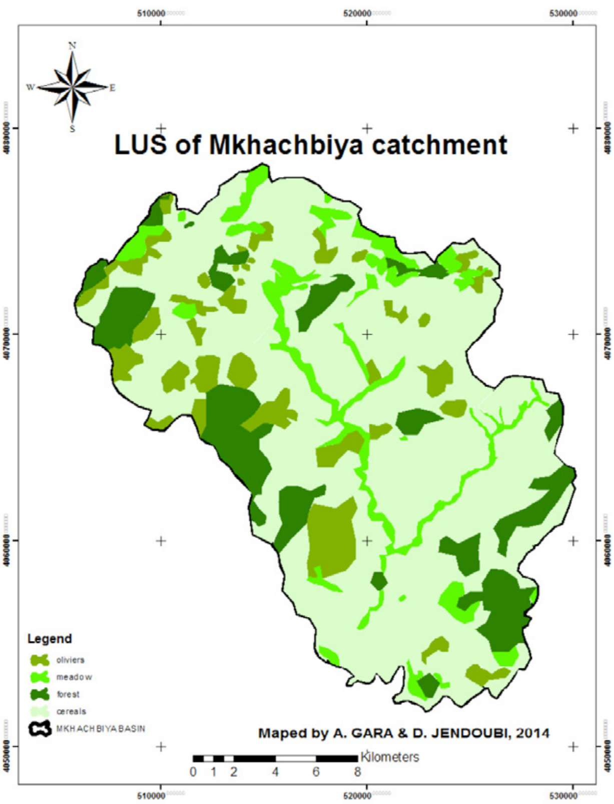

Figure 1: LUS of El Mkhachbiya catchment.

An example of LUS units combined with administrative units is presented in Figure 1.

Referring to the topographic map and satellite images at the study area; Cereal occupying 75% (6650 ha), olive trees occupy 3.5%, natural meadows represent 3.3% and forests occupy 10% of the total area of the watershed.

Majority of changes are occurred in the middle and downstream of the watershed (Figure 1).

3- WOCAT Approach

3.1- WOCAT Mapping Questionnaire

The mapping WOCAT-LADA-DESIRE tools is based on original questionnaire WOCAT QM Mapping (Liniger et *al.,* 2007). The methodology was developed by LADA and DESIRE projects.

It is currently tested and applied in 16 study sites worldwide in 14 countries (including Tunisia) on DESIRE project. WOCAT mapping approach has been expanded to give more attention to various processes such as desertification, land degradation / water and soil conservation and put more emphasis on direct and indirect socio-economical pressures of these phenomena including their impact on ecosystem functions (production function, ecological, socio-cultural and human) according to MEA, 2005. It assesses the different types of land currently degraded, where and why and all that was done about it in terms of SLM. The integration of collected information and developed data inside the online system enables the development of maps and calculations of area in various forms (physical land degradation / desertification and conservation practices).

Through this questionnaire, LUS is considered as basic unit of evaluation.

Several adjustments and more improvements are needed at the national level to provide the appropriate units where land degradation and conservation can be described and evaluated to improve the global map of land use systems currently exist (Nachtergaele and Petri, 2007). It is important to assess the current situation, taking into account the history of the past decade.

Then, it is recommended that the questionnaire must be completed by a multidisciplinary team (scientists, farmers, actors) on the degradation and land conservation in collaboration with land users with different knowledge and experience. This requires analytical skills among the evaluators, with the use of existing documents (maps, GIS, images satellite) and advice from other specialists and land users as much as possible to improve the quality and reliability of data. The questionnaire should be used as an assessment tool of land degradation and conservation practices undertaken in the study site. Also, final map provide a powerful tool to get an overview of degradation and land conservation at different scales (local, national and global) (Liniger et *al.,* 2008) .

3.2- Collection of data

The WOCAT questionnaire includes five steps: the first involves the collection of data on land degradation and management of their use, and water and soil conservation in the studied watershed, done by a multidisciplinary team from ODESYPANO Beja and myself, which has interviewed farmers in the field.

The study area was divided by referring to the administrative organization and the type of land use into 4 LUS: cereals, olive trees, meadows and forests. Subsequently, and after the determination of the different LUS, the second step involved estimation of the size of each LUS in the past ten years in each unit, and a worse estimation of the intensity of land use of each system.

The third phase focused on determining the extent and degree of different types of land degradation currently occurring in each LUS as a percentage.

In addition, estimation of degradation rate during the last decade and determination of direct and indirect causes of this degradation and finally estimation of its impact on ecosystems.

The fourth stage involved the identification, inventory, classification of different techniques of land conservation, determining the purpose of implementation of each technique (prevention, mitigation, etc.), extent (percentage of map unit) and identification of the degradation involved in conservation measures. It was also considered the "efficiency class" technology identified by LUS, to show trends (increase or decrease) the effectiveness of conservation to determine the impact (type and level) on the ecosystem, and indicate the date of installation of each technology and assign a reference in the WOCAT questionnaire technologies (QT) describing the practices already mentioned. The fifth step was to provide for each map unit, expert recommendations (adaptation, prevention, mitigation and rehabilitation), comments and additional information on conservation practices and sustainable land management.

3.3 Spatial data

A WOCAT online mapping database was used to produce thematic maps for the study area (watershed El Mkhachbiya) based on land investigations (questionnaires) and using the GPS positioning satellite imagery, topographic and Google Earth maps visualization.

Indeed, the high capacity of spatial analysis of WOCAT online mapping database has integrated the collected spatial data and descriptive characters to produce a cartographic support. It represents in one hand, a spatial interpretation of the state of land degradation and conservation location and on the other hand, is an aid to making decision for the conservation and natural resources sustainable management.

Results and Discussion

1- Cereals

The gully erosion (Wg), loss of topsoil (Wt), mass movements (Wm), fertility decline and reduced organic content (Cn), habitat loss (Bh) and the physical deterioration of soil by compaction (Pc) are the main types of land degradation (Figure 2). These types of degradation are for almost all of the total area of the LUS with a high degree of degradation by compaction with degradation rates increasing rapidly for soil erosion by water, which is directly due to erratic rainfall and poor soil management such as monoculture and inappropriate tillage (Figure 2).

Although population pressure, land tenure and the shortage of rural labor is the main indirect causes of land degradation. The majority of these causes have a negative impact on the ecosystem functions, particularly on animal and plant production and soil cover. Consequently, some conservation practices have been established to mitigate and prevent water erosion and biological degradation such as soft techniques (vegetation cover) having 30% as extensive and high efficiency, crop rotation with a range of 30% and control gullies that spans of 30% of the entire LUS (Figure 3). These measures have a positive impact that will contribute positively from 10 to 50 % to changes in the ecosystem (plants and animal productivity, soil cover, water cycle consumption and socio - cultural and human well-being functions).

As a recommendation, we can introduce the adequate instrument tilling the land slopes, preventive treatment cultures (tillering) and introduce organic amendments to conserve natural resources and their productive and environmental functions on land that may be more affected by degradation.

In order to stop ongoing deterioration and improve resources and their functions, we recommend the soil structure preservation especially by tilling of land

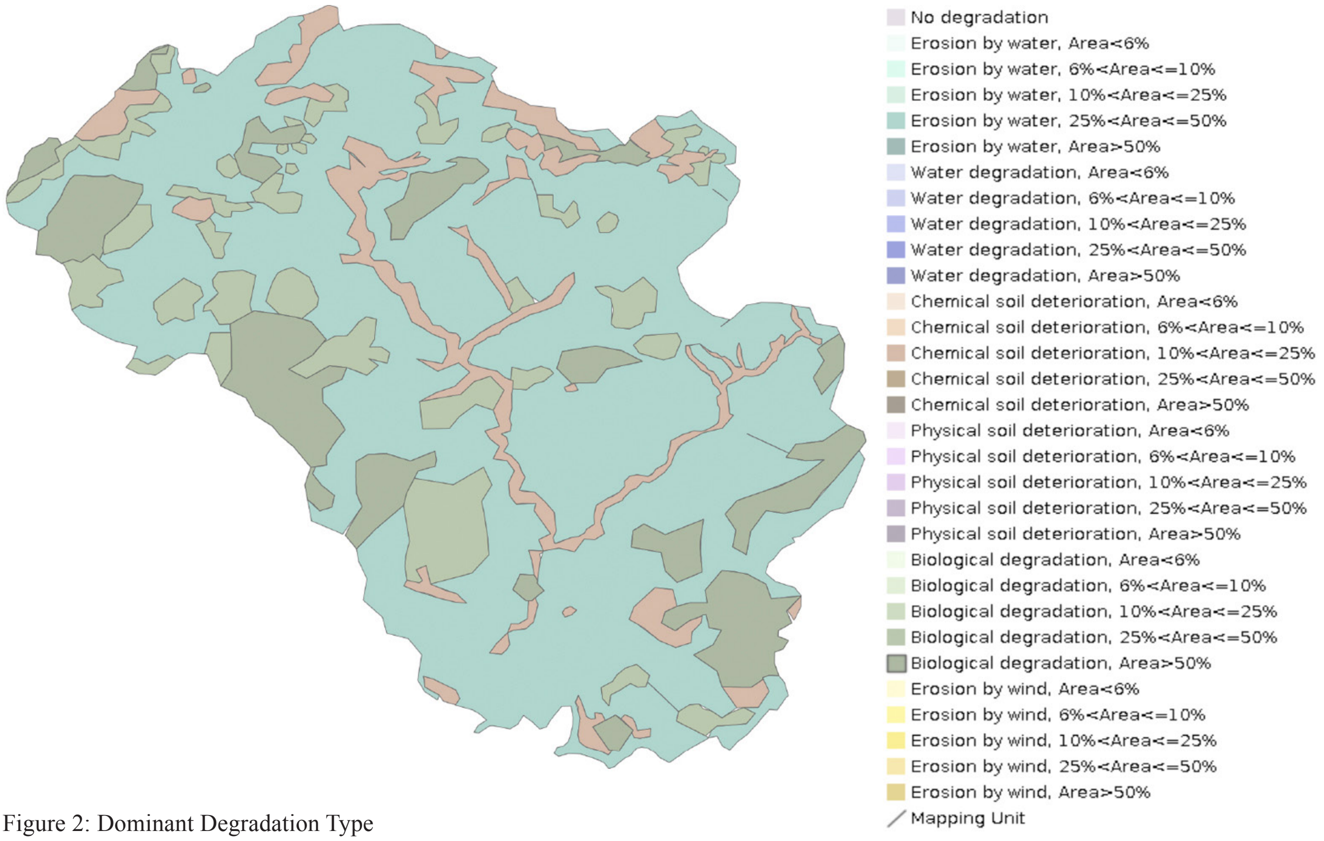

Figure 2: Dominant Degradation Type

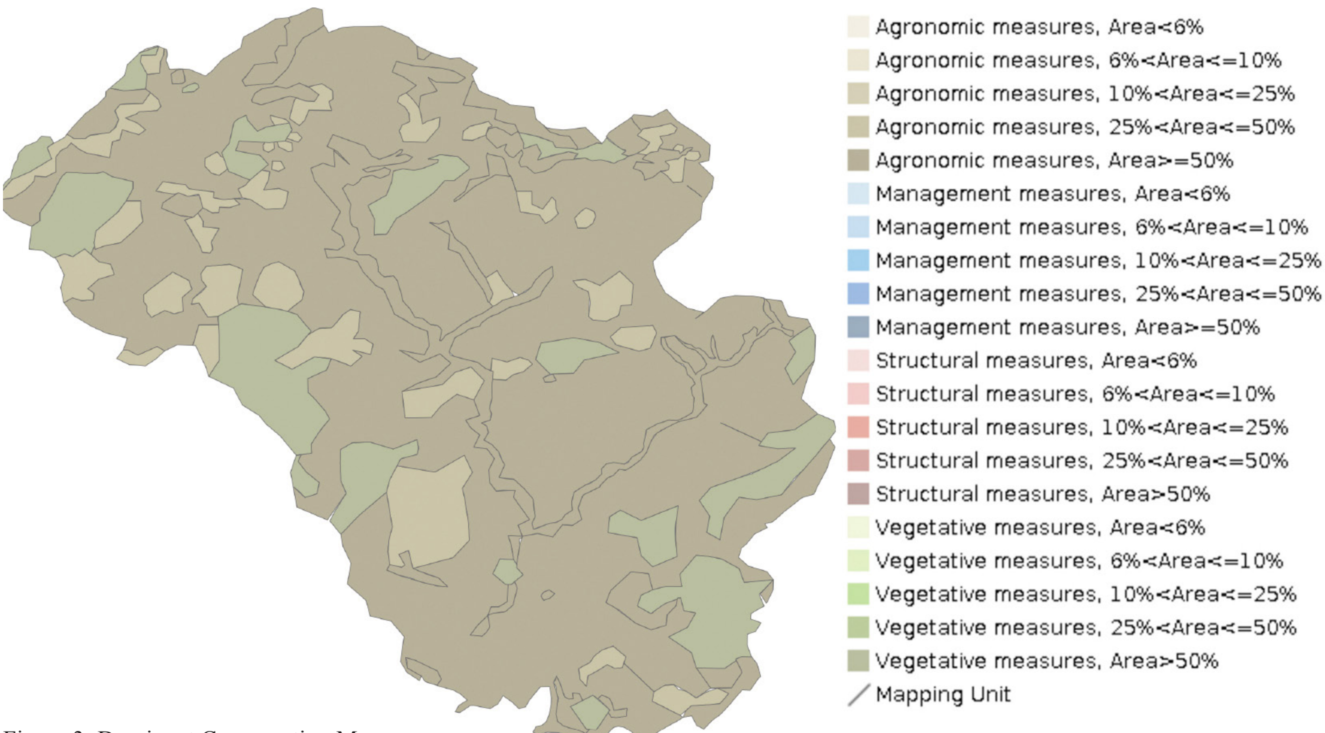

Figure 3: Dominant Conservation Measures

slopes and minimum tillage (conservation agriculture).

We recommend also the appropriate choice of crops such as perennial crops as Sulla and forage fescue. Introduce fallow and improve the management mode (choice of suitable rotation cycles). Finally, avoid plowing the soil in the same direction of the slope, harrowing and plowing wet soils.

2- Olives

Olives system is newly introduced by ODESY-PANO in the area (1983). And despite that, this system is affected by water erosion of soil surface (Wt) with an extended area of 10%, chemical degradation (Cn) by loss of nutrients and reduction of organic matter (OM) by weakening the topsoil that reduce nutrient availability and organic matter with extended area of 10% and increased pest and disease (Bp) due to poor or non-use of phytosanitary treatment, since increasing humidity from Sidi Salem barage that causes the spread of disease, and this degradation is estimated at 35%. These indications of deterioration are visible and easy to be restored to a slowly increasing degradation rate.

In fact, land degradation is caused by absence or inadequacy of soil conservation measures, tillage practice, inadequate application of fertilizer, pesticides and nutrient mining. In addition, it has indirect causes such as land tenure, population pressure, poverty, availability of labor. Therefore, all these causes have many impacts on the ecosystem services (ES) with different levels (negative or positive): there is a small negative impact on animal and plant production (quantity and quality, including biomass for energy) where land degradation contributes negatively (10-50%) in ecosystem changes. A negative impact on ecological functions (water cycle, status of OM, plant cover and soil structure), which contributes to a change between 10-50% on ES and socio-cultural and human well-being functions which contribute to a negative change between 10-50%.

In order to prevent and mitigate land degradation and desertification, many land conservation technologies have been undertaken in these LUS such as: soft techniques, landscaping, individual bowls and mechanical correction. The effectiveness of SLM implementation of a technology is different to each other. In this case, there are significant efficiency for conservation practices and structural management and acceptable efficiency for vegetative practices combined with physical structures. These SLM practices have a significant positive impact on loss of topsoil, fertility decline and reduced organic matter and biological degradation.

In addition SLM technologies already indicated, it is recommended to increase perennials crops to consolidate land already planted with olive trees and train farmers on olive culture as it is a new background for them (especially on the treatment of diseases...).

3- Meadows

Surface erosion (Wt), Riverbank erosion (Wr), decreased fertility and reduced organic content (Cn), biological degradation (Bc.), physical deterioration of soil by compaction (Pc) are the main forms of land degradation of meadows in the studied watershed with an extent of 90%, (figure 4) with a high degree and a high rate especially for wind erosion and biological degradation. This degradation is caused by the absence or inadequacy of soil conservation measures, low infiltration rate / increase surface runoff, changes in seasonal rainfall, heavy / extreme rainfall, overgrazing, fires meadows and road construction.

We mention also poverty, population pressure and land tenure as main indirect causes. Therefore, there are impacts on ecosystem services: on plant and animal production and water cycle with a negative impact on biodiversity. Faced with this situation, several conservation practices needed to prevent and mitigate land

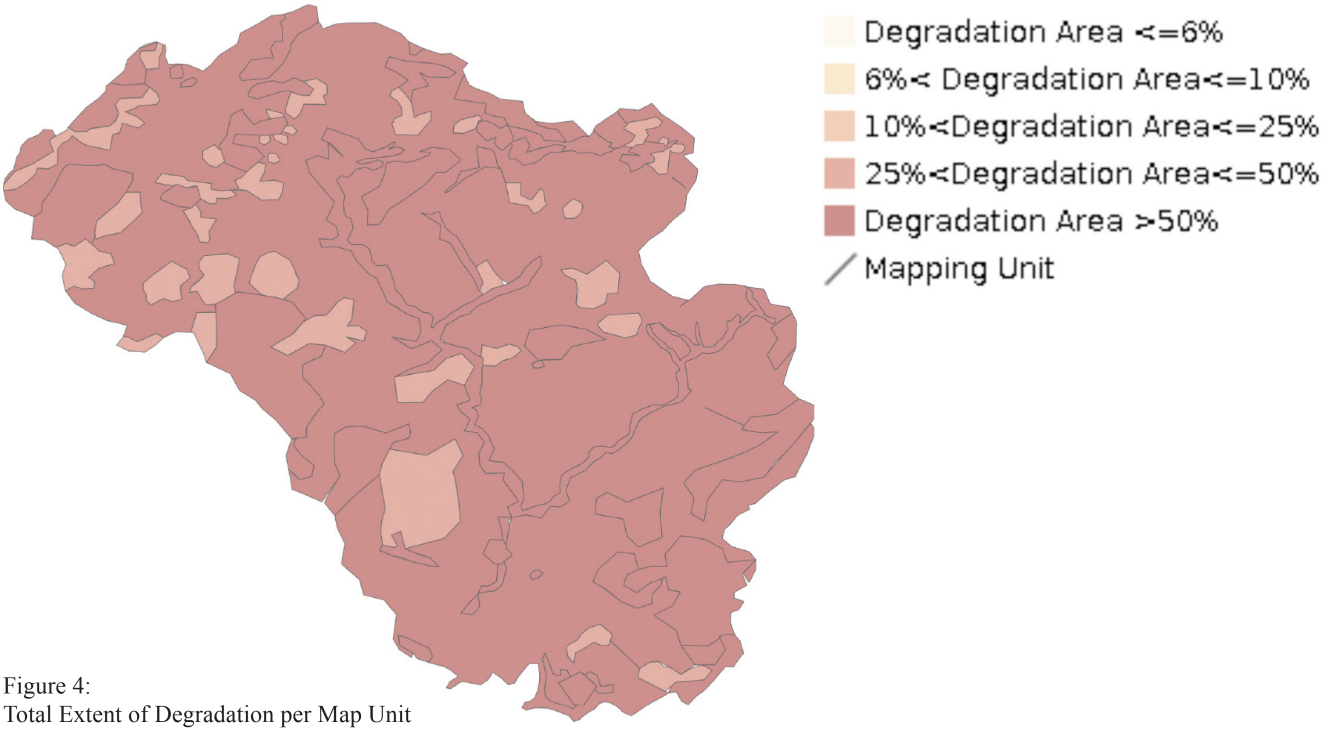

Figure 4:
Total Extent of Degradation per Map Unit

degradation. Practices currently adopted in this unit are mainly: the exclosure / rest (winter and summer) that was used with very high efficiency: which means it improves the past status and has positive impacts on animal and plant production and biodiversity. However, it is recommended to extend the areas of the exclosure and reduce livestock number in order to prevent and avoid land degradation.

Nitrogen and phosphate fertilization is practiced at the end of autumn with expanded 25% to mitigate biological degradation, subsidence and soil compaction and fertility decline and reduced organic content.

Also agroforestry, which remains one of the most effective conservation measures in the region, extended on 20% and which comes to prevent and mitigate land degradation.

Improved grazing land management (GR) refers to change of control and regulation of grazing pressure.

These measures have a positive impact that will contribute positively with 10-50 % in ecosystem changes (plants and animals productivity, soil cover, cycle and water consumption and socio-cultural and human well-being functions).

These technologies cover almost all of the total area of the unit with very high efficiency (when practical control not only the problems of land degradation but also improve the situation compared to the previous situation) and have positive effects on the water cycle and biodiversity.

In addition to these practices, it is recommended to reduce livestock number (respect of ration cattle size / grazing area) and preferably to follow the rotation of set-aside during the famine (partial or biennial), while limiting extensions culture that induce restoration of vegetation cover, in addition to consolidation of water and soil conservation (CES) and grazing land protection activities.

4- Forests

This LUS have several types of land degradation, such as loss of topsoil / surface erosion (Wt), decrease in quantity / biomass (Bq) and increase in pests and diseases (Bp).

The extent of land degradation is 70% with a high degree of reduction in vegetation cover. This deterioration is directly caused by lack of soil conservation practices (S2), expansion of urban areas (F2), fire (F4) and low infiltration rate / increase surface runoff (W1).

They have a negative impact on ecosystem services: on plant and animal production, availability of land and all ecological functions (biodiversity, water cycle, soil structure, OM status...). In this system of land use, afforestation and forest protection and development are the common land conservation practices that cover 80% of the area and have a high efficiency. In addition, there is a positive impact on biodiversity, land availability, water cycle, organic matter status, soil cover, nutrients cycling (N, P, K) and carbon cycle (C), soil formation, micro-climate and socio-cultural and human well-being functions. In fact, the adjudication is highly

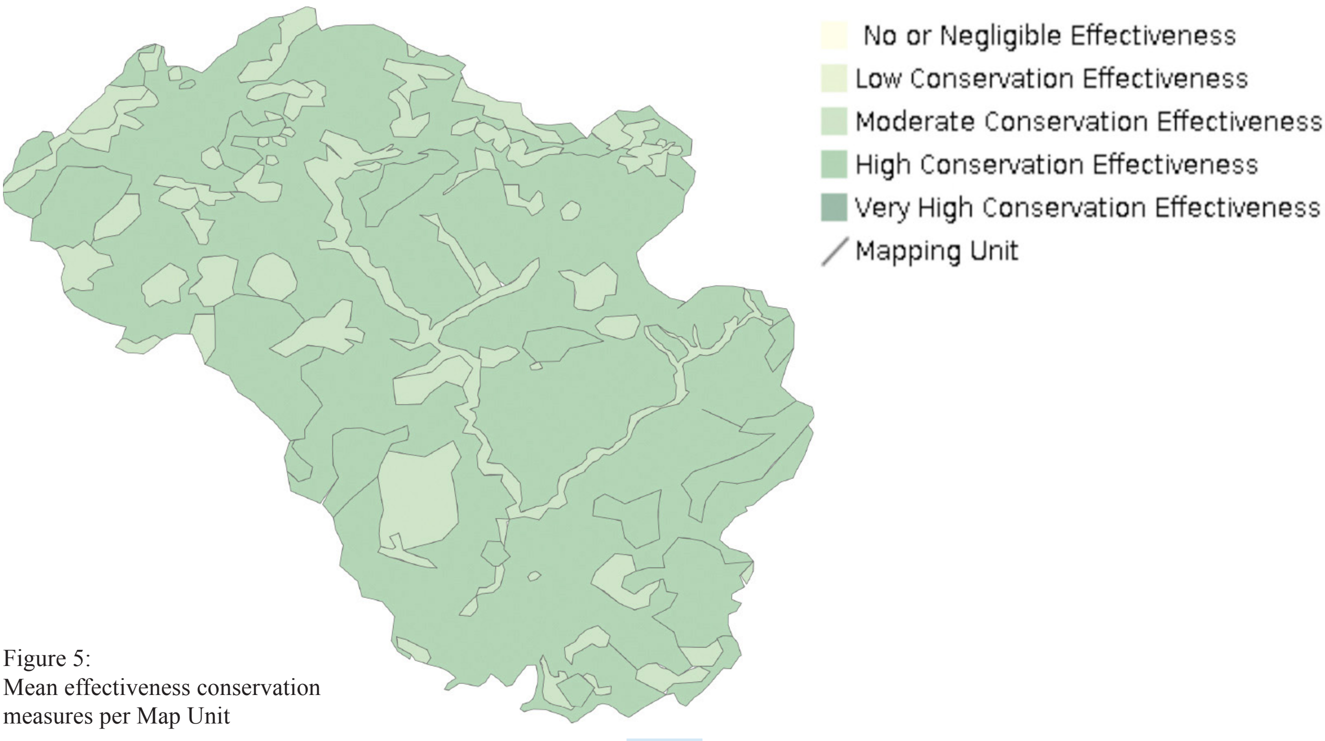

Figure 5:
Mean effectiveness conservation measures per Map Unit

recommended and urgent with the opening of access to forest management and conflict resolution and reward priority, also identification of water and soil conservation technologies, their preservation and maintenance are recommended (especially after the fires).

5- Interpretations maps

The establishment of these maps was an important step in this research. Knowledge of land use systems, similar physical conditions (climate, soil, vegetation) and common characteristics of land degradation is very high (Figures 2, 3). Three major types of land degradation were identified in the study area: water erosion surface, biological degradation and chemical degradation.

The extent of degradation is almost total with varying degrees of land degradation from medium to high especially in agriculture cereal systems.

Maps of conservation show that almost all land conservation technologies have a moderate to significant effectiveness in different land use systems (soft techniques, decks, mechanical and biological corrections, fertilization, agroforestry and deferred grazing...).

All maps are drawn from collected data from the field. The most important result for policy makers is the map of the effectiveness of conservation practices (figure 5) that are defined in terms of degree of reduced degradation (how much) or in terms of method of implementation and maintenance (how). This gives a good indication of the situation in relation to that preceding the degradation and to what extent conservation technologies could address the problems of land degradation.

6- Discussion

Throughout the watershed, there is a large degraded extend where the percentage reaches 100% in land use Cereals system (Table 1).

This degradation peaked, with 90% as deteriorated land among meadows. The main causes of this degradation are erratic and torrential rainfall, inappropriate soil working techniques, overgrazing, topography and human activities that can amplify the situation.

Despite presence of some conservation practices (Table 1) in the LUS (soft techniques exclosure, agroforestry and biological and mechanical correction), land degradation remains a very serious problem in this area and SLM practices must be improved and strengthened to fight against desertification, restore vegetation cover and ensure sustainable development.

Conservation practices (Table 1) were very important and have varied roles in the studied watershed and contribute to sustainable land management, but they must be strengthened and protected in order to preserve natural resources.

Conclusions

Objectives of this work are the application and integration of WOCAT mapping tools to assess land degradation in the catchment of El Mkhachbiya, determine different causes of affected area, degradation rate and degree and their impacts on natural and human resources. It is also to analyze activities related to natural resources use, including determination of degradation extent and identifying environmental indicators and agronomic risks in the study site, to obtain a clear presentation of land degradation / conservation distribution and characteristics as well as SLM activities. The methodology is based on field assessment work, the use of WOCAT online mapping tool database for analysis, elaboration and interpretation of thematic maps.

Results are presented on four land use systems: Cereal, meadows, forests and olive. In fact, land degradation is higher in cereal systems (100% of area) and meadows (90% of total degraded area). Map of land conservation give good indicators of protected areas and those that do not cause risk of degradation. Although tool has proven very useful to get a clear presentation and explanation of distribution of the process of land degradation and its magnitude and various conservation technologies and their effectiveness. Several improvements are needed to ensure a better

Table 1: Summary table of different types of degradation and conservation practices in the watershed of El Mkhachbiya

Land Use System	Degradation types	Degrated area (%)	Conservation Practices
Cereals	W0, Wr, Wg, Wt, Wm, Cn, Bh	100 %	Soft techniques, crop rotation (introduction of fodder crops and legumes), gully control (mechanical correction).
Meadows	Wt, Wr, Cn, Bc, Pc	90 %	Nitrogen and phosphate fertilizer (late fall), exclosure (winter and summer), agroforestry, land tenure (forest)
Forets	Wt, Wr, Bp, Bq	70 %	land tenure (forest), exclosure
Olives	Wt, Bp, Cn	50 %	Soft techniques, landscaping, individual bowls, Mechanical correction

link with other WOCAT questionnaires (QA, QT) and their use by local actors.

Finally, results of this questionnaire can help local actors (CRDA, DGACTA, ODESYPANO.) and policy makers to make decisions, plan intervention strategies and consolidate national support and lead to its analysis. In addition, it may be useful for SLM dissemination (especially in similar arid environments) and can also serve as a means to take necessary measures to deal with erosion phenomenon and climate changes.

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Abreviation List

W : Erosion hydrique du sol

Wt : Perte de la couche arable du sol / érosion de surface

Wg : Erosion en ravine / ravinement

Wr : Erosion des berges (de cours d'eau)

E : Erosion éolienne du sol

Et : Perte de la couche arable du sol

Ed : Déflation et dépôt

C : Dégradation chimique du sol

Cn : Baisse de fertilité et réduction de la teneur en matière organique

Cs : Salinisation/alcalinisation

P : Dégradation physique du sol

Pc : Compaction

Pw : Saturation en eau du sol

H : dégradation des ressources en eau

Ha: Aridification

Hs : Changement de la quantité des eaux de surface

B: Dégradation biologique

Bc: Réduction de la couverture végétale

Bh: Perte d'habitats

Bq: Baisse de la quantité / biomasse

S6 : sécheresse

S2 : manque des pratiques de conservation

S6 : sur les infrastructures privées et publics

M5 : Gestion du parcours

V2 : reboisement

S8 : fixation mécanique des dunes de sable

UAA : Used Agricultural Area

CES : Conservation des Eaux et des Sols

ODESYPANO : Office de Développement Sylvo-Pastorale de Nord Ouest

DGACTA : Direction Générale d'aménagement et de conservation des terres agricoles

GDT : Gestion durable des terres

LUS : Land Use System (Système d'utilisation des terres)

MO : Matière Organique

QA : Questionnaires approaches

QT : Questionnaire technologies

WOCAT : World Overview of Conservation Approaches and Technologies