*Université de Liège*
*Faculté des Sciences*
*Département des Sciences et Gestion de l'Environnement*

# APPLICATION OF GEOMATICS FOR THE ASSESSMENT OF PASTORAL RESOURCES IN MOROCCO

***Hamid MAHYOU***

Thèse présentée en vue de l'obtention du grade de Docteur en Sciences

**Composition du jury :**

**Président:**
Pr Roger PAUL (ULg-Gembloux, Belgique)
**Promoteurs:**
Pr Bernard TYCHON (ULg-Campus Arlon, Belgique)
Dr Riad BALAGHI (INRA-Rabat, Maroc)
**Lecteurs:**
Pr Bas VAN WESEMAEL (UCL-Louvain la neuve, Belgique)
Pr Mohamed BADRAOUI (INRA-Rabat, Maroc)
Dr Pierre OZER (ULg-Campus Arlon, Belgique)

Juillet 2012

# Remerciement

Je tiens à exprimer mes remerciements les plus sincères au Professeur Bernard Tychon, mon promoteur de thèse, pour m'avoir conseillé, encouragé et soutenu tout au long de la thèse avec patience et disponibilité et pour la confiance qu'il m'a accordé. J'ai beaucoup appris à ces côtés et je lui exprime toute ma gratitude.

Je remercie également le Docteur Riad Balaghi co-promoteur de la thèse pour sa disponibilité, pour son apport scientifique et son enthousiasme quotidien pour cette recherche.

Je remercie le Professeur Mohamed Badraoui (Directeur de l'INRA Maroc) pour l'intérêt qu'il a porté à mon travail, ainsi que pour les remarques constructives émises lors des réunions annuelles au sein de l'INRA. Je suis très honoré qu'il a accepté de faire partie de mon jury de thèse.

Je tiens à exprimer ma profonde gratitude au Professeur Roger PAUL (ULg), qui m'a fait l'honneur de présider le jury de thèse de doctorat, pour l'intérêt et le soutien chaleureux dont il a toujours fait preuve et le partage de ses nombreuses connaissances lors des réunions du comité de thèse.

Je remercie le Professeur Pierre OZER (ULg) et le Professeur Bas VAN WESEMAEL (UCL) pour avoir accepté d'être membre de jury de cette thèse. Je les remercie pour les remarques, conseils et critiques constructives.

Je remercie le gouvernement belge et particulièrement la Coopération Technique Belge pour le cofinancement d'une partie de cette thèse par une bourse d'étude.

J'ai bénéficié également du soutien et de l'aide du Professeur Hamid NARJISSE (ex-Directeur de l'INRA Maroc) et de Monsieur Mohammed BEQQALI (Chef de division DGRH). Je voudrais les remercier, ainsi que tout le personnel de l'INRA Maroc.

Je remercie Dr Jamal MIMOUNI (DRA Oujda) de m'avoir accompagné le long de ma thèse, pour ses encouragements et les discussions fructueuses.

Je remercie le personnel du Centre Régional de la Recherche Agronomique Oujda pour son aide et soutien.

Je remercie tous mes amis de l'Unité Eau, Environnement et Développement du département Sciences et Gestion de l'Environnement du Campus d'Arlon pour leur soutien et leur aide. Je voudrais remercier en particulier Amani Louis KOUADIO, Antoine Denis, Djaby BAKARY, Mohammed Bouizmarni, Djénéba Mané, Farid Traoré et Moussa El Jarroudi. Un grand merci à tous les autres amis doctorants du campus d'Arlon.

Mes sincères remerciements à Hassan benaouda, Mohamed Jlibene, Mohamed El Mourid, Mohamed Karrou, Mostapha tahri, Abdessamad Touil, Rachid Mrabet et Mounir Louhaichi.

Cette thèse n'aurait jamais pu voir le jour sans le soutien et le sacrifice de ma femme et mes filles Israe et Hiba. Je voudrais les remercier pour m'avoir toujours encouragé et s'être inquiétés du bon déroulement de mes études.

Enfin, mes sincères remerciements à tous ceux qui m'ont apporté de près ou de loin, aide et conseils lors de l'élaboration de cette thèse de doctorat notamment

# Dédicace

**À mère**

Pour ton amour…

Pour tous tes sacrifices…

Pour tous l'enseignement que tu m'as transmis…

En témoignage de mon éternelle reconnaissance.

**À ma femme**

Pour tous tes sacrifices…

Pour ton soutien moral, et ta patience...

En témoignage de mon amour.

**À mes filles Israe et Hiba**

En témoignage de mon amour

Que Dieu vous protège et vous prête bonne santé et longue vie.

**A toute ma famille**

Pour votre soutien et votre intérêt envers mon travail

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## General Abstract

Rangeland or natural arid pastures of Morocco are defined as ecosystems where there is a natural or semi-natural vegetation composed of steppes, shrubs and grassland used mainly for livestock production as climate and soil are unsuitable to agriculture. The arid rangelands of Morocco occupy an area of over 33 million hectares between the isohyets of 100 and 400 mm. These areas represent livelihoods for thousands of people and protect the country from desertification. The main objective of this study is to provide scientific community and decision-makers methodological tools for assessing arid rangelands, based on geomatics and biophysics data.

This study is divided in four parts:

1. The first part presents an overview of the threat of the desertification, emphasizes on the causes and consequences of rangeland degradation in Morocco, from literature sources, statistics, climate data and maps. Morocco rangelands are located in ten different pastoral zones that differ from each other by their floristic composition, soil and climatic conditions. According to Globcover map these rangelands are mainly composed by bare soil, herbaceous vegetation, shrubs and deciduous savanna mosaic / shrub or forest. The largest pastoral zones are: the Saharan zone, Pre-Saharan, the Oriental plateaus and the Valley of Moulouya. These zones are the most degraded with respectively 97, 89 and 69% of their total area. Available information on several pilot areas shows that the Moroccan rangelands are degraded due to many factors, which include overgrazing, cultivation, population increase and climate variation.

2. The second part of the study demonstrates the usefulness of remote sensing for assessing drought in arid rangelands of Morocco. Bi-weekly TERRA Moderate Resolution Imaging Spectroradiometer (MODIS 250 meters) data were used for this purpose. A Preliminary mapping by using Landsat TM5 of major land cover types was carried out to extract the pasture area. A comparison of annual and seasonal Normalised Difference Vegetation Indices (NDVI), Vegetation Condition Index (VCI) and rainfall during the time period of 2000–2008 were carried out. Results show significant correlations of either NDVI (r= 0.72**) or VCI (r=0.42*) with past season (3 months) rainfall. NDVI variation is a good indicator of vegetation changes and consequently can give a reliable indication on drought conditions in the study area. NDVI values lower than 0.2 are indicative of drought occurrence. NDVI values between 0.20 and 0.28 indicate average weather conditions and values higher than 0.28 correspond to humid conditions.
3. The third part presents an original knowledge-based approach for mapping the degradation of rangelands in North Africa. The study area is located in the high plateaus of eastern Morocco which include 3.5 million hectares of arid rangeland steppes. The approach consists in using datasets derived from Landsat TM satellite imagery, lithology, phytogeographic data and field indicators. The field indicators are: the steppes composition, perennial vegetation cover, annual perennial production, grazing level and the prevalence of rangeland cultivation. Results show that the knowledge-based approach is a valid method for evaluating rangeland degradation. The proposed knowledge-based approach discriminated between rangeland categories that would not have been discernible using only remote sensing. Overall classification accuracy of rangeland degradation obtained using this approach was 93%. This approach revealed that 11, 36 and 30% of the study area have shown very severe, severe and moderate degradation level, respectively.
4. The fourth part concerns the assessment of Alfa grass (*Stipa tenacissima*) tussocks at various degradation levels of Alfa grass steppes in the high plateaus of eastern Morocco, based on field hyperspectral data (350 – 2500 nm) and digital images during fall and spring seasons. Digital images of Alfa grass tussocks were taken using a digital camera to classify of the tussocks according to their proportion in green leaves (green, mixed and dry tussock). Assess software (Image Analysis Software for Plant Disease Quantification, APS 2002) was used to obtain the

proportion of greenness in each tussock. Hyperspectral data of three states of tussocks (Green, Mixed and Dry tussock leaves) were collected within three degradation levels of Alfa grass steppes (Slight, Moderate and Severe degradation) with the ASD FieldSpec® 3 spectroradiometer. Paired t-test, Normalized difference spectral reflectance (NDSR) and Stepwise Discriminate Analysis were used to discriminate between various tussock status and different Alfa grass steppes. The results indicate that Alfa grass had shown an intraspecific variability in reflectance spectra.  The proportion of green leaves in Alfa grass tussock strongly influences the spectral response. The discrimination of different Alfa grass tussock status was better during fall than spring. The spectral behavior of Alfa grass tussock is problematic for the mapping and the assessment of Alfa grass steppes by conventional remote sensing techniques.

## Résumé général

Au Maroc, les terres de parcours sont des écosystèmes portant une végétation naturelle ou semi naturelle composée de steppes, arbustes et prairies, utilisés essentiellement pour la production animale, le climat et le sol étant très défavorables pour l’agriculture. Ces terres occupent une superficie de plus de 33 millions d'hectares entre les isohyètes de 100 et 400 mm. Elles offrent des moyens de subsistance à des milliers de personnes et protègent le pays d’une désertification rapide. L'objectif principal de cette étude est de fournir aux scientifiques et aux décideurs des outils méthodologiques permettant d'évaluer les parcours arides du Maroc basés sur la géomatique et les données biophysiques. Cette étude est divisée en quatre parties:

1. La première partie présente un aperçu sur la menace de la désertification, en détermine les causes et analyse ses conséquences sur les parcours au Maroc à partir de sources bibliographiques, des statistiques, des données climatiques et des cartes thématiques disponibles. Au Maroc les terres de parcours se retrouvent sur dix zones pastorales qui diffèrent les unes des autres par leurs compositions floristiques et leurs conditions édapho-climatiques. L’analyse de la carte Globcover , montre que ces terres de parcours sont dominées essentiellement par les classes: sol nu, végétation herbacée, végétation arbustive décidue et mosaïque savane/arbuste ou forêt. Les zones pastorales les plus importantes en termes de superficie, notamment la zone saharienne, présaharienne et le Plateaux de l’Oriental et la Vallée de la Moulouya, présentent des taux de dégradation respectifs de 97, 89 et 69%. Les informations disponibles à partir de plusieurs zones pilotes montrent que les parcours Marocains sont menacés par la désertification. Les principales causes de cette dégradation sont les actions anthropiques, notamment le

surpâturage et la mise en culture des parcours, accentuées par la variation climatique et la croissance démographique.

2. La seconde partie traite une étape importante dans la conception et la mise en œuvre des plans de gestion des risques de la sécheresse dans les zones pastorales. Elle concerne l'évaluation des risques de sécheresse dans les zones de parcours à l'aide de la télédétection spatiale. L'Indice de Végétation par Différence Normalisée (NDVI) ainsi que l'Indice d'état de la végétation (VCI), dérivés des images MODIS (250 m), ont été corrélés aux précipitations sur la période de 2000-2008. Les résultats montrent des corrélations significatives du NDVI (r = 0,72**) et du VCI (r = 0,42*) avec les précipitations de la saison précédente, indiquant ainsi que NDVI est un bon indicateur des changements de l'état de la végétation. Il peut par conséquent, être utilisé pour le suivi de la sécheresse dans la zone d'étude. Les valeurs de NDVI inférieure à 0,2 sont révélatrices de l'occurrence d'une sécheresse. Les valeurs de NDVI entre 0,20 et 0,28 indiquent des conditions météorologiques moyennes et les valeurs supérieures à 0,28 correspondent à des conditions humides.

3. La troisième partie présente une approche originale basée sur l'utilisation de la télédétection spatiale et les données biophysiques pour la cartographie de la dégradation des parcours arides au Maroc. La zone d'étude est localisée dans les terres de parcours des hauts plateaux du Maroc Oriental sur une superficie de 3.5 millions hectares. L'approche consiste en la combinaison des informations dérivant des images satellites Landsat TM avec la phytogéographie, la lithologie et les indicateurs de dégradation collectés sur le terrain. L'évaluation de la dégradation des parcours est basée sur les paramètres de la végétation, l'intensité de pâturage et l'importance de la mise en cultures des terres de parcours. Les résultats ont montré que cette approche est une méthode appropriée pour l'évaluation de la dégradation des parcours arides. Le degré de précision de la cartographie de la dégradation de ces parcours est de 93%. Les résultats montrent que 11, 36 et 30% de la superficie des parcours des hauts plateaux du Maroc Oriental connait une dégradation très sévère, sévère et moyenne, respectivement.

4. La quatrième partie porte sur l'évaluation du comportement spectrale des touffes d'alfa (*Stipa tenacissima*) dans différents états de dégradation des steppes d’alfa au niveau des hauts plateaux de l’Oriental Marocain, basée sur l’utilisation combinée des données hyperspectrales de terrain (350 - 2500 nm) et des photos numériques collectés durant l'automne et le printemps. Les photos numériques de touffes d'Alfa ont été prises avec un appareil photo numérique pour classer les touffes en fonction de leur pourcentage en feuilles vertes (touffes vertes, mixtes et sèches). Le logiciel « Assess software » (Image Analysis Software for Plant Disease Quantification, APS 2002) a été utilisé pour calculer le pourcentage de feuilles vertes dans la touffe d’alfa. Les données hyperspectrales de trois états végétatifs des touffes d’alfa (vertes, mixtes et les sèches) ont été collectées dans trois niveaux de dégradation des steppes d'Alfa (dégradation légère, modérée et sévère) avec l'ASD FieldSpec spectroradiometer® 3. Le test t apparié, la réflectance spectrale de différence normalisée (NDSR) et l’analyse discriminante pas à pas ont été utilisés pour la discrimination entre les différentes états de dégradation et végétatif. Les résultats ont montré une variabilité intra-spécifique des réflectances chez cette espèce. Le pourcentage de feuilles vertes dans les touffes contrôle la réponse spectrale de l’alfa. La discrimination entre les différents états des touffes était meilleure durant l’automne. Cette variabilité intra-spécifique de l’alfa limite la précision de la cartographie et l'évaluation des steppes d'alfa par les techniques conventionnelles de la télédétection spatiale.

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## List of acronyms and abbreviations

ANOVA: Analysis of variance

APS: American Phytopathological Society

AR4: Fourth Assessment Report

ASD: Analytical Spectral Devices

CRU: Climate Research Unit

CV: coefficient of variation

FAO: Food and Agriculture Organization

GLOBCOVER: Global Land Cover

GDP: Gross domestic product

Ha: hectares

IPCC: International Panel on Climate Change

Km$^2$: Square Kilometer

Landsat TM: Land Satellite Thematic Mapper

LSD: least significant difference

m$^2$: Square meter

MA: Millennium Ecosystem Assessment

MADRPM : Ministère de l’Agriculture, du Développement Rurale et de la Pêche Maritime

MARA : Ministère de l’Agriculture et de la Réforme Agraire

mm: millimeter

MODIS: Moderate Resolution Imaging Spectroradiometer

NDSR: Normalized Difference Spectral Reflectance

NDVI: Normalized Difference Vegetation Index

NIR: near infrared

P: precipitation

PAN: Programme d’Action National

PET: potential evapotranspiration

R: Coefficient of correlation

R$^2$: Coefficient of determination

SAS: Statistical Analysis System

SDA: Stepwise Discriminate Analysis

SIG: Système d'Information géographique

SPOT: Satellite Pour l’Observation de la Terre

SWIR 1: shortwave infrared 1

SWIR 2: shortwave infrared 2

T/ha/year: Ton by hectare by year

UNCCD: United Nations Convention to Combat Desertification

UNEP: United Nations Environment Programme

UTM: Universal Transverse Mercator

VCI: Vegetation Condition Index

VIS: Visible

WGS: World Geodetic System

°C: degree Celsius

# Introduction

Dryland areas, according to the 2000 statistics (Safriel and Adeel, 2005), occupy 41% of the 6.2 billion hectares (Ha) of global Earth's land area, supporting crops, pastures and domestic animals for a third of the human population which amounts to 2 billion people in the year 2000. In the dryland areas, production of crops, forages, woods, and other services provided by ecosystems, is mainly limited by water scarcity. The aridity index, which reflects this water scarcity, allowed classification of Dryland areas (Reynolds, 2001), into four zones, namely: hyper-arid, arid, semiarid and dry sub-humid.

The majority of drylands (90%) is a mix between rangelands and croplands, supporting an integrated agro-pastoral livelihood. Up to 10 to 20% of these lands is severely degraded, affecting directly some 250 million people in the developing world, an estimate likely to expand substantially due to climate change and population growth (MA, 2005).

Rangelands account for 65% of dryland areas (MA, 2005) and are either natural or semi-natural ecosystems, used mainly for livestock production due to climate and soil unsuitability for agriculture or agro-forestry (Stoddart et al., 1975; Society for Range Management, 1989). They support approximately 50% of the world's livestock and provide feed for both domestic animals and wildlife (Puigdefabregas, 1998).

Rangelands play an important role in the current global environmental issues and, they are just as worthy of international attention. They are a major sink of carbon, which can be increased by reversing degradation and improving the production capacity, reducing the need for so many animals, at the same time reducing the methane emission per animal and increasing the livelihood chances of people in developing countries. In addition, loss in rangeland productivity greatly affects local population income and the measures taken for protecting these lands from degradation and desertification. Degradation implies the reduction of the natural resources through different processes. It has been attributed to a combination of climatic and human activities (Lambin et al., 2009; Geist and Lambin, 2004). The degradation of rangelands can lead to loss of the vegetation cover and biomass productivity over time and in space (Prince et al., 2009).

According to Puigdefabregas and Mendizabal (2004), rangelands composed by Human population and natural resources may be considered as two linked elements in a single system, which is affected by climatic or socioeconomic disturbances (Figure 1). Climatic disturbance include, climate change (droughts, humid periods, floods, etc.), besides normal climatic temporal fluctuations. Socioeconomic disturbances involve changes in demography, grazing, croplands, market and technology, which enable or hinder access to those resources. Under the equilibrium conditions, the intensity and duration of disturbances remain within the range of those that have appeared throughout the history of the system. They have been included in its own progress, so that it recovers quickly after they have stopped. On the other hand, a very extreme disturbance may changes the system beyond the resilience of the rangeland[1]. This may occur as an increased availability of resources (i.e. a humid period, the introduction of a new technology), an increased demand for products (i.e., higher prices, local increase in agricultural population), or on the contrary, as a reduction of available resources (i.e., extreme drought). In both cases, resources become over-exploited. If the system has feedback mechanisms to reverse this condition, it can recover and return to steady state. Otherwise, it falls into a loop that leads to overexploitation further decline, leading to desertification (MA, 2005; Hill et al., 2008). In Rangeland ecosystems, the successions of increase and decrease in resource availability (i.e., rain spell followed by drought) are the initiator of desertification. The former attracts people and investment while the latter gives rise to over-exploitation.

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[1] Resilience is '*a measure of the persistence of systems and their ability to absorb change and disturbance and, still maintain the same relationships between populations or state variables*'.

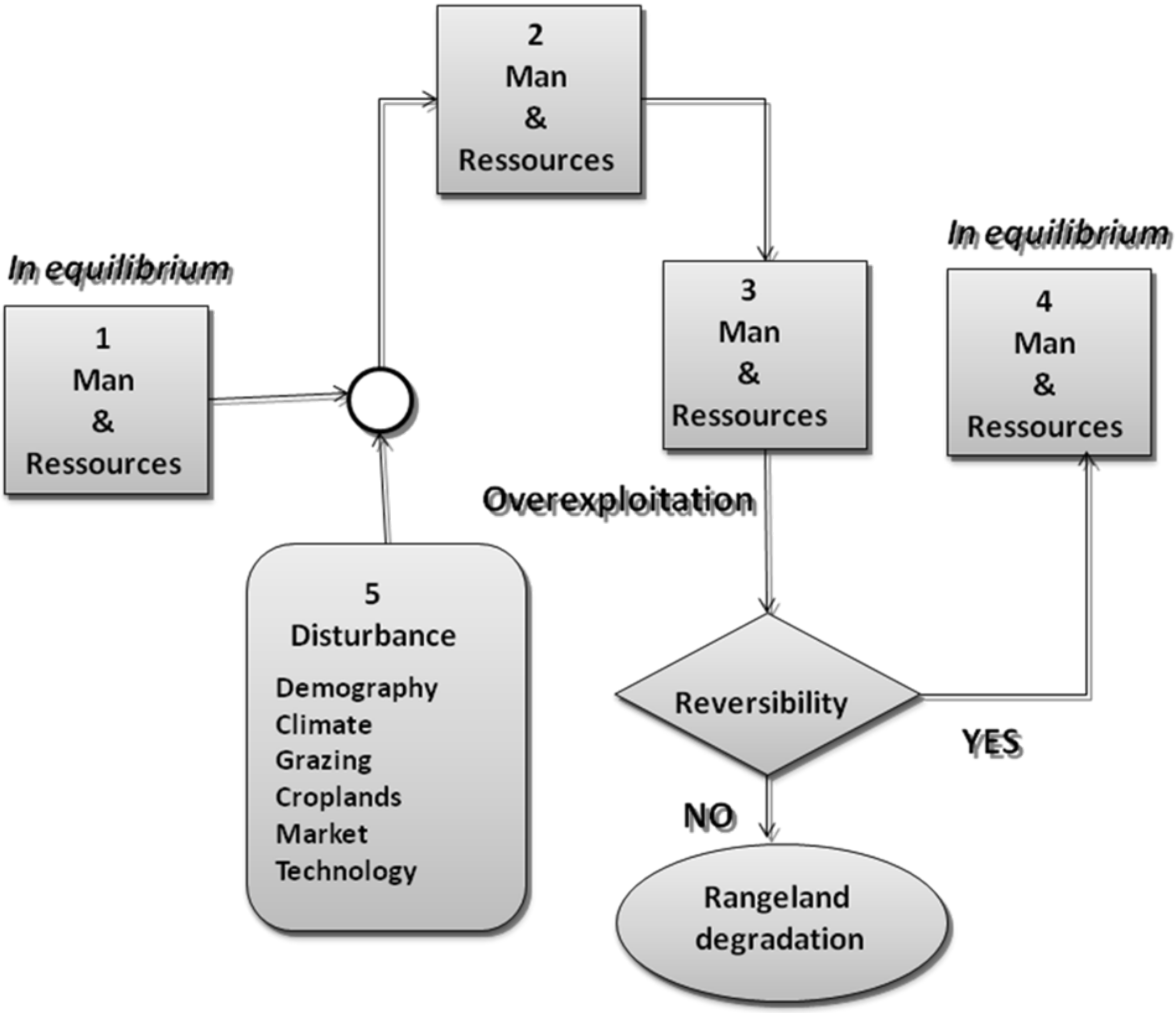

**Figure 1:** Summary of degradation process: Boxes 1 and 4 show the systems in equilibrium with the normal long-term variability of resources in the rangeland. Box 2 shows the system stressed by the presence of a disturbance embodied in box 5. Box 3 shows the system in the regime of exploitation, once the disturbance has ceased (Puigdefabregas, 1995).

Rapid population growth, with concomitant high population densities and rapid urbanization, implies growing demand for land, crop production and fodders. Overgrazing is a major cause of disturbances leading to desertification (Prince et al., 2009). Overgrazing occurs when livestock density becomes excessive and too many animals are grazing on the same area, leading to the rangeland degradation. High grazing pressure on rangeland leads to a consumption of palatable vegetation by animals faster than they can regenerate. The main cause of overgrazing is the growing of herd sizes within a given area beyond its regenerating capacity (Weber and Horst, 2011). Market demand for animal products caused an increase in livestock growth in many arid rangelands beyond rangeland capacity, further accentuated by the introduction of veterinary treatments and subsidies of livestock fodder by some governments.

In addition, at the rise of the 20th century, conversion of rangelands to croplands increased the risk of desertification because of increased pressure on the remaining rangelands and unsustainable cultivation practices. Approximately 15% of the arid rangelands were converted to cultivated systems during the first half of the 20th century. A somewhat faster conversion has taken place in the last five decades referred to as the Green Revolution era (MA, 2005). The invasion of croplands within rangeland is also the consequence of some national policies seeking for increased food production or even increased cash crops production.

Climate change contributed to rangeland degradation, as arid rangelands are climatically determined. In Morocco, climate change scenarios suggest shifts in rainfall patterns but the major impact will come through increased variability. In fact, the seasonal and annual rainfall in arid areas is highly variable, with coefficients of variation of annual rainfall of 25 to 100%, depending on location. Spring precipitation decreased by -40%, and average temperatures increased by 0.16ºC per decade since the sixties. Like for past decades, future trends show decreased rainfall and increased temperatures in Morocco (Gommes et al., 2009). Also, extreme events, such as prolonged droughts and intense rains, are expected in arid rangelands.

However, the determination of the contribution of climate change to desertification is not an easy matter. Rangeland degradation may be aggravated by climate change (Darkoh, 1998) in particular, by prolonged and frequent drought, especially in the sub-Saharan Africa. According MA (2005), desertification is associated with biodiversity loss and contributes to global climate change through loss of carbon sequestration capacity and an increase in land-surface albedo (Figure 2). Over-exploitation of rangeland vegetation leads to primary production loss, therefore reducing carbon sequestration. The disruption of the interlinked services jointly provided by dryland biodiversity is a key trigger for desertification and its various manifestations, including the loss of habitats for biodiversity. Also, the desertification affects global climate change through soil and vegetation losses. An estimate of 300 million tons of carbon is lost to the atmosphere from drylands every year, as a result of desertification contributing about 4% the total global emissions from all sources combined (Cox et al., 2000).

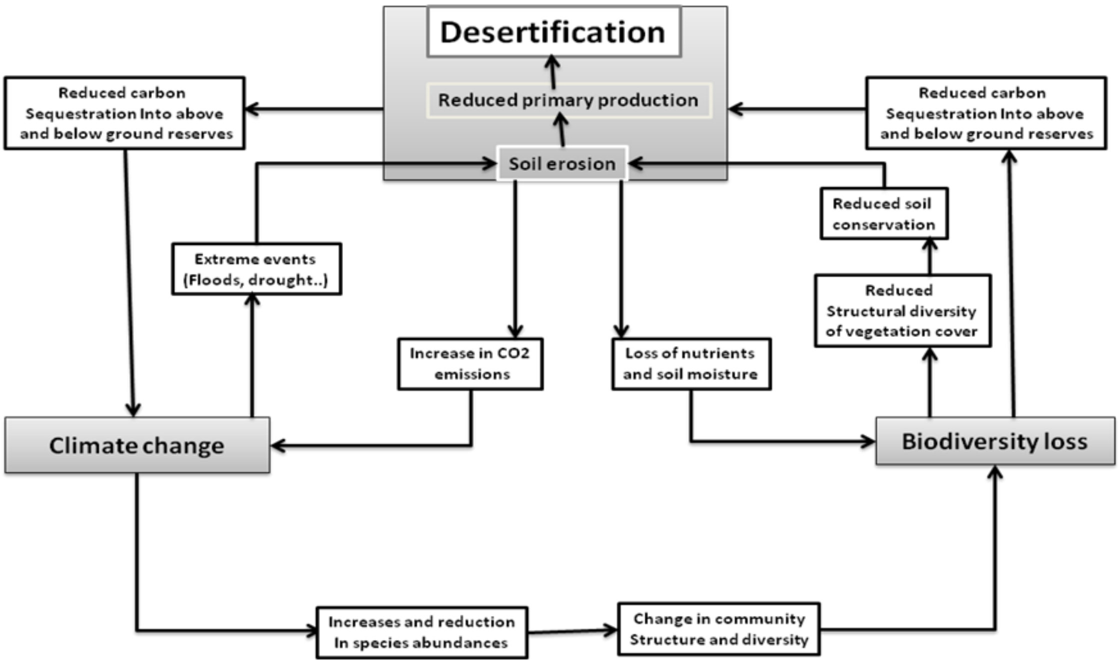

**Figure 2:** Linkages and feedback loops among desertification, climate change, and biodiversity loss (Source: MA, 2005).

Despite the importance of desertification, there is much controversy in the literature including disagreements over the actual magnitude of the problem. It is frequently reported that as much as 70% of the world's drylands (3.6 billion hectares) may suffer from desertification (Lamprey, 1975; UNEP, 1984). According to UNEP (1991) assessment, 995 million hectares of rangelands (74 % of the total area) in Africa are affected by desertification at a moderate to higher level. While most scientists agree that large areas of the surface of the earth have been desertified (Prince et al., 2009), there is a contestation on estimates of desertification in previous studies (Tucker et al., 1991; Veron et al., 2006). Others contest this interpretation (Reynolds and Smith, 2002) and questioned the methodology used by previous studies and find no evidence of such an extent of desertification. New research has also questioned these studies because of methodological and conceptual problems, showing that the assessment of desertification remains controversial (Veron et al., 2005; Veron et al., 2006; Prince et al., 2009). Lack of accurate inventory studies on desertification, despite a large amount of data on land resources, has not yet made possible to draw a clear picture of the status of land degradation at regional or national levels. Generally, the assessment of desertification has been approached by general views, by journals or book chapters that dealt with concepts, definitions, causes, consequences and processes involved in the phenomenon of desertification, but have not addressed the problem of its evaluation in a comprehensive way (Reynolds and Smith, 2002; Veron et al., 2006).

Other researchers have studied desertification using remote sensing techniques from satellites. Remote sensing techniques are widely viewed as time and cost effective alternative when significant amount of information is needed, but budgets are declining (Escadafal, 2007; Hill et al., 2008; Lambin et al., 2009). Remote sensing can play a useful role in environmental change detection at regional and global scales. It can be used to enhance monitoring efforts as well as to provide valuable information on arid rangeland degradation. However, the low vegetation cover and the heterogeneity in arid rangelands is a significant obstacle to the use of remote sensing techniques in arid rangelands (Okin, et al., 2001). Also, satellites can detect land surface variables that respond to desertification, such as albedo, surface temperature, and vegetation cover. Unfortunately, factors that are not related to desertification also affect these variables. For example, remote sensing has been used to monitor inter-annual changes of vegetation cover in dry regions (Tucker et al., 1991; Anyamba and Tucker, 2005; Huang and Siegert, 2006) which is frequently caused by rainfall fluctuations, not desertification. According to Prince (2002) persistent reduction in rangeland productivity is an expression of desertification and, is generally measured using satellite derived indices such as Normalized Difference Vegetation Index (NDVI). This author suggested that a persistent reduction of production below its potential level, i.e. a reduction that does not disappear during wetter periods, could help identifying areas facing desertification. However NDVI is not suited for areas where vegetation cover and chlorophyll activity is very low (low reflectance of vegetation). Other techniques, such as Spectral mixture analysis, multiple endmember spectral mixture analysis, are indeed not able to provide reliable retrievals of vegetation type when landcover is low. Spectrally undetermined vegetation types, characterized by low spectral contrast, is difficult to model correctly even at relatively high covers. Intraspecies spectral variability and nonlinear mixing also lead to uncertainties in spectral reflectances (Okin et al., 2001).

In Morocco, most rangelands are located in arid and semi-arid areas. Arid rangelands of Morocco are ecologically, economically and socially important because they provide livelihood for thousands of people and protect the country from rapid desertification. Today, these rangelands suffer from important changes and, desertification (Bounejmate et al., 2001). Despite the importance of these rangelands, the literature is very controversial on the extent of desertification. Official documents of the Moroccan government announce catastrophic figures on the rate of degradation and on the area affected by desertification (PAN, 2001). On the opposite, other sources (Davis, 2005) announce that desertification has been overvalued for decades in order to support policies that are systematically disadvantageous for local people and other stakeholders. Given the lack of robust and reliable information on rangeland conditions in Morocco, most development projects were implemented in pastoral areas, based primarily on expert opinion or on ancillary sources.

Assessment of change in the Moroccan and North Africa rangelands is a substantial task. In fact, drought and rangeland degradation are the challenges of development, and require urgent attention in policies and actions of these countries. Thus, the lack of reliable monitoring information in Morocco, based on robust empirical data, methodologies and assessments of rangeland hinders the monitoring of any change and the implementation of programs to drought mitigation or land degradation alleviation. Conventional methods for monitoring drought and desertification are not adapted to the spatial scale of these phenomena. They are also not compatible with the rhythm of change and, are often long to detect, complicated to archive, and update is still a heavy and costly action.

The exceptional growth of geomatics tools during the last two decades represents a unique opportunity to properly assess rangeland all over the arid and semiarid zones at any reasonable spatial scale. However, for the arid rangelands, the use of remote sensing alone has some limitations and it does not provide reliable information for monitoring desertification, especially when vegetation is sparse; plants are a mixture of dry and green leaves that deviates too much from a normal plant and their reflectance are similar to bare soil.

Hence, the monitoring of arid rangelands in Morocco requires more advanced approaches. They should provide accurate information on rangeland drought risk and degradation through geomatics and biophysical indicators. Thus, the study revolves around an overview of rangeland degradation in all Morocco based on available information. The study focus then on Eastern Morocco which is chosen as pilot area for developing indicators to assess drought and for developing an appropriate method for rangeland degradation mapping. Regarding the mapping of rangeland degradation, an additional study has been done on Alfa grass (*Stipa tenacissima* is a significant component of the arid and semiarid areas of the Mediterranean Basin) by exploring their spectral behavior at various degradation levels of Alfa grass steppes, based on hyperspectral field data. In addition, it is suggested that the approaches developed in this study can be used by other countries of North Africa due to the arid rangeland similarity of these areas.

The objective of this study is to develop methods of rangeland monitoring in Morocco based on remote sensing data from satellite sensors, combined with biophysical indicators and expert knowledge.

The four specific objectives of this study are:

1. Provide an overview of arid rangeland degradation in Morocco.
2. Develop a methodology for assessing drought arid rangelands.
3. Develop a methodology for assessing rangeland degradation based on satellite images, phytogeography, lithology and parameters of perennial vegetation.
4. Assess the spectral behavior of Alfa grass based on field hyperspectral data.

Each of these four specific objectives is developed in a separate part, which has been already published (parts 1 and 2), already submitted for publication (part 3) or in progress for a submission to publication (part 4).

# I. Part I: Désertification des parcours arides au Maroc

Publié dans TROPICULTURA, 2010, 28 (2) : 107-114

http://www.tropicultura.org/text/v28n2/107.pdf

## Résumé

Les terres de parcours naturels arides du Maroc sont des écosystèmes avec une végétation naturelle ou semi naturelle composée de steppes, d'arbustes et de prairies.  Elles représentent 82 % de la superficie des terres arides marocaines. Ces terres offrent des moyens de subsistance à des milliers de personnes et protègent le pays d'une désertification rapide. Malgré l'importance de ces zones fragiles, il est étonnant qu'il n'y ait, à ce jour, aucune évaluation globale de leur état et de leur évolution, entravant ainsi tout plan d'aménagement ou de lutte contre la désertification. Toutefois, les informations disponibles sur certaines zones pilotes montrent que ces terres sont menacées par la désertification. Ce phénomène agit grandement sur la perte de la biodiversité végétale et contribue, en outre, aux changements climatiques. Les causes principales de la dégradation sont les actions anthropiques qui sont accentuées par le climat. La mise en place d'un système de surveillance global basé sur de la télédétection spatiale, des données biophysiques et socio-économiques doit être envisagée pour fournir aux décideurs un outil opérationnel adapté du suivi spatio-temporel de la désertification.

**Mots clés:** Parcours arides, désertification, indicateurs, surveillance.

## Abstract

Rangeland or natural arid pastures of Morocco are ecosystems where there is a natural or semi-natural vegetation composed of steppes, shrubs and grassland. They cover about 82 % of the Moroccan arid lands. These areas represent a source of life for thousands of people and protect the country from desertification. Despite the importance of the rangelands and the threat of desertification, it is surprising that up to date there is no comprehensive assessment of their state and development, hindering any plan for desertification alleviation. However, the available information on several pilot areas shows that these rangelands are threatened by desertification. It's associated with biodiversity loss and contributes to climate change.  The leading causes of land degradation are the Human actions combined with climate.

The installation of a monitoring system based on remote sensing, biophysics and socio-economic data allows the development a data base and desertification indicators.  This can support decision makers in monitoring desertification.

**Key words:**  Arid rangeland, desertification, indicators, surveillance

## 1.1 Introduction

Au Maroc, les terres de parcours correspondent à des écosystèmes portant une végétation naturelle ou semi naturelle composée de steppes, arbustes et prairies, utilisés essentiellement pour la production animale, le climat et le sol étant très défavorables pour l'agriculture. La plupart de ces terres se trouvent dans les zones arides et semi-arides (54% du territoire). Elles se situent dans les régions où les isohyètes[2] sont inférieures à 600 mm/an (FAO, 1987). Ces terres sont classées en trois sous-types d'aridités: hyperaride, aride, semi-aride respectivement pour des zones situées dans les isohyètes inférieures à 100, 100-400 et 400-600 mm (Le Houérou, 2006). Le niveau d'aridité typique pour chacun de ces sous-types est défini par un indice d'aridité correspondant au rapport entre les précipitations[3] annuelles moyennes et l'évapotranspiration[4] potentielle annuelle moyenne[5]. La suite du texte ne considérera plus que les deux zones arides et semi-arides qui seront reprises sous le terme unique de zone aride dans la suite du texte (Figure 1.1, encadré dans la partie supérieure droite de la figure). Ces terres de parcours offrent des moyens de subsistance à des milliers de personnes et protègent le pays d'une désertification rapide.

Le terme désertification désigne la dégradation des terres dans les zones arides, semi-arides et subhumides sèches par suite de divers facteurs, parmi lesquels les variations climatiques et les activités humaines (UNCCD, 1994).  En ce sens, la dégradation des terres désigne la « diminution ou la disparition, dans les zones susmentionnées, de la productivité biologique ou économique et de la complexité des terres cultivées non irriguées, des terres cultivées irriguées, des parcours, des

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[2] Une **isohyète** est une ligne reliant des points d'égales quantités de précipitations.

[3] Somme de la pluie et de la neige.

[4] Somme de l'évaporation du sol et de la transpiration des plantes.

[5] Evapotranspiration mesurée en condition standard, représentant le pouvoir évaporant de l'air.

pâturages, des forêts ou des surfaces boisées, du fait de l'utilisation des terres ou d'un ou de plusieurs phénomènes tels que l'érosion des sols causée par le vent et/ou l'eau, la détérioration des sols et la disparition à long terme du couvert végétal » (UNCCD, 1994).

Malgré l'importance des terres de parcours, la littérature sur leur état au Maroc est très controversée. Les documents officiels du gouvernement annoncent des chiffres alarmants sur le taux d'avancée du désert et sur les surfaces affectées par la désertification (PAN, 2000). D'autres sources, en revanche, annoncent que la désertification a été surévaluée depuis des décennies pour faciliter et justifier les politiques et les changements de lois qui sont systématiquement désavantageux aux populations locales et aux autres acteurs, causant ainsi des dommages à l'environnement (Davis, 2005). Étant donné le manque d'informations scientifiques cohérentes sur l'état des parcours au Maroc, la plupart des projets de développement des terres de parcours ont été mis en application en se basant principalement sur des opinions d'experts ou sur des sources secondaires. Cet article a pour but de présenter un aperçu sur la menace de la désertification qui pèse sur les terres de parcours marocaines, d'en déterminer les causes et d'en analyser les conséquences pour conduire à une proposition de surveillance spatio-temporelle à long terme.

## 1.2 Matériels et méthodes

L'approche utilisée s'articule sur la récolte et l'analyse de trois sources d'informations: les sources écrites ou bibliographiques, les sources cartographiques géoréférencées et les sources statistiques ainsi que les données climatiques.

### 1.2.1 Sources bibliographiques:

Il s'agit de réaliser une exploitation des documents officiels, des études et rapports existants au niveau national ou au niveau des zones pilotes sur la dégradation des parcours arides marocain. La bibliographie internationale et la documentation disponible sur d'autres régions similaires ont aussi été utilisées. Ces informations ont été exploitées de façon à explorer les processus de désertification des parcours arides, de connaître les indicateurs, les causes et les outils de surveillance. Cette étape nous a permis l'élaboration d'une synthèse documentaire sur la désertification des parcours arides.

### 1.2.2 Sources cartographiques:

Afin de compléter la documentation disponible, une base de données sous forme de Système d'Information géographique[6] (SIG) a été élaborée. Les principales sources utilisées en cartographie sont les limites administratives, la carte d'occupation du sol extraite à partir de Globcover (Globcover, 2008), la carte des écosystèmes pastoraux marocains, la carte d'aridité et d'autres données auxiliaires. La carte digitale d'occupation des sols « Globcover », élaborée en 2008, est l'unique référence, issue de la télédétection spatiale, à moyenne résolution spatiale publiée en la matière et qui intègre le Maroc dans sa zone de couverture. Toutefois, elle présente des limites concernant la réalité de la couverture végétale, notamment son incapacité à bien différentier le sol nu de la végétation naturelle dégradée comme en témoigne la classification de la zone des Plateaux de l'Oriental, surestimant très largement la part attribuée aux sols nus (Mahyou et al, 2005). Les différentes informations ont été intégrées dans un SIG puis traitées et analysées dans le but d'aider à expliquer le phénomène de désertification dans les zones arides marocaines. Les cartes thématiques disponibles sous format papier ont été scannées, puis digitalisées. Ces différentes cartes thématiques ont permis de délimiter les zones arides du Maroc, les différentes zones pastorales, l'occupation du sol des parcours arides par zone pastorale, l'état de dégradation ainsi que les statistiques correspondantes.

### 1.2.3 Sources statistiques et données climatiques:

Les statistiques officielles sur les petits ruminants durant la période 1979-2006, ont servi de base de données pour l'analyse des tendances actuelles concernant la

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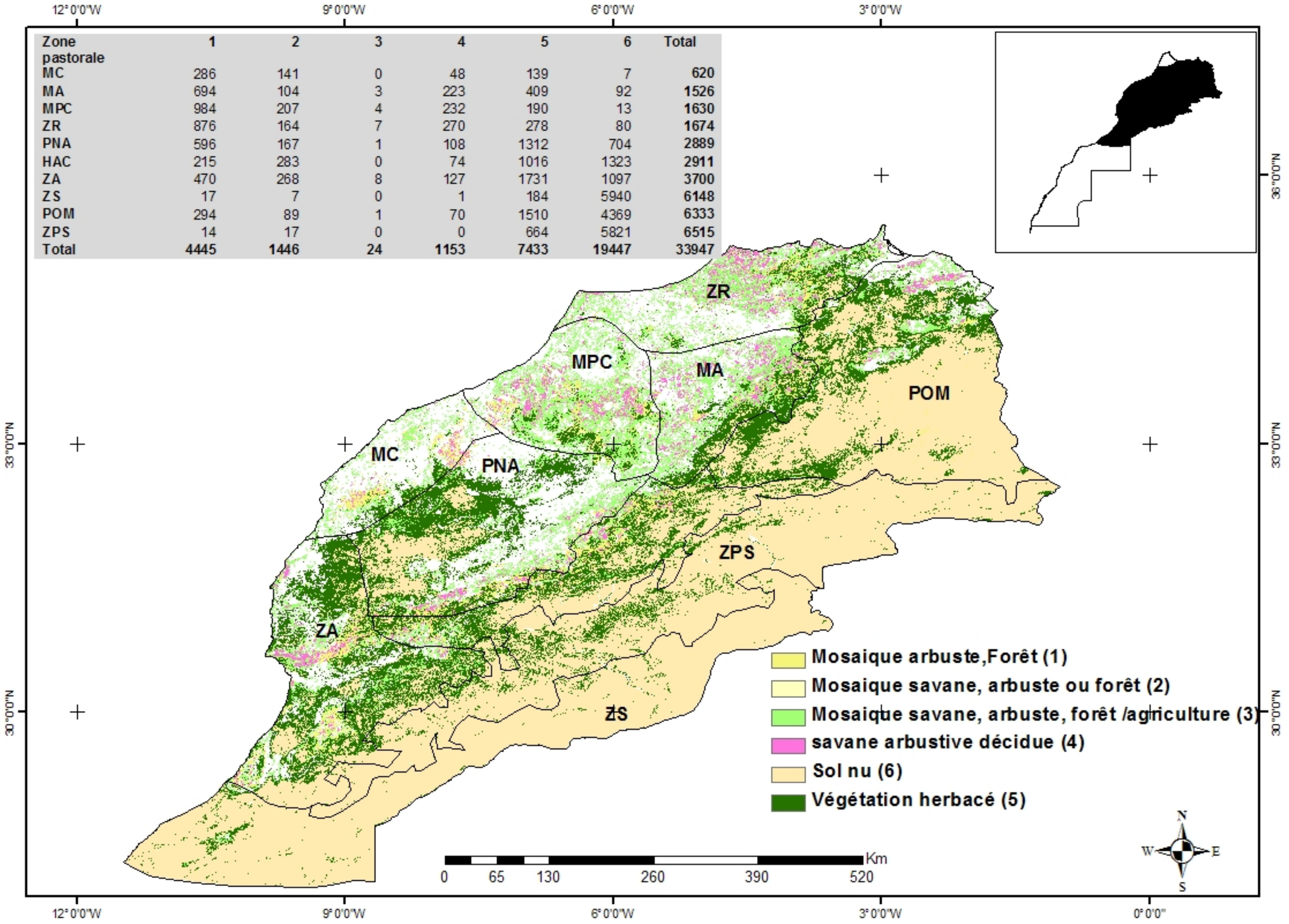
[6] Application informatique qui permet de stocker, de visualiser, et d'analyser l'information géographique

répartition du cheptel ruminant. Également, une analyse climatique a été réalisée en se basant sur des séries pluviométriques mensuelles qui s'étalent de 1979 à 2006.



| Zone pastorale | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|
| MC | 286 | 141 | 0 | 48 | 139 | 7 | **620** |
| MA | 694 | 104 | 3 | 223 | 409 | 92 | **1526** |
| MPC | 984 | 207 | 4 | 232 | 190 | 13 | **1630** |
| ZR | 876 | 164 | 7 | 270 | 278 | 80 | **1674** |
| PNA | 596 | 167 | 1 | 108 | 1312 | 704 | **2889** |
| HAC | 215 | 283 | 0 | 74 | 1016 | 1323 | **2911** |
| ZA | 470 | 268 | 8 | 127 | 1731 | 1097 | **3700** |
| ZS | 17 | 7 | 0 | 1 | 184 | 5940 | **6148** |
| POM | 294 | 89 | 1 | 70 | 1510 | 4369 | **6333** |
| ZPS | 14 | 17 | 0 | 0 | 664 | 5821 | **6515** |
| **Total** | **4445** | **1446** | **24** | **1153** | **7433** | **19447** | **33947** |

**Figure 1.1:** Occupation du sol des terres de parcours par zone pastorale (en 1000 ha) dans la zone aride du Maroc.

**Données Sources:** MARA (1992) et Globcover for North Africa (2008). **MC :** Meseta Côtière, **MPC :** Zone de la Mamora et Plateau Central, **RB:** Zone Rifaine et ses Bordures, **MA :** Le Moyen Atlas

**PNA :** Plateaux et Plaines Nord Atlasiques, **HAC :** Zone du Haut Atlas Central et Oriental, **ZA :** Zone de l'Arganier, **ZS :** Zone Saharienne, **ZPS :** Zones Présahariennes, **POM :** Plateaux de l'Oriental et Vallée de la Moulouya.

## 1.3 Résultats et discussion

### 1.3.1 État actuel des terres de parcours arides

Au Maroc les terres de parcours se retrouvent sur dix zones pastorales (Figure 1.1) qui différent les unes des autres par leurs compositions floristiques et leurs conditions édapho-climatiques (MARA, 1992).

L'analyse de la carte Globcover sur SIG montre que 82 % de la superficie des zones arides est occupée par les terres de parcours (Tableau 1.1). Les principales espèces végétales sont citées dans la littérature en fonction des zones pastorales (Berkat et al, 2004)**.**

Les terres de parcours sont dominées essentiellement par les classes : sol nu, végétation herbacée, végétation arbustive décidue et mosaïque savane/arbuste ou forêt. On constate que les terres de parcours désertifiées (classe « sol nu ») représentent 57% de la superficie des terres de parcours arides. Les zones pastorales les plus importantes en termes de superficie, notamment la zone saharienne (**ZS**), présaharienne (**ZPS**) et le Plateaux de l'Oriental et la Vallée de la Moulouya (**POM**)**,** sont les plus dégradées avec respectivement 97, 89 et 69%.

**Tableau 1.1:** Superficie et pourcentage des classes d'occupation du sol dans les zones arides du Maroc selon la carte Globcover 2008.

| ***Classe d'occupation du sol*** | ***Superficie (X1000 ha)*** | ***(%)*** |
|---|---|---|
| **Agriculture** | 7264,4 | **17,4** |
| **Forêt dense** | 71,2 | **0,2** |
| **Ville** | 238,0 | **0,6** |
| **Eau** | 122,2 | **0,3** |
| **Mosaïque savane, arbuste, forêt (50-70%)/agriculture (20-25%)** | **4445,9** | **10,7** |
| **Mosaïque arbuste ou forêt (50-70%) / savane (20-50%)** | **1445,4** | **3,5** |
| **Mosaïque savane (50-70%) / arbuste ou forêt (20-** | **24,2** | **0,1** |

| | | |
|---|---:|---:|
| **50%)** | | |
| **savane arbustive décidue** | **1153,2** | **2,8** |
| **Végétation herbacée (<15%)** | **7428,5** | **17,8** |
| **Sol nu** | **19463,9** | **46,7** |
| **Total** | **41656,9** | **100,0** |

### 1.3.2 Les indicateurs de la désertification

Les indicateurs de désertification peuvent être divisés en trois principaux groupes, notamment les indicateurs physiques, biologiques et socio-économiques. Le manque de publications sur tous ces indicateurs de dégradation au niveau des parcours arides nous amène à n'aborder dans cette partie que les indicateurs biologiques principalement ceux liés au végétal.

#### 1.3.2.1 Réduction des surfaces et perte de la biodiversité végétale

La carte d'occupation du sol «Globcover» met en évidence l'étendue des parcours dégradés. Ainsi, les sols nus représenteraient 57 % de la superficie des parcours des zones arides (Tableau 1.2).

Les études récentes ayant trait à la dynamique de la végétation peuvent illustrer cette situation. En effet, l'analyse de deux images satellitaires Landsat TM, prises en 1988 et en 2000 dans le périmètre pastoral de Ain Béni Mathar au nord des **POM,** a permis d'estimer la perte annuelle des steppes alfatière (*Stipa tenacissima*) et à armoise blanche (*Artemisia herba alba)* à 3%, avec une tendance vers la disparition de l'armoise blanche (Mahyou et al., 2001)**.**

Dans une autre étude (Mahyou et al., 2005), la comparaison de trois périodes (1970, 1988 et 2004), respectivement par une carte de végétation et deux images satellites Landsat, couvrant 700 000 ha dans le sud des **POM,** montre une réduction de la surface des steppes et un changement dans sa composition floristique. Les steppes alfatières et à armoise blanche sont remplacées par des espèces indicatrices de dégradation de la végétation, telles que *Noaea mucronata* et *Peganum harmala,* ou laissent place à des sols nus. Les steppes à armoise blanche ont quasiment disparu et les steppes alfatières ont subi des pertes annuelles moyennes de 2.7 % (Mahyou et al., 2005).

**Tableau 1.2:** Superficie désertifiée des terres de parcours arides.

| | **Superficie parcours (x1000ha)** | **Surface désertifiée (x1000ha)** | **(%)** | **Surface non désertifiée (x1000ha)** | **(%)** |
|---|---|---|---|---|---|
| **ZS** | 6148 | 5940 | 97 | 208 | 3 |
| **ZPS** | 6515 | 5821 | 89 | 694 | 11 |
| **POM** | 6333 | 4369 | 69 | 1964 | 31 |
| **HAC** | 2911 | 1323 | 45 | 1588 | 55 |
| **ZA** | 3700 | 1097 | 30 | 2603 | 70 |
| **PNA** | 2889 | 704 | 24 | 2185 | 76 |
| **MA** | 1526 | 92 | 6 | 1434 | 94 |
| **ZR** | 1674 | 80 | 5 | 1594 | 95 |
| **MPC** | 1630 | 13 | 1 | 1616 | 99 |
| **MC** | 620 | 7 | 1 | 613 | 99 |
| **Total** | **33961** | **19464** | **57** | **14497** | **43** |

#### 1.3.2.2 Réduction de la productivité des parcours

Malgré l'importance de la productivité fourragère des parcours, les informations disponibles sur ce paramètre sont loin de rendre compte de la diversité des écosystèmes pastoraux, et encore moins de leur variabilité dans le temps, due aux conditions climatiques. L'évolution de la production n'est que rarement appréhendée sur un grand nombre d'années. Dès lors, il est difficile de dresser un tableau exhaustif des productions. Le manque de stations de mesures et de suivi des ressources pastorales est très marqué et les données disponibles dans la littérature correspondent le plus souvent uniquement aux pics de production des parcours (en avril, mai et juin).

La production était de 300-590 kilogrammes de matière sèche par hectare et par année (Kg MS/ha/an), 240-600 Kg MS/ha/an, 750-830, 590-883 et inférieure à 200 Kg MS/ha/an, respectivement dans les zones présahariennes (**ZPS)**, Zone du Haut Atlas Central et Oriental **(HAC)**, Plateaux et Plaines Nord Atlasiques **(PNA),** Meseta Côtière **(MC)** et Zone de l'Arganier **(ZA)** (MARA, 1986)**.** Ces productions sont mentionnées à titre indicatif car les références sont anciennes et ne reflètent plus nécessairement la réalité actuelle.

Dans la zone **POM,** qui est la plus étudiée et qui est située sur des sols limoneux à argileux et sous une pluviométrie annuelle moyenne de 200 mm, la production oscille entre 10 et 100 Kg MS/ha/an (MADRPM, 2007). L’analyse des données disponibles en 1970 (MARA, 1970), 1989 (Berkat et al., 1990) et 2006 (MADRPM, 2007) montre une forte évolution de la variabilité de la production: d'un facteur de 1 à 27 pendant les années 1970, avec une moyenne élevée de 272 Kg MS/ha/an, la production a varié d'un facteur de 1 à 20 en 1989, avec une moyenne de 156 Kg de MS/ha/an, pour se réduire considérablement en 2006 où la production maximum a été à peine 10 fois supérieure au minimum pour une production moyenne très faible de 44 kg MS/ha/an.

Cette tendance est confirmée par les productions moyennes des steppes alfatières citées par plusieurs auteurs à différentes périodes (MARA, 1970 ; Berkat et al., 1990 ; Ghazi, 2003 ; Maatougui et al., 2005) (Figure 1.2). Avant 1990, La variabilité de la production était normale et suivait celle de la pluviométrie. À partir de 1990, on observe que la production diminue malgré des années pluvieuses. Cette tendance régressive débouchera, à terme, sur des steppes à faible couvert végétal et à faible potentialité qualitative et quantitative**.** Ce type d’évolution a été noté ailleurs, comme conséquence de la dégradation des espèces pérennes (Aïdoud et al., 2006).

Le recouvrement global aérien est généralement inférieur à 10 % dans la plupart des parcours (MADRPM, 2007). La production fourragère y varie entre 20 et 60 Unités

Fourragères par hectare (Maatougui, 2005). L'apport des parcours dans le bilan fourrager du cheptel s'est fortement réduit, passant de 37% à 21 % entre les périodes 1989 à 1992 et 2000 à 2003 (Boulanouar et al., 2006).

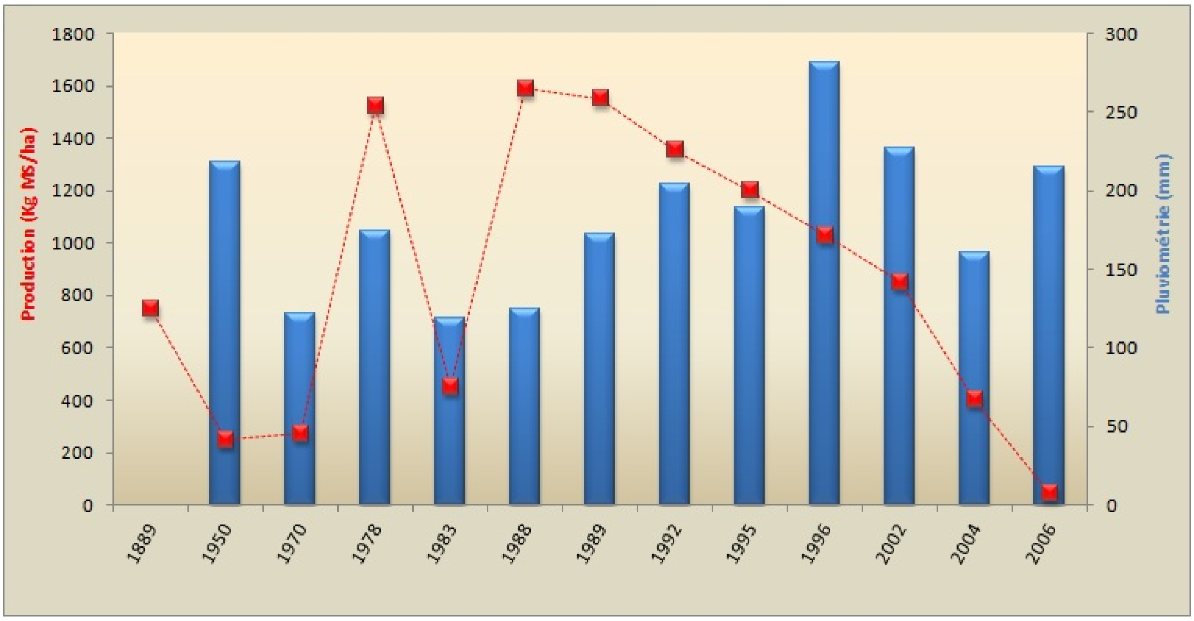


**Figure 1.2:** Variabilité interannuelle de la production des steppes alfatières (en kilogramme de matière sèche par hectare) et de la pluviométrie dans l'écosystème « Plateaux de l'Oriental et Vallée de la Moulouya ».

### 1.3.3 Les causes de la désertification

La désertification des terres de parcours est causée par une combinaison de facteurs qui évoluent dans le temps : les facteurs indirects, tels que la croissance démographique, et les facteurs directs, comme les pratiques d'utilisation de ces terres et les changements climatiques.

#### 1.3.3.1 Croissance démographique.

De 1950 à 2004, la population marocaine a triplé (Haut commissariat au plan, 2004) et les projections futures montrent qu'elle dépassera les 50 millions d'habitants en 2050 (Brauch, 2002). La population urbaine représente actuellement 55% de la population totale, alors qu'elle ne représentait que 30% en 1960 (Haut commissariat au plan, 2004; Brauch, 2002).

La croissance démographique semble être parmi les principales causes de dégradation des terres de parcours marocain en raison d’un changement dans le mode de consommation et une forte demande des produits issus des zones pastorales. La diminution de la population des zones pastorales, en raison de l’émigration interne et externe, s’est traduite par une tendance à la sédentarisation. On assiste à la disparition du libre accès aux parcours, et à une appropriation de ces terres conduisant à une surexploitation des ressources pastorales et une conversion des parcours en zones de culture.

### 1.3.3.2 Changements climatiques.

Au Maroc, la pluviométrie saisonnière et annuelle des zones arides est fortement variable avec des coefficients de variation de la pluviométrie annuelle de 25 à 100% selon l’endroit (Knippertz, 2003). Ce sont surtout les précipitations printanières qui ont diminué (-40%), et les températures moyennes ont augmenté de 0.16ºC par décennie depuis les années soixante (Driouech, 2006).

Les tendances futures, montrent, en général, une baisse des précipitations et une augmentation des températures au niveau national. La pluviométrie annuelle baissera de l’ordre de 20% d’ici 2050 et de 40% à l’horizon 2080. Cette chute affectera surtout les saisons pluvieuses notamment, l'automne et le printemps (Gommes et al, 2009). Le réchauffement avoisinera 3°C d’ici 2080 et atteindra même 5°C dans certaines zones pastorales. Cet accroissement entraînera une augmentation de l’évapotranspiration de l’ordre de 20% d’ici 2050 et 40% à l’horizon 2080 (Gommes et al, 2009). De même, il est tout à fait possible que les événements extrêmes, tels que les sécheresses prolongées et les pluies intensives, deviennent fréquents dans les terres de parcours arides (Driouech, 2006). Ces tendances futures, conjuguées aux impacts déjà existants, vont entraîner une perte de la biodiversité des terres de parcours et augmenter leur vulnérabilité à la désertification.

### 1.3.3.3 Extension des zones de culture

Au Maroc, les terres de parcours ont, pour la plupart, un statut juridique collectif. La règle appliquée à ces terres, reprise du droit coutumier et inscrite dans le droit moderne, affirme que c'est l'appartenance au groupe ethnique (tribu, fraction, lignage..) qui ouvre le droit au parcours collectif (Narjisse, 2006).

La substitution progressive des entités administratives et élues aux organisations communautaires coutumières a entravé les règles communautaires régissant l'accès aux terres de parcours, au bénéfice des règles basées sur la propriété privée (Narjisse, 2006). L'expression la plus plausible de ce changement est l'accentuation du défrichement et l'extension des labours sur les terres de parcours dans le but de s'approprier individuellement ces terres.

Ainsi, la progression des terres de culture, avec une sédentarisation des familles, s'accélère. La comparaison entre les recensements généraux de l'agriculture de 1974 et 1996 et les statistiques officielles récentes du Ministère de l'Agriculture révèlent que la superficie cultivée au Maroc est passée de 7.2 à 8.5 puis à 9.2 millions, d'hectares notamment par le biais du défrichement des terres de parcours**.** Les superficies mises en cultures ont été multipliées par 5 et 14 respectivement dans le sud et le nord du **POM** en référence à l'année 1970, avec un rythme annuel de 500 ha et de 300 à 400 ha (El Koudrim et al., 2001; El Koudrim et al, 2005). Cette conversion des parcours de façon anarchique en terres de cultures fait partie des principaux facteurs de dégradation et de conflits dans les zones pastorales. Elle joue un rôle clé dans la désertification par un surpâturage sur les terres non défrichées et une perte des sols par érosion éolienne et hydrique des terres mises en culture.

### 1.3.3.4 Surpâturage

La disparition progressive de la gestion des parcours par l'organisation communautaire traditionnelle a engendré l'émergence d'une situation de «tragédie des communs» où une forte compétition sur les ressources pastorales est constatée entre la population d'un groupement ethnique. La principale conséquence en est le surpâturage qui est considéré comme la cause principale de la désertification des parcours (MA, 2005).

Le surpâturage est une conséquence directe d'une augmentation de l'effectif des petits ruminants car les terres de parcours sont la principale source d'alimentation. Aujourd'hui, cet effectif dépasse les 22 millions de têtes dont 76 % sont des ovins (Tableau 1.3).

Globalement, sur les vingt-huit dernières années, le cheptel ovin a enregistré une augmentation, tandis que les caprins ont connu une diminution. Ces tendances ont varié d'un écosystème pastoral à l'autre. On remarque une augmentation très marquée des ovins dans les zones POM, Moyen Atlas (MA) et Rifaine et bordures (RB) (Figure 1.3). La zone RB, d'habitude caractérisée par l'élevage caprin voit, quant à elle, le cheptel ovin augmenter, probablement suite à la sédentarisation des éleveurs via la complémentation par l'achat d'aliments pour le bétail et à la dégradation des terres de parcours propices aux caprins.

L'augmentation de l'effectif du cheptel ovin n'est pas liée à la variation pluviométrique. À ce titre, l'exemple de la zone **POM** est frappant. Malgré une tendance de la pluviométrie à la baisse (-0.25%/an), le cheptel ovin augmente de façon extraordinaire, en moyenne de 16500 têtes/an (+4%/an). La mise en place, par le gouvernement marocain, du « fonds de sauvegarde du cheptel » a permis d'apporter un soutien aux éleveurs, sous forme de subvention d'aliments pour bétail et de prise en charge des frais de transport, ce qui a encouragé le maintien d'un nombre important d'ovins durant les périodes de sécheresse.

**Tableau 1. 3:** Importance du cheptel par écosystème pastoral (moyenne 1979-2006)

| Système | Nombre de têtes ovines (x1000) | Nombre de têtes Caprines (x1000) |
|---|---|---|
| **ZA** | 653,8 | 618,0 |
| **POM** | 2209,6 | 717,0 |
| **ZS** | 64,3 | 82,3 |
| **MA** | 1781,9 | 182,5 |
| **PNA** | 1792,4 | 426,3 |
| **MPC** | 1439,6 | 181,0 |
| **RB** | 760,3 | 495,6 |
| **ZPS** | 1074,7 | 923,1 |
| **HAC** | 752,4 | 624,8 |
| **MC** | 2067,6 | 93,8 |

**MC :** Meseta Côtière **MPC :** Zone de la Mamora et Plateau Central **RB:** Zone Rifaine et ses Bordures **MA :** Le Moyen Atlas **PNA :** Plateaux et Plaines Nord Atlasiques **HAC :** Zone du Haut Atlas Central et Oriental **ZA :** Zone de l'Arganier **ZS :** Zone Saharienne **ZPS :** Zones Présahariennes **POM :** Plateaux de l'Oriental et Vallée de la Moulouya

**Données Sources:** Ministère de l'Agriculture, des Pêches Maritimes et du Développement Rural. (2007).

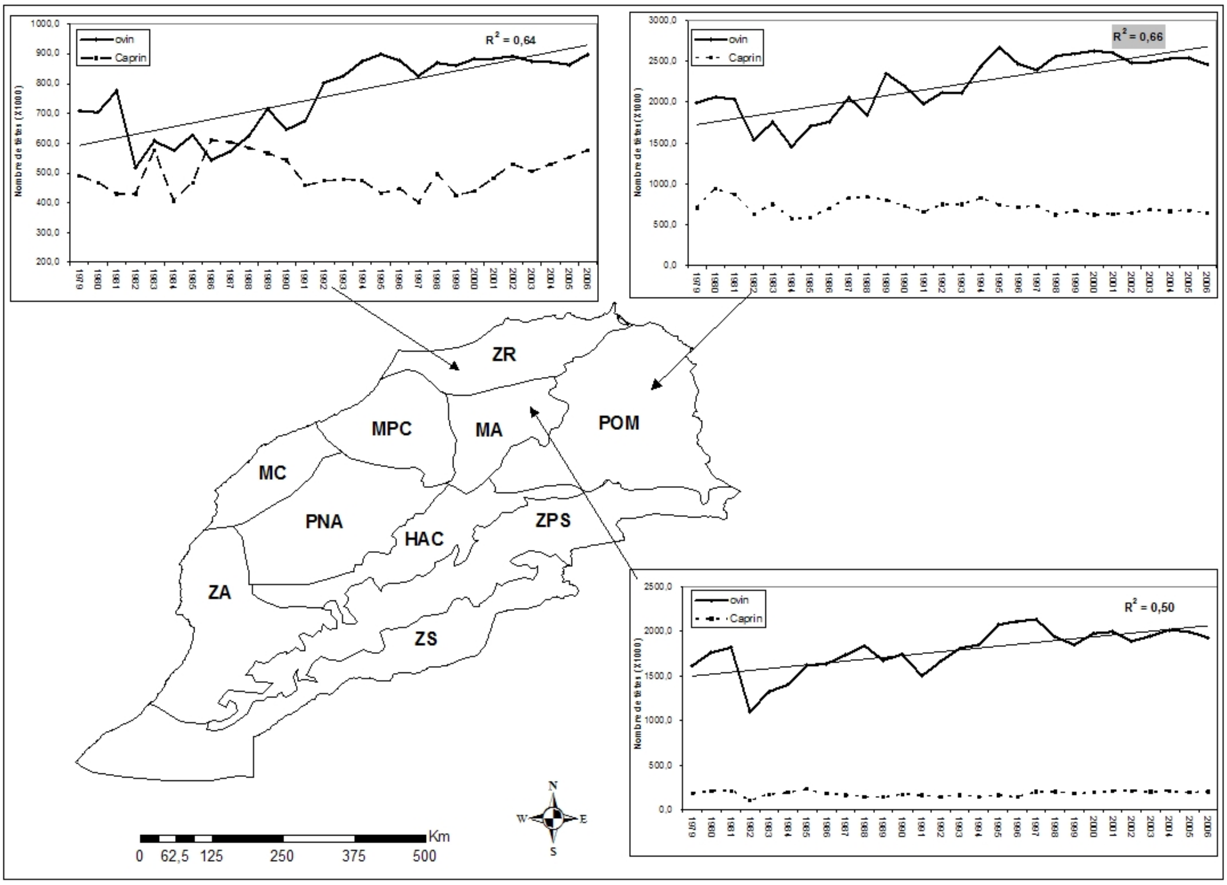


**Figure 1.3:** Evolution du cheptel ovin et caprin illustrée par trois zones pastorales (POM, RB et MA).

### 1.3.4 Surveillance de la désertification

L’absence de données précises sur le niveau global de dégradation des parcours arides et la contribution des différents facteurs rendent extrêmement difficiles la conception et la mise en application d’un système de lutte ou même le lancement d’actions préventives.

L’installation de stations de mesure des ressources pastorales au niveau de différentes zones est obligatoire pour permettre une surveillance efficiente à long terme. Cependant, les méthodes conventionnelles de surveillance de la désertification ne sont pas adaptées à l’échelle spatiale des parcours, qui couvrent d’immenses étendues et présentent des niveaux de désertifications très variables et fortes peu corrélés spatialement. En effet, les méthodes traditionnelles sont peu compatibles avec la vitesse de dégradation du milieu. Elles sont souvent longues à réaliser, compliquées à archiver et à diffuser, et leur mise à jour est toujours une opération lourde et très coûteuse.

La géomatique[7] peut permettre de réaliser un outil de surveillance continu de la désertification et d'offrir des informations pour concevoir des scénarios de lutte (Tueller, 1989). Cet outil doit se baser sur une série d'indicateurs spatiaux de dégradation du milieu issus d'une intégration pertinente de la télédétection spatiale combinée à de la biophysique de terrain, à l'agro-climatologie et aux informations socio-économiques dans un SIG.

La désertification étant un phénomène lent et graduel touchant de grands territoires, elle nécessite de longues séries d'images satellitaires de plusieurs dizaines de milliers de km². Les images à haute résolution spatiale sont limitées par leur coût élevé surtout quand il faut traiter de grands espaces. En définitive, les images de moyenne résolution spatiale (250m x 250m de taille de pixel) peuvent constituer un compromis intéressant en association avec les images satellitaires à haute résolution spatiale en des endroits ciblés du territoire à surveiller (Escadafal, 2007).

Le système de surveillance pourra être amélioré par l'intégration des données agro-climatiques, obtenues à partir d'un réseau de stations climatiques. A défaut de stations d'observation au sol, des données dérivées de modèles météorologiques peuvent être utilisées, comme celles issues du centre européen de prévision météorologique à moyenne échelle qui a de nouveau analysé toutes les observations météorologiques des 40 dernières années et les a rendues sous forme de grilles d'un demi degré. Enfin, des informations socio-économiques, notamment celles sur la population et le cheptel, viendront renforcer l'outil de suivi spatial en renseignant dans chaque zone pastorale sur les sources possibles de dégradation du milieu.

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[7] L'ensemble des outils et méthodes permettant de représenter, d'analyser et d'intégrer des données géographiques

### 1.4 Conclusion

Les terres de parcours aride du Maroc s'étendent sur dix zones pastorales, soit une superficie dépassant 33 millions d'hectares. Ces zones contribuent à la subsistance de milliers de ruraux à faibles revenus et protègent le pays contre la désertification. L'évaluation de la désertification dans ces zones été approchée par des vues générales, par des opinions d'experts, ou par des documents officiels qui ont traité les causes, les conséquences et le processus impliqués dans le phénomène, mais en raison des problèmes méthodologiques, l'évaluation de la désertification demeure controversée. Le manque d'études d'inventaires scientifiquement robuste sur la désertification n'a pas encore rendu possible l'obtention d'une image claire de l'état de dégradation de ces terres.

Le Maroc est amené à rechercher une méthode de surveillance basée sur l'information issue de la télédétection spatiale, de données biophysiques et socio-économiques pour le développement d'une base de données et d'indicateurs de désertification.

Un tel outil est réalisable actuellement au Maroc et il pourrait constituer une aide précieuse à la lutte contre la désertification des terres de parcours du pays.

# II. Part 2: Drought risk assessment in pasture arid Morocco through Remote Sensing

Published in African Journal of Environmental Science and Techonology, 2010, 4 (12): 845-852

## Abstract

During the last three decades, Morocco has experienced several stern and extended episodes of drought that severely affected pasture production. To cope with this phenomenon, the policy makers have put emphasis on a reactive short term management approach rather than on pro-active risk-based management measures. The purpose of this study is the assessment of drought by remote sensing, which is an important step in the design and implementation of drought management plan. To reach this objective we used bi-weekly TERRA Moderate Resolution Imaging Spectroradiometer (MODIS 250 m) data in arid pasture of Morocco. A Preliminary mapping by using Landsat TM5 of major land cover types was carried out to extract the pasture area. A comparison of annual and seasonal Normalised Difference Vegetation Indices (NDVI), Vegetation Condition Index (VCI) and rainfall during the time period of 2000–2008 were carried out. Results showed that stronger relationship of NDVI with previous seasonal rainfall as compared to VCI indicating that NDVI variation is a good indicator of vegetation changes and consequently can give a better idea on drought conditions in the study area.

**Keywords:** Drought monitoring, Pasture area, vegetation indices,

## 2.1 Introduction

Drought is considered as most complex but least understood of all natural hazards, affecting more people than any other hazard. Drought can be defined as a period when the rainfall is low in regard to long-term average conditions. During the last decades, drought has become globally more frequent. In fact, the Fourth Assessment Report ("AR4") by the International Panel on Climate Change (IPCC, 2007) foresees a temperature rise globally in the range of 2 to 6 °C by 2100. For North Africa, including Morocco, there will be likely a reduction in rainfall. Moreover, precipitation decline, evaporation increase and vegetation degradation are making Moroccan lands more vulnerable to drought. The assessment of drought magnitude is necessary for effective drought mitigation efforts. Since the consequence of drought varies from a land cover type to another, mapping of this cover is often the primary source for determining the current vegetation types and it is used as a baseline for drought monitoring.

Due to repeated and widespread of drought impacts, more emphasis on drought risk management is needed. Development of drought monitoring system and management plan or policy will enforce the coping capacity of the country.

The impact of drought depends on its timing and duration, particularly in relation to growth stages of particular crops or plants and the tolerance of individual species or cultivars to drought. The use of remote sensing data presents a number of advantages when determining drought’s impact on vegetation. The information covers the whole of a territory and the repetition of images provides multi-temporal monitoring (Kogan, 2001).

There are many sensors on board of numerous satellites, which can be used to assist in the prediction of drought. The Moderate Resolution Imaging Spectroradiometer (MODIS) data are used for climate and environmental changes including drought monitoring and climate impact assessment at regional and global scales (Wan et al., 2004; Gao al., 2008).

In addition, vegetation indices obtained from satellite data allow areas affected by droughts to be identified (Kogan, 1995; Vicente-Serrano, 2007). The Normalized Difference Vegetation Index (NDVI) is the most common indicator that is sufficiently stable to permit meaningful comparisons of seasonal, inter-annual, and long-term variations of vegetation structure, phenology, and biophysical parameters (Tucker and Sellers, 1986). In other words, it has been documented that there is a direct correlation between NDVI and the amount of stress vegetation is experiencing (Schmidt et al., 2000; Wong, 2003). Also, the comparison between NDVI values and rainfall data shows dependence of the NDVI values on the sum of the amount of rainfall with a time lag (Schmidt et al., 2000; Rahimzadeh, 2008). However, several studies suggest that Vegetation Condition Index (VCI) captures rainfall dynamics better than the NDVI particularly in geographically non-homogeneous areas. In fact, VCI has been used for drought monitoring over India (Singh et al., 2002), southern Great Plains, USA (Wan *et al*., 2004), southeast Spain (Vogt *et al*., 2000) and Southwest Asia (Thenkabail et al., 2004). It was concluded from the above studies that VCI allows an assessment of spatial characteristics of drought, as well as its duration and severity and it is in good agreement with rainfall patterns (Rahimzadeh, 2008).

The Eastern part of Morocco is experiencing the driest periods in its recorded history. As it is not possible to prevent drought occurrence, its impacts can be mitigated through management methods and technologies.

The objectives of this study were to use Landsat data for mapping the pasture area in the Eastern part of Morocco, determine the relationships between MODIS Vegetation Indices and rainfall, and to evaluate the time lag between the occurrence of rainfall and vegetation response in this area.

## 2.2 Materials and methods

### 2.2.1 Study area

The study area is the rural district of Tancherfi in eastern part of Morocco which is located between 2 ° 15'-2 ° 42 'W and 34 ° 10'-34 ° 40' N. It covers an area of approximately 649 Km$^2$ (Figure 2.1). It is characterized by the predominance of mountains in the south and plains in the north. The climate is arid, dry in summer and cold in winter. The long-term annual average rainfall (1970-2007) is 242 mm and the annual average temperature is 17°C and ranges between -4°C in winter and 45°C in summer.

The main soil types that dominate this area are shallow with low fertility and water retention capacity. They vary from clay sandy loamy to rocky calcareous soils. Livestock grazing is the primary land use activity.

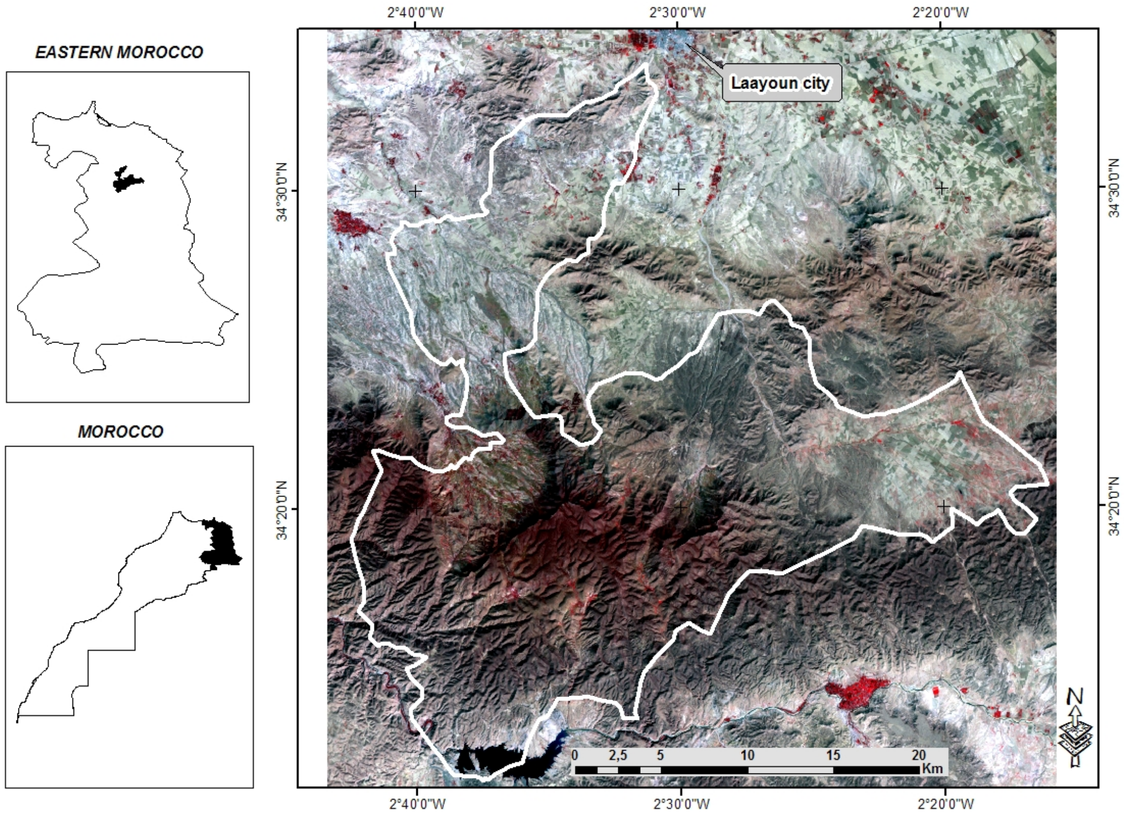

**Figure 2.1:** Landsat TM5 subscene of Tancherfi Commune

### 2.2.2 Methodology and data acquisition

In the first step of this study, Landsat imagery is used to develop a Tancherfi land cover map. A sub-scene of Landsat TM5 scene (30m) used was acquired on 13 March 2007 from path 199, row 36. This scene was acquired in UTM projection (WGS 84, zone 30N).

Field data were used as the training area for the Maximum Likelihood classification (Foody *et al*., 1992; Maselli *et al*., 1994). A set of 160 reference pixels were randomly selected and compared to ground truth data to determine the accuracy assessment (Congalton, 1991).

In the second step, the MODIS Normalized Difference Vegetation Index (NDVI) 16-day product (MOD13Q1; 250m; Version 5) (Huete *et al*., 2002) was used in this study. NDVI is based on the near infra-red channel (NIR), where the vegetation has an important reflectance, and the red channel (R), where the vegetation has a low reflectance. The formula for determining NDVI is: **NDVI = (NIR - R)/ (NIR + R)** (Rouse *et al*., 1974; Tucker, 1979**)**.

The time series starts on February 18th, 2000 and ends on April 5th, 2008. The MODIS data were re-projected from the Sinusoidal projection to the UTM projection (WGS 84, zone 30N). The mask of pasture area was produced within a GIS using the created land cover map and re-sampled to 250 m pixel. So, the dataset contained 187 Vegetation index observations per pixel for pasture area.

The VCI was used to estimate the climate impact on vegetation. It is defined as: **VCI = (NDVI - NDVImin)/ (NDVImax - NDVImin)** (Kogan, 1995), where NDVI, NDVImax, and NDVImin are the smoothed two weekly NDVI, multi-year maximum NDVI and multi-year minimum NDVI, respectively, for each grid cell. VCI varies from 0 to 1, corresponding to changes in vegetation conditions from extremely unfavorable to optimal.

In the third step, rainfall data were collected with 16-day rainfall values over a nine-year period (2000-2008) at ground station of Laayoun city located at a distance of 12 km from the study area (Figure 2.1).

Finally, statistical analyses were performed using one- way ANOVA and the mean comparisons were made using the least significant difference (LSD) method with $p<0.05$. In order to study the statistical relationships between rainfall and NDVI or VCI, Pearson correlation analysis and partition method were performed.

## 2.3 Results and discussion

### 2.3.1 Land cover

Figure 2.2 presents the land cover map of Tancherfi for the year 2007. The map depicts five land cover types corresponding, respectively, to forest (44%), pasture (30%), cropland (24%), water (1%) and others (1%) (Table 2.1). The analysis on drought monitoring focuses on the pasture area.

Field data shows that the main vegetation species of pasture area are *Stipa tenacissima, Artemisia herba-alba, Anabasis aphylla and Noaea mucronata*. Vegetation cover is less than 15% and it is in an advanced degradation stage. Estimates indicate that the overall accuracy of the classification is 81%.

**Table 2.1:** Land cover types and their relative spatial importance in Tancherfi

| Land cover | Area (ha) | Area (%) |
|---|---|---|
| **Forest** | 30271 | 44 |
| **Cropland** | 20449 | 30 |
| **Pasture area** | 16735 | 24 |
| **Water bodies** | 458 | 1 |
| **Others** | 684 | 1 |
| **Total** | **68597** | **100** |

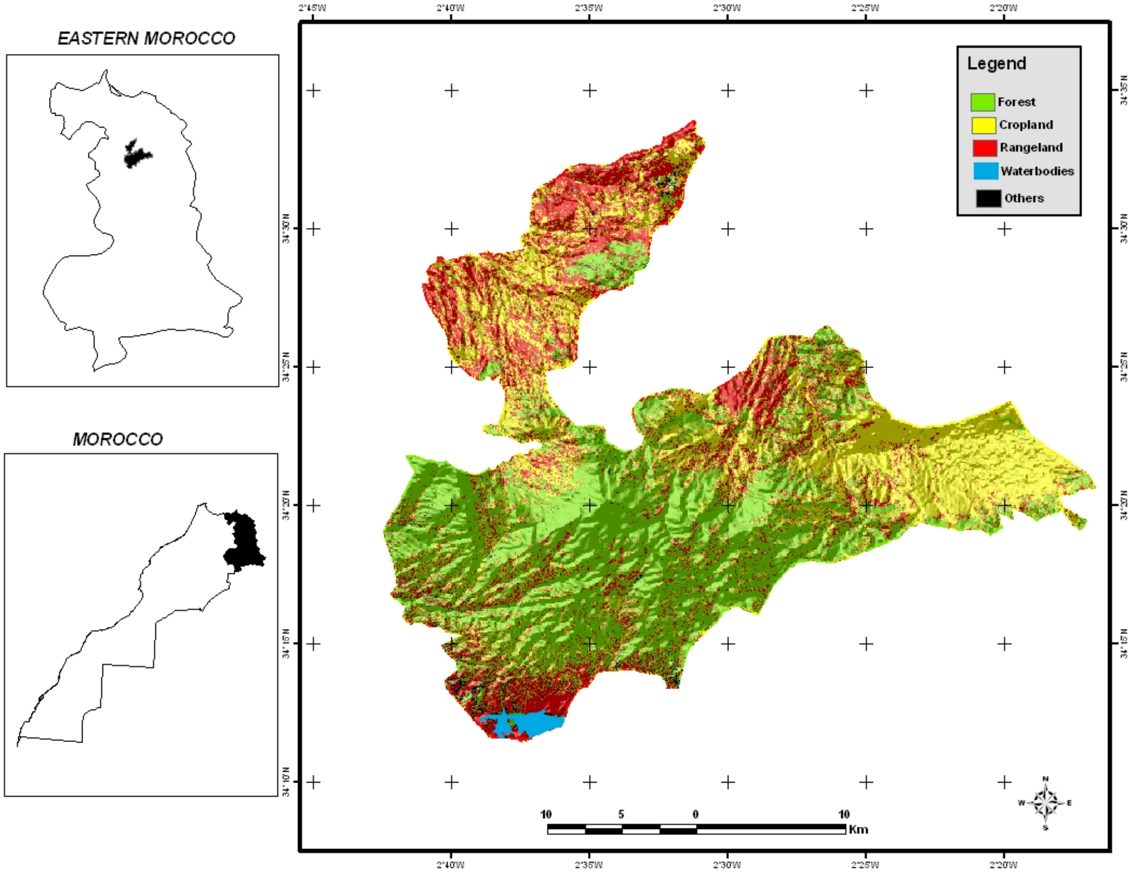

**Figure 2.2:** Land cover of Tancherfi Commune

### 2.3.2 Trends in vegetation indices and annual rainfall

Figure 2.3 shows the annual variations of NDVI, VCI and rainfall. Values vary from 0.19 to 0.24, from 0.41 to 0.48 and from 127.60 to 334.40 mm for NDVI, VCI and rainfall, respectively. In general, observed NDVI values were relatively low as compared to other regions (Balaghi, 2007), indicating a weak vegetation cover in this zone. A good agreement was observed between the peak values of NDVI and rainfall values.

A significant difference ($p<0.05$) was observed among years for both indices. However, for rainfall, there was no significant year effect and this was due mainly to the high intra-annual variability of rainfall (CV = 76 %).

LSD test revealed one group of years with NDVI values varying between 0.17 and 0.34 (Mean = 0.24; CV = 21 %) and it was composed of years 2002-03, 2003. During these years, NDVI response to rainfall showed better vegetation cover as compared with other years. This was confirmed by the important rainfall recorded during the vegetation growth cycle (Figure 2.3).

The NDVI values of the second group ranged from 0.15 to 0.30 (Mean = 0.20; CV = 16 %) and included the remaining years. Although, the rainfall recorded during 2001-02 was higher than the average (242 mm), the NDVI value of that year was less than or equal to those of the other years, because a significant amount of rainfall was received late in the season, and hence did not have any effect on the vegetative cover. By contrast, 2004-05 is considered as a dry year due to the fact that the rainfall recorded was low. However, NDVI value was equal to that of the normal years because the rainfall distribution was good. This shows the dominant impact of rainfall distribution on vegetation response to drought.

The highest and lowest VCI values were recorded in 2002-03 and 2006-07, respectively. As seen in figure 2.3, the lowest rainfalls coincided with the lowest VCI values indicating a relatively good agreement between minimum VCI and minimum rainfall. However, the irregular distribution of the high rainfall of 2006-07 caused a low VCI.

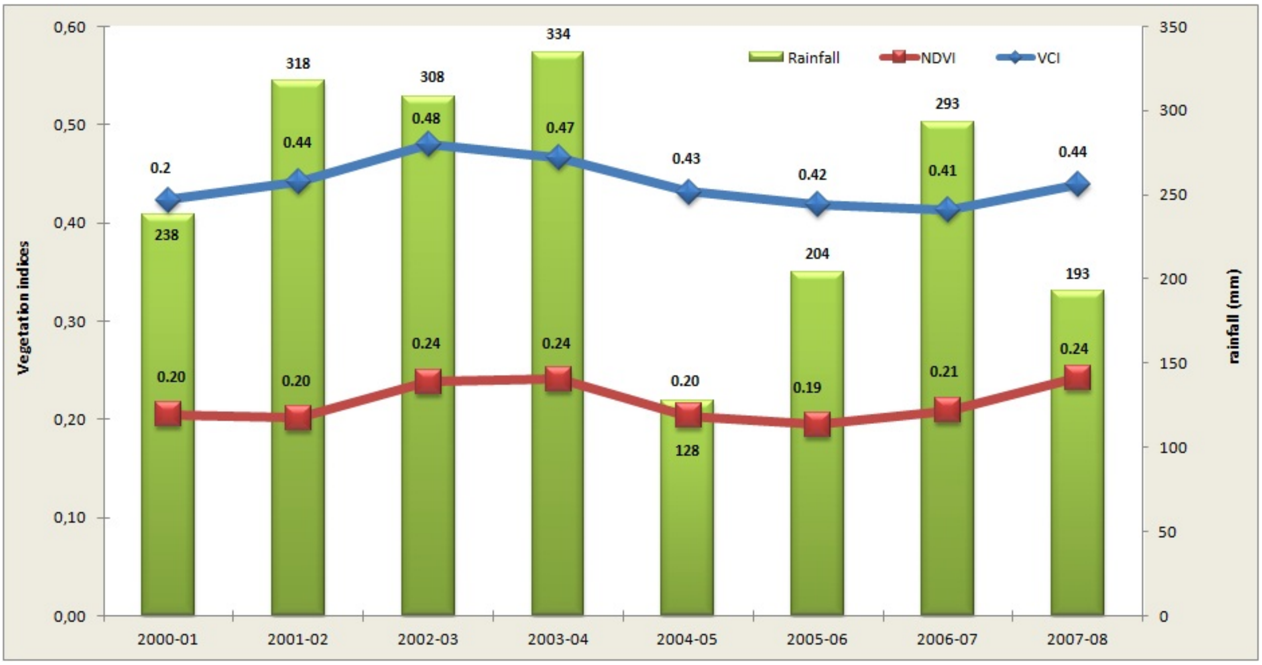

**Figure 2.3:** Average NDVI, VCI and annual rainfall profiles at Tancherfi pasture area

### 2.3.3 Seasonal rainfall, NDVI and VCI variation

The seasonal NDVI, VCI and rainfall varied from 0.15 to 0.31 (NDVI average = 0.21; CV = 19 %), 0.36 to 0.54 (VCI average = 0.44; CV= 8 %) and 2 to 171 mm (rainfall average = 64 mm; CV = 76%), respectively. The analysis of variance of these indices showed significant ($P < 0.05$) differences among seasons (Table 2.2).

The LSD test showed that NDVI observed in winter (December, January and February) and spring (March, April and May) were higher and significantly different than those observed in autumn (September, October and November) and summer (June, July and August). However, this test on rainfall showed one group with high values composed of autumn, winter and spring and another group with low represented by summer only. Moreover, the analysis showed a significant difference in the temporal rainfall distribution among the seven years. The highest NDVI values were observed when the rainfall was better distributed throughout the year and, in fact, there was no well-defined break between autumn, winter and spring rainy seasons (case of 2002-03, 2003-04). The average NDVI was obtained when a significant rainfall was registered during winter and spring (case of 2001-02). Also, a small quantity of well-distributed rains generated a normal NDVI (2004-05). However, the lowest NDVI values were registered when an important rainfall was recorded during autumn, a little rainfall was obtained during winter and spring was dry (2000-01).

An interesting observation concerning the rainfall distribution was that precipitation of spring or summer did not have any effect on vegetation. In fact, there is a tendency to have lower NDVI values in late spring even though high rainfall was recorded at that time. However, a better agreement was noticed between the rainfall season and NDVI values.

It is worth noticing from table 2.2 that the highest seasonal variation in rainfall occurs in summer followed by spring. However, the largest CV in vegetation indices corresponds to spring and the lowest to autumn.

LSD analysis of VCI indicated high values corresponding to spring and summer and a normal VCI values corresponding to autumn and winter. This result is opposite to the actual situation observed on the ground because during summer there is very little vegetation in comparison to autumn or winter. Despite that many authors suggest that VCI captures rainfall dynamics better than the NDVI in non-homogeneous areas (Singh et al., 2002; Vogt et al., 2000; Kogan et al., 2004), our study showed that VCI appeared to be less sensitive to detect the variation among seasons. In this study area, more vegetation was recorded in autumn than in summer. However, data on VCI showed opposite trends

The peak of VCI was registered after April. The values of this index were more or less in agreement with previous rainfall. For example, during 2002-03 and 2003-04, the lowest VCI values were observed from September to March; but the highest were registered in April.

The general lack of agreement between VCI values and rainfall data clearly showed that the maximum and minimum NDVI values used to determine the VCI at local scale were not influenced by the weather condition but by other factors.

While rainfall is the dominant factor that controls plant growth in arid pasture land, its distribution during the plant growing cycle is at least as important as the amount received. In Tancherfi region, plant growth is dependent on both amount and three periods of occurrence, namely October-November, December-January and Mars-April. A wet year is considered as the one where rainfall occurs in each of these three periods. A normal year is characterized by rainfall occurring in two of these periods, while a dry year has rainfall occurrence in only one period.

**Table 2.2:** Seasonal NDVI, VCI, rainfall values and their variation coefficients at Tancherfi pasture area.

| | **NDVI** | | **VCI** | | **Rainfall** | |
|---|---|---|---|---|---|---|
| | Value | CV (%) | Value | CV (%) | Value (mm) | **CV (%)** |
| **Winter** | 0.24 a | 10.27 | 0.44 ab | 6.66 | 65.13 a | 41.22 |
| **Spring** | 0.24 a | 18.54 | 0.46 a | 9.65 | 80.13 a | 77.91 |
| **Autumn** | 0.19 b | 8.43 | 0.41 b | 5.75 | 91.38 a | 45.57 |
| **Summer** | 0.18 b | 10.40 | 0.45 a | 5.88 | 17.50 b | 99.96 |

Levels not connected by same letter are significantly different

### 2.3.4 NDVI-Rainfall and VCI-Rainfall relationships as indicators of drought in pasture area.

The relation between the vegetation indices and rainfall was used by several authors to monitor vegetation cover **(**Evans and Geerken, 2004**).** Indeed, Davenport *et al*., (1993) and Wong *et al*., (2003) showed a high correlation between NDVI and rainfall. Liu and Kogan (1996) found that the NDVI was highly correlated with water deficit and rainfall for Cerrado (Savanna grassland) and Caatinga (woodland and open woodland) which both grow in areas with distinct wet-dry seasons. Also, Wang and al. (2004); Vogt *et al*., (2000) and Thenkabail *et al*., (2004) showed high correlation between VCI and rainfall.

As presented above, NDVI showed a positive response to previous rainfall, except after April when the vegetation is not responsive to a significant rainfall. In fact, the determining factor of biomass production in Morocco is rainfall that occurs before May. Figure 2.4 presents average season NDVI, VCI and previous total season rainfall (winter, autumn and Spring). This figure clearly shows that vegetation was responsive to previous season rainfall. The highest and lowest average NDVI values corresponded to the highest and lowest previous season rainfall, respectively. However, in our study, average season VCI presents a relatively positive response to previous season rainfall.

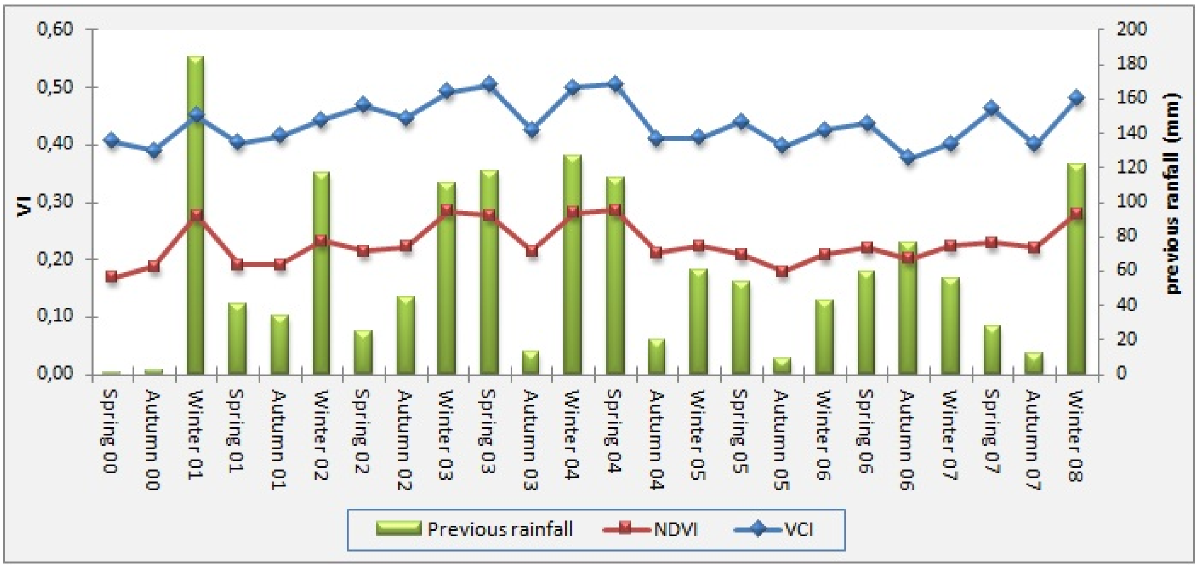

**Figure 2.4:** Average NDVI and VCI and previous sum season rainfall (winter, autumn and spring) in Tancherfi rangeland area from 2000 to 2008.

### 2.3.5 Correlations and partition analysis

In order to study the relationships between various time lag periods and NDVI or VCI, Pearson correlation analysis and partition method were performed.

The partition (recursive partitioning) is a mining process for extracting information from large amounts of data. The partition divides data using NDVI and VCI to find previous rainfall values that are close to each other.

Coefficients of correlation were determined using, on one hand, the average NDVI and VCI, and on the other hand the sum of previous-season rainfall for winter, autumn and spring.

The results (Figure 2.5) show significant correlation of either NDVI (r= 0.72**) or VCI (r=0.42*) with past season rainfall[8]. The stronger relationship of NDVI with seasonal rainfall as compared to VCI indicates that NDVI variations can be a good indicator of vegetation changes and consequently of drought conditions in the study area.

Furthermore, vegetation status-based indices can be useful tools to assess drought occurrence in a region. The partition for previous season rainfall of NDVI values lower than 0.2 are indicative of drought occurrence in a region. However, previous season rainfall of 47 mm generates a normal NDVI value (between 0.2 and 0.28) and previous season rainfall corresponding to 129 mm produces NDVI value higher than 0.28, indicative of a wet year.

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[8] Correlation between Vegetation Indices (NDVI, VCI) and monthly or bimonthly previous rainfall is not significant.

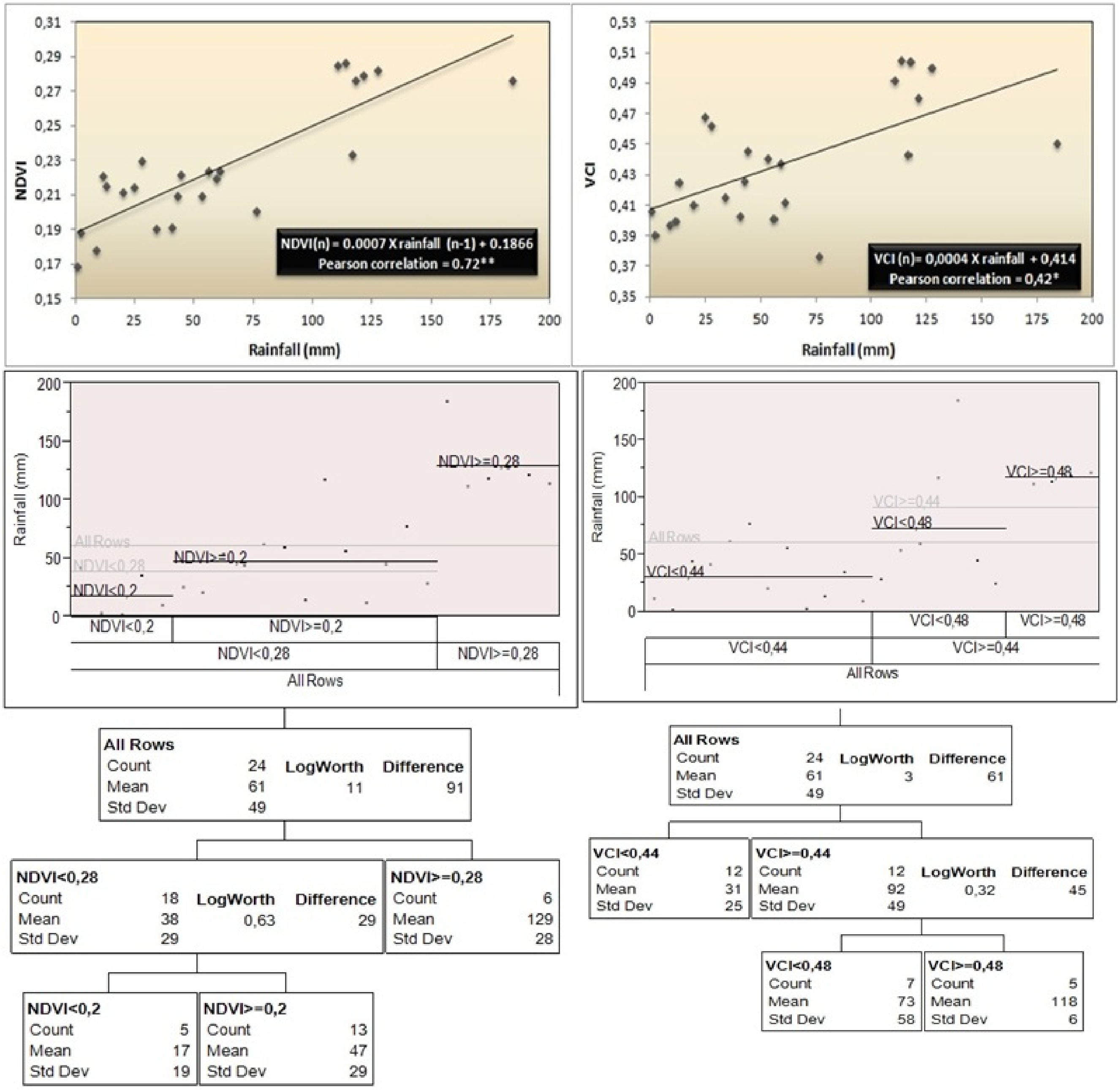

**Figure 2.5:** Correlation and partition between NDVI, VCI and previous season rainfall (winter, autumn and spring) in Tancherfi pasture area.

From this study we can conclude that vegetation status-based indices can be useful tools to assess drought occurrence in the study region. NDVI values lower than 0.2 are indicative of drought occurrence. Values between 0.2 and 0.28 indicate average year and higher than 0.28 correspond to a good year. Moreover, significant correlations were found between NDVI and rainfall data at Laayoun station. Therefore, NDVI can be used for monitoring and mapping drought conditions in the study area. However, in order to obtain more reliable results there is a need for wider time span of satellite data. VCI values from the existing data in this area proved to be less reliable.

# III. Part 3: A knowledge-based approach for mapping degradation in North Africa arid rangelands

Submitted to Land degradation & development

## Abstract

Rangelands cover about 82% of the arid lands of Morocco. It is largely recognized that these areas are threatened by desertification. Controlling desertification requires an accurate knowledge on the current rangeland degradation status. Remote sensing is widely used to assess changes in land cover, but it is difficult to produce accurate maps showing degradation in arid rangelands due to the spectral confusion between different land cover types. The objective of this study was to assess the spatial extent and the severity of rangeland degradation in the high plateaus of eastern Morocco, based on remote sensing combined with ancillary data, through a knowledge-based approach. This latter relies on the contribution of various datasets derived from Landsat TM satellite imagery, field investigations, lithology and phytogeographic data. The different levels of rangeland degradation were assessed using indicators, such as vegetation parameters, grazing levels and the intensity of rangeland cultivation. This approach provides a high level of accuracy for mapping and monitoring arid rangeland degradation. Results showed that total degraded rangelands in the high plateaus of eastern Morocco amounts to about 17,000 km², accounting for 47% in the studied area.

**Keywords:** Arid steppes, desertification, remote sensing, phytogeography, lithology, indicators.

# IV. Part 4: Spectral behavior of Alfa grass (Stipa tenacissima) species based on ground hyperspectral data.

To be submitted

## Abstract

The Alfa grass (*Stipa tenacissima*) steppes constitute one of the most important vegetation types in the arid and semiarid areas of the Mediterranean Basin. They have suffered from severe degradation. An efficient and reliable assessment of the area extent of Alfa grass steppes is necessary for the monitoring of rangeland degradation. This study explores the spectral behavior Alfa grass tussock at various degradation levels of Alfa grass steppes in the high plateaus of eastern Morocco, based on field hyperspectral data.

Field hyperspectral data of three states of tussocks were collected within three degradation levels of Alfa grass steppes with ASD spectroradiometer (350 – 2500 nm) during fall and spring seasons in the high plateaus of eastern Morocco. In addition, digital images of Alfa grass tussocks were taken with a digital camera to classify Alfa grass tussocks according to their proportion in green leaves (green, mixed and dry tussock). Paired t-test, Normalized Difference Spectral Reflectance (NDSR) and Stepwise Discriminate Analysis were carried out to discriminate between tussock status and among various Alfa grass steppes. The results indicate that Alfa grass had shown an intraspecific variability in reflectance spectra. The proportion of green leaves in Alfa grass tussock strongly influences the spectral response. The discrimination of different Alfa grass tussock status was better during fall than spring.

**Keywords:** Stipa tenacissima, field spectra, degradation, reflectance, intraspecific variability.

# 5. General conclusion

Rangelands are an extensive but critical resource. They play an important role in the global environmental issues of today and they are equally as deserving of international attention. Rangeland degradation is not only linked to environmental degradation, inappropriate land use and loss of biodiversity but become also closely linked to food security, poverty reduction and lack of development.

In Morocco, loss in rangeland productivity greatly affects pastoralist's income and measures applied for protecting the land from further degradation and desertification. Rangeland degradation has also become linked with the long term droughts which have affected the vulnerability of Morocco rangelands. The economy of all North African rangelands, especially in Morocco, is affected by longer periods of drought that have resulted in a drop in GDP from agriculture. According to IPCC report the largest negative trends in annual precipitation since 1901 are observed over eastern Morocco while temperature has increased during the same period.

Monitoring and understanding changes in these rangelands are important for a rapid and effective intervention to maintain or improve the ecological, economic and social values. However, Monitoring data, in conjunction with other available information, should be converted into useful forms for decision makers.

This study is a contribution to a regional literature documenting rangelands of North Africa. Efficient and operational methodologies are presented, for monitoring drought and assessing rangelands degradation, at national and regional scales. These methodologies rely on available remote sensing, basic biophysical data and local knowledge expertise.

Rangelands or natural arid pastures of Morocco are defined as ecosystems where there is a natural or semi-natural vegetation composed of steppes, shrubs and grassland. The available information on several pilot areas shows that these rangelands are threatened by desertification. The leading causes of land degradation are the Human actions combined with climate. The conversion of rangelands to croplands plays a key role in desertification. The substitution of community organizations by the administration and elected officials have hindered the customary rules governing access to grazing areas in favor of rules based on private property. The main objective for the cultivation of rangelands is land appropriation by local communities, as currently rangelands are collectively owned. The progressive disappearance of traditional rangeland management generated the emergence of a situation of "tragedy of the commons" where a high competition on the pastoral resources is noted between the populations of the same ethnic group.

In Morocco, desertification can be exacerbated or triggered by climate variability. Drought is one of the most important factors affecting the vulnerability of North African rangelands. The relationships between MODIS NDVI and time lagged rainfall, has been studied for arid rangelands in Eastern Morocco. Results show that vegetation status-based indices can be useful to assess drought occurrence in arid rangelands of Morocco.

A knowledge-based approach for mapping degradation in North African arid rangelands has been proposed. The approach is original as it derives degradation levels of rangelands based on remote sensing, phytogeography data, lithological data, field indicators and expert-knowledge. It’s an approach that renews the famous phytogeography approach published by Le Houérou in 1989. The proposed knowledge-based approach led to greater classification accuracy, distinguishing between rangeland categories that would not have been discernible using only remote sensing data, such as that obtained from parametric classification. Major strengths of this approach are: it’s flexibility with regard to data sources, its potential application for different research questions, its ability to deal with interactions between land uses and perennial vegetation parameters and its ability to provide a visualization of rangeland status. Moreover, the study emphasized on field data for assessing ecological changes linked to the disturbances in rangelands. The field indicators are: the disappearance of high-quality rangeland, a change in vegetation composition, a loss of biodiversity and a decrease in perennial plant cover and annual biomass production. Specific species also provide indications of degradation: previously prevalent species such as *Stipa tenacissima* and *Artemisia herba-alba* tend to disappear and be replaced by invasive vegetation such as *Noaea mucronata*, *Atractylis seratuloides*, *Peganum harmala*, and *Anabasis aphylla*, as well as other species such as *Thymelea microphylla* that appear when sand accumulation becomes prominent. The degradation mapping of arid rangelands reveals that 17,000 km², accounting for 47% in the high plateaus, has undergone degradation to different extents. Many factors may have contributed to this rangeland degradation, but the most important ones are: overgrazing and changes in land use from rangelands to croplands. Although this approach was simple, it allowed identification of information gaps, like in particular, the absence of a soil map and the sparse network of meteorological stations. The knowledge-based approach highlighted a number of secondary findings. First, the extent of land degradation in the area is less than indicated in the “Globcover” map, due to the fact that certain area covered by perennial vegetation were considered as degraded in "Globcover". Second, the approach highlights that human activities are the primary agents for land degradation in the area.

The study also tested the usefulness of ground hyperspectral data for the assessment of Alfa grass (*Stipa tenacissima*) tussocks at various degradation levels of Alfa grass steppes. The spectral signature of different Alfa grass tussocks is low and dissimilar to the green vegetation. An intra-specific variability in reflectance was observed in this species. The proportion of green leaves in the tussocks has influenced the spectral response of different Alfa grass. The spectra curves of slight, moderate and severe degraded Alfa grass steppes were dissimilar due to the tussock status. Spectral reflectance response of different Alfa grass steppe is influenced by the season, amount of Alfa grass tussock status and the proportion of green leaves in the tussock. This behavior is problematic for the assessment of Alfa grass steppes by remote sensing. This excluded the use of any remote sensing green vegetation indices for monitoring Alfa grass steppes. Enhancing the hyperspectral methodology for combining soil, cover, self-shading of Alfa grass tussock in the future will greatly improve our ability to deal with the complexities that lie ahead of us.

The rangeland assessment methods that have been applied in the study area have attempted to fulfill the basic elements required for a more holistic assessment of arid rangeland. The approaches developed provide an important tool to assess the changes in arid and semi-arid rangelands. Modern tools such as remote sensing and GIS, and information from all sources (field data and geospatial databases) provide better information about rangeland status for decision making. The study has shown that very few information is available in the field of rangeland change and degradation in Morocco. Many information gaps, differences in the quality and coverage of data across the country and, unavailability of meteoological station are manifest. However, the study has been successful in assessing degradation despite these constraints. Methodologies and tools are proposed to policy-makers, rangeland managers and scientists, for monitoring arid rangelands degradation in Morocco and North Africa. The proposed approach and tools could constitute an important step towards building a Rangeland Monitoring System.

Future research could further improve the accuracy of the rangeland degradation classification by introducing other variables such as soil maps and local climate data when available. We also expect to assess the possibility of impacts under climate change and carbon balance on rangelands. If current efforts with this approach are able to demonstrate feasibility, the approach could be expanded to a national effort to monitor rangelands across Morocco. We still need to monitor the vegetation and soil, the movement of sand dunes, the increase of livestock, the extension of cultivated land, and the impact of drought.

Finally the implementation an education process focused on the users and stakeholders, aimed at making them actors in the development processes that overcome the rangeland desertification problems. Another challenge is to develop educational programs that build up the awareness of the society about rangeland desertification.

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