DETECTION OF CHANGE IN LAND SURFACE PROPERTIES USING SPACE-BORN IMAGES

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DETECTION OF CHANGE IN LAND SURFACE PROPERTIES USING SPACE-BORN IMAGES IN SEHOUL, MOROCCO

By

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ABSTRACT

In the area around Rabat in Morocco, land degradation and desertification are increasing problems for both environment and local communities. This study is part of the DESIRE project that aims to fill a lack of insight on these problems and to address these with policy makers to counter degradation and desertification. DESIRE selected the Sehoul plateau as research area, which is where this study was conducted.

In this research, the aim was to provide an overview of changes in land surface properties in the Sehoul using Landsat TM images. Selected hotspots of changes were analysed with field data in order get insight in the links between these changes and socio-economic and/or natural phenomena. Additionally, this analysis was upscaled for temporal trends, to detect underlying causes for a short term (with MODIS data) and a long term (precipitation data) period.

Also, the classification method used by DESIRE was validated to get insight in the possibilities of land cover classes for all DESIRE study sites. A reclassification was made in order to show which classes are interesting to add to enlarge the analytical value for the Sehoul site specifically.

The results indicated that three phenomena were predominant causes for change in Sehoul. First of all, a shift from traditional to modernized agriculture, resulting in compaction and thus increasing land degradation; secondly, demographic changes, increasing the pressure in and on Sehoul, resulting in for example overgrazing and decreasing forest condition; and thirdly, the seasonal variability of precipitation, which, in combination with current cultivation seasons, results in high erosion risks.

It was recommended that policy makers and researchers focus especially on the third issue, in follow-up studies and policies, adjusted to the changes that are ongoing in Sehoul.

ACKNOWLEDGEMENTS

I'm happy to take this opportunity to thank all people who helped and inspired me during my thesis. Foremost, I would like to express my gratitude to my supervisor, dr Eli Argaman, for his encouragement, support and knowledge from the start to the end. This thesis could not have been completed without his guidance, inspiring me to be ambitious.

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GLOSSARY

2CMV	Two Colour Multi-View
ETMz	Enhanced Thematic Mapper Plus, Landsat 7 satellite image
GIS	Geographical Information System
LST	Land Surface Temperature
LULC	Land use and land cover
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Landsat Multi-Spectral Scanner image
NDII	Normalized Difference Infrared Index
NDVI	Normalized Difference Vegetation Index
PCA	Principal component analysis
RGB	Red, green and blue colour composite
SLM	Sustainable Land Management
TC	Tasselled Cap
TM	Thematic Mapper

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I. INTRODUCTION

The main focus of this research lies on the ***"Detection of change in land surface properties using space-born images"*** and the study area is situated on the Sehoul plateau, which lies east of the capital city Rabat in Morocco. Here, land degradation and desertification are increasing problems for both the environment and local communities. Part of the explanation for the cause for this degradation can be found in the expansion of, and urbanisation around Rabat, causing pressure on the surrounding agricultural and forested areas. Although some insight exists in the degradation processes and the socio-economic changes occurring in this region, policies are not addressing these. In order to fill the knowledge gaps and lack of insight on the problems and to address these with policy makers, here and in similar areas elsewhere in the world, the DESIRE project aims to work on interventions, policies and conservation measures to counter degradation and desertification.

In Sehoul, in order to tackle these problems efficiently, a clear overview where these degradation processes are predominant is needed to get insight in the linkages that exist between degradation features and socio-economic or natural phenomena (for instance urbanization and climate change). This thesis aims to provide such an overview by making a temporal assessment using the change detection to research the development of the occurring processes.

Thus, by taking into account that this research is part of the DESIRE project and therefore follows the goal of the desire project to *'protect the environment from land degradation and desertification'*, it is, by detecting land surface properties and gaining insight on the (physical) causes of occurring changes, part of the ambition to address these causes by introducing and changing policies to prevent further degradation and desertification, not alone in this area, but also in other DESIRE sites.

II. STUDY AREA

II.I Geography

The Sehoul plateau, the area in which this research was conducted, is situated about 25km (south-) east of Morocco's capital city Rabat. The study area covers approximately 397km^2 and has the highway from Rabat to Fes as its Northern and the Bou Grou River as its Southern border. In addition, the Bou Regreg River and the artificial lake Sidi Mohammed Ben Abdellah are the most important features of the plateau (Chair UNESCO-GN).

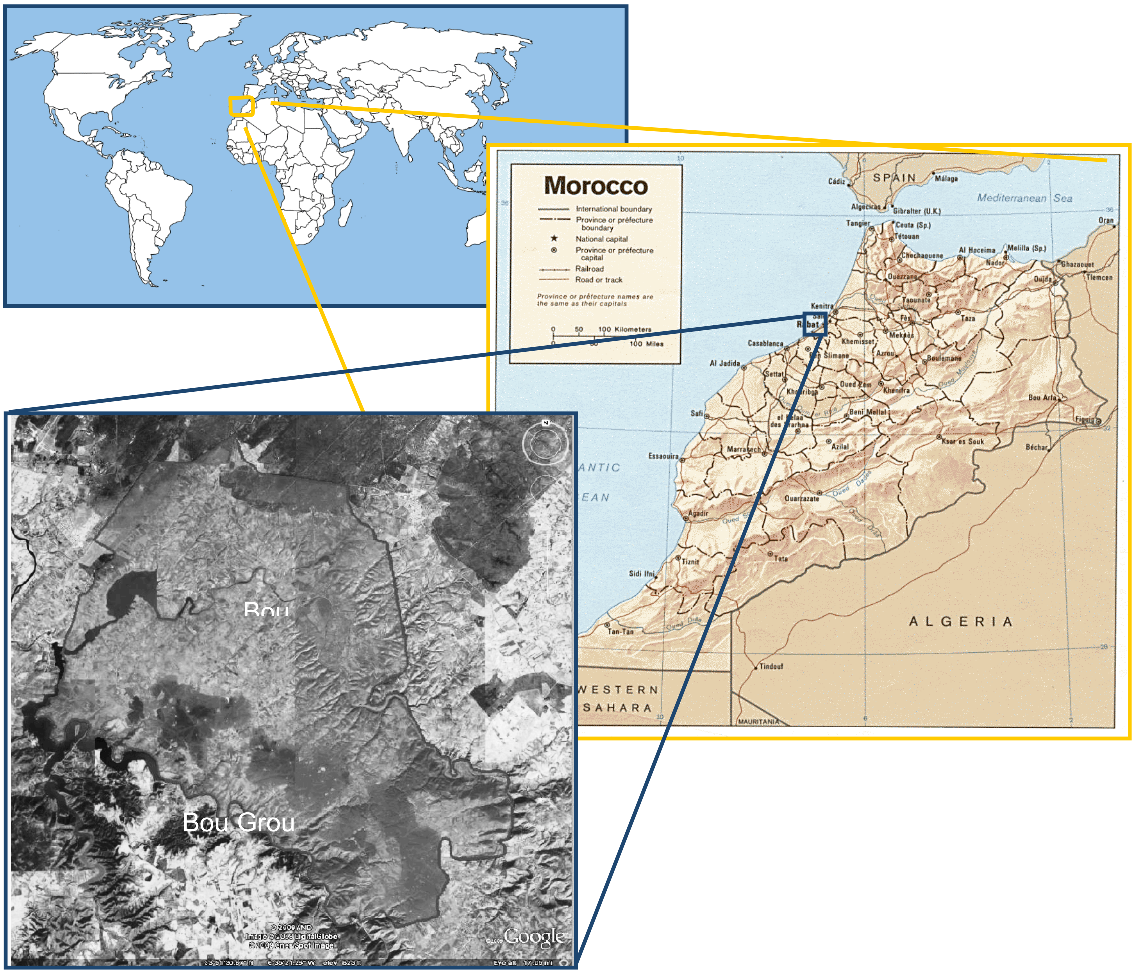


Figure 1 a. World Map [Online] Updated 2010-02-10 Available at Wikipedia Commons website; Accessed: 2010-02-10; b. Map Morocco [Online] Available at Africa UPENN website, CIA Maps; accessed: 2010-02-10; c. Sehoul Study Area - based on Google Earth Updated: 2009; Accessed 2009-09-12

II.II Geology

As can be seen in figure 2, the plateaus' relief is clearly formed by the incised river crossing the area. Up from the river, different layers of terraces can be found.

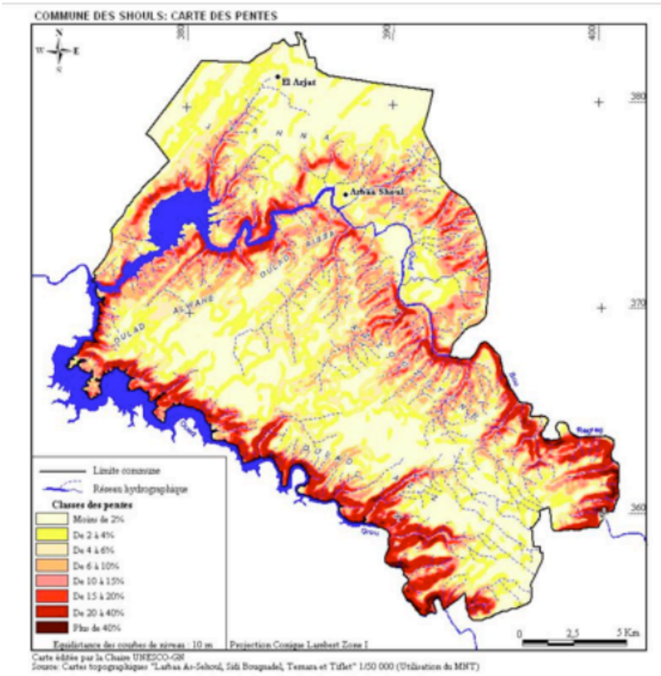


Figure 2 Elevation Map, Sehoul, Morocco (Chair UNESCO-GN)

Two water tables are found in the subsurface of Sehoul. The first goes through the sand-rich soils of the Pliocene and old alluvial terraces, as the lower part of these Pleistocene dunes are rich in clay and infiltration is difficult. The second can be found on top of the Palaeozoic bedrock, in the Miocene Mollasse (figure 3)(pers. comm. Prof Miloud Chaker, 30 Oct. 2009; Chair UNESCO-GN).

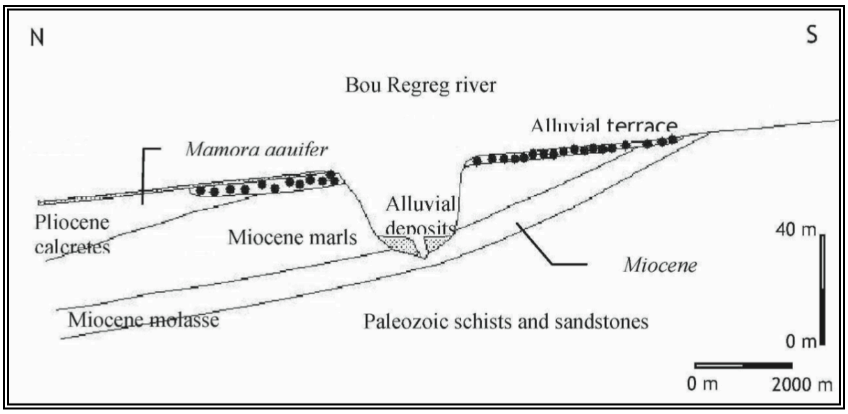


Figure 3 Geological cross-section through Sehoul region and groundwater systems (italic) (van Dijck et al 2003)

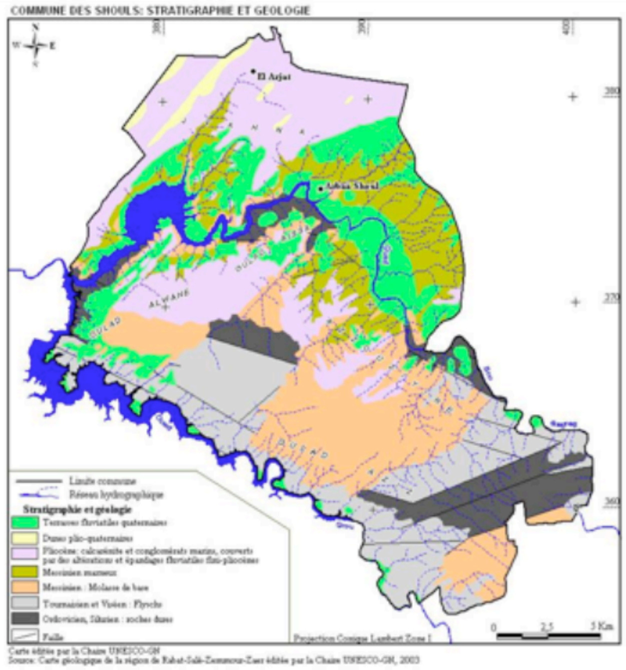


Figure 4 Geological Map of Sehoul, Morocco (Chair UNESCO-GN) [legend translation in Annex 1]

In the northern part of Sehoul consists of a humic topsoil that originates from Holocene times. Underneath lies a sandy, leached soil that was removed during the 22000-18000y BP but deposited again during Holocene (11000 BP). It originated from deeply weathered Pliocene and Pleistocene calcarenites (5.3mln-1.6mln; 1,6mln-11000 BP). The latter can still be found in northern Sehoul and just south of the Bou Regreg River (shown in lilac, figure 4). Underneath this second layer, the old Pleistocene dunes, which are not weathered, can be found. In central Sehoul, around the Bou Regreg River, fluvial terraces (green) lie on top of a layer with sandstone with pebbles, on top of a layer of marls, on top of a layer of molasses, on top of the bedrock. Although at certain places, the marls form the upper layer, due to erosion of the overlying material (olive green).

In the southern part of the Sehoul study area we find Messinian sandstone (6.5-5.3mln BP; orange), but also much more older geological layers as flysch (grey) from the Tournaisian (360-352mln BP) and Visean (352-333mln BP) and hard rock material (dark grey) from the Ordovician (490-440mln BP) and Silurian (440-410mln BP) (pers. comm. Prof Miloud Chaker, 30 Oct. 2009; Chair UNESCO-GN; Morris, 2010-03-25).

II.III Soils

Dominant soil types found in the Sehoul area are fluvisols, found in figure 5 in a light shade of green as river terraces on the northern shore of the Bou Regreg River and in pink in the valley between the Bou Regreg River and the Bou Grou River where Plio-quarternary fluvisols are overlain by fersiallitique leached stony soils. Both are used for crop cultivation, grazing land and, especially on the alluvial terraces, for tree crops.

Furthermore, isohumic, Holocene soils are found both on top of the sandy formations of the Mamora forest (dark green) and along the Bou Regreg River (olive green). These are rather deep, brown soils with a relatively coarse texture, and especially suitable for cereal production. The main problem here, as with the calci-magnetic soils (yellow) that are found on the marl slopes north of the Bou Regreg River, is the formation of calcareous crusts. In this case, these soils should better be used as grazing land (Mtimet, 2001; FAO, 2001; Chair UNESCO-GN).

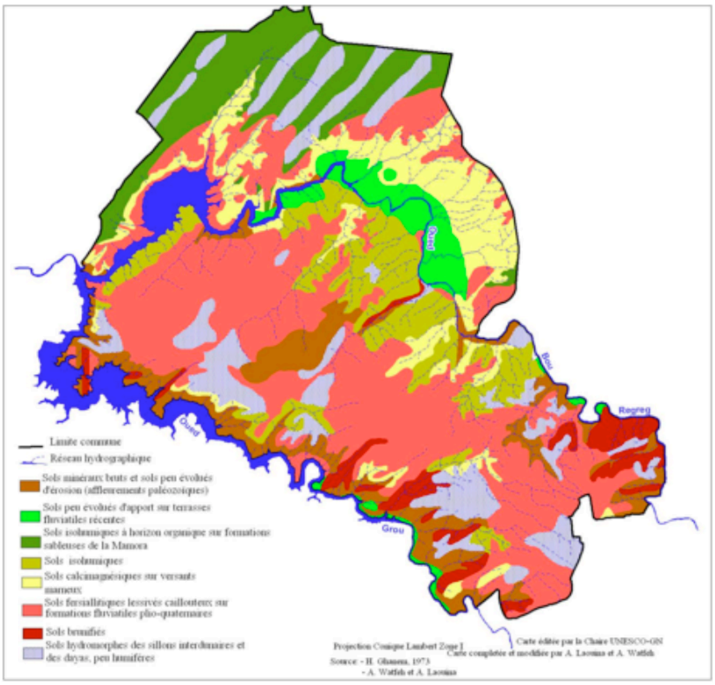


Figure 5 Soil Map of Sehoul, Morocco (Chair UNESCO-GN) [legend translation in Annex 1]

II.IV Climate

The Sehoul plateau is situated just east, inland, of Morocco's capital city Rabat, on the West coast of Morocco. This area has a semi-arid Mediterranean climate with an average annual precipitation of about 500 mm, spread over rainy winters and warm, dry summers. Figure 8 shows the monthly average temperatures. Precipitation patterns are thoroughly discussed in chapter 10.

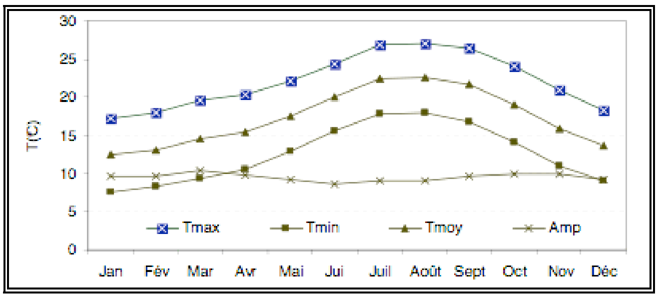


Figure 6 Monthly averages in temperature, Rabat-Salé (1970-2003) (Antari, 2007)

II.V Vegetation and land use

The Sehoul plateau is mainly a flat area with incised valleys and can be divided in three regions on the basis of the dominant land use form (Laouina et al., 2007a):

1. (Cork Oak) forests
2. Agriculture and grazing land
3. Deep streams

Forests can be found either in the form of natural cork oak forest or in plantations of Eucalyptus or pine trees. Agricultural land rotates its use between years of cultivation and years of restoration and pastoral land. Cultivated crops are dominantly grains and maize, but fruit trees, vegetables and vineyards are also found. The pastures are grazed by cattle, sheep, goats and mules. Apart from these dominant forms, other land use types can be found: natural bushes and shrubs; home gardens; urban areas and bare land, the latter which is mostly found along the river banks.

These river banks are often heavily eroded, covered by rills and gullies caused by the combination of steep slopes and an absence in vegetation (mainly because of overgrazing). On shores with somewhat more vegetation in the small formation of shrubs and bushes, the amounts of rills decreased but small landslides, slums, are found instead.

II.VI Degradation and desertification

Sehoul receives about 500 mm precipitation per year. This is, however, not equally distributed over the year but occurs in high peaks especially during autumn, causing floods that result in high amounts of sediment (Laouina et al., 2007a).

Based on numbers from the UN Convention of Climate Change in 2001, van Dijck et al (2006) predict that the Moroccan climate will follow the global trend of climatic changes. They predict an increase in annual temperature between 0.6-1.1°C, but with a decrease in annual precipitation of 4%. Hulme et al. (2001) found a similar pattern in their long-term climate analysis of Africa between 1900-2100. For Morocco, they predicted an average annual temperature rise between 0.5-1.0°C and changes in precipitation of ± 10%.

Although this has its impacts mainly on the available water sources, both literature and field experts emphasize that in Morocco the main causes for land degradation are not linked to climatic change but can be related to anthropogenic activities (pers. comm. Prof. M. Chaker, 30 Oct. 2009; Mikesell, 1960; Puigdefábregas & Mendizabal, 1998; Hulme et al, 2001; Dimanche & Hoogmoed, 2002; van Dijck et al, 2006; Ouassou et al, 2006).

Deforestation is one of the negative effects of these anthropogenic activities. According to Ouassou (2006), forest decline of Moroccan forests happens with a rate of 31.000ha per year, of which

22.000ha can be contributed to fuel wood harvesting. In these numbers, overgrazing was not even taken into account, as this mainly limits the regeneration of the forest. It was estimated that in the whole Maghreb only 6% of the natural forest compared to 50 years ago remains. Main causes for deforestation in Morocco are: 1) overgrazing by livestock, mainly large flocks of sheep and goat; and 2) external pressure by humans, e.g. population growth, urbanization and an increasing complexity of landownership. These phenomena have an increasing effect on a) the domestic and industrial consumption of wood, and b) the burning or cutting of forest to clear it for agricultural land, although the latter became less significant as between 1920-1930 the forest limits became fixed (Mikesell, 1960; van Dijck et al. 2006).

The effect of this deforestation, especially because of overgrazing, is the expansion of shrub formations of xerophytes, replacing the natural Cork Oak (*Quercus suber*) forest. The two most dominating shrub species are the Palmetto shrub (*Chamaerops humilis*) and the Camel thorn (*Zizyphus lotus*), although the latter, with its thorns, can also be of protection to Cork Oak seedlings (Mikesell, 1960).

A second negative effect of the anthropogenic activities in Morocco lies in the degradation of cultivated land. Land degradation in Morocco consists mainly of salinization, as result of an increase in irrigated land, wind erosion due to the removal of vegetation, and soil erosion and silting of dammed lakes, as results of increased runoff due to crust formation and soil compaction, caused by on-going bad land management (van Dijck et al, 2006).

Thus, changes in climate but especially changes in Sehoul's socio-economic situation might have changed the environment of the Sehoul plateau and degradation processes can therefore have their cause in a large variety of phenomena. To get an overview of the causes and processes linked to the degradation sites, so-called 'hot-spots' must be identified and analysed. By doing this for a large area such as Sehoul, maps can be produced to give an overview of the dominant degradation processes in the plateau. Knowing the locations of changes in land surface temperature, vegetation cover and land use practices will make it easier to locate and address the causes of these degradation processes in policy making. A recent degradation process is the occurrence of gullies in the valley bottoms and on steep slopes.

III. ASSUMPTIONS AND PROBLEM STATEMENT

III.I Main assumptions

- The changes in land surface properties are indirect and direct results of degradation and desertification processes.
- Degradation processes in this area are enhanced by a combination of anthropological activities and climatic changes.

III.II Problem statement

The main problem in the area is land degradation and desertification. These processes have several causes (Laouina et al., 2007a; DESIRE website, 2009):

1. The expansion of Rabat leads to an increasing demand from the city for food, thus leading to intensified agriculture in the Sehoul area. This results in changing agricultural practices in the upper catchments.
2. The city expansion also demands space for transport and activities.
3. Forest degradation is mainly caused by overgrazing, woodcutting, forest diseases and climate change, which all have its impact on regeneration.
4. In the deep incised valleys and streams, critical degradation rates occur and the population is leaving these areas.
5. The presence of thick sandy leached soils (old Pleistocene dunes). When vegetation is removed this fixed dunes can become mobile again and are very vulnerable for erosion.

Another problem linked to the degradation processes is the area's water shortage (Chair UNESCO-GN). The agricultural, tourism and urban sectors struggle all for their share of water. This deficit is mainly present because the groundwater is only recharged with precipitation.

The reason for this research is that at the moment no overview exists of degradation hotspots and processes occurring here. Nor has a link been made between detection of change in land surface properties through remote sensing and the validation of these detected changes in the field. Since working with remote sensing and GIS software is relatively young in the science field, there is still a gap between field research and GIS based research. Therefore, this research will be a first attempt to integrate these two types of research. The aim is to create an overview of degradation hotspots for this area, and thereby providing more into-depth characteristics of these sites, which are to be achieved through fieldwork.

IV. RESEARCH APPROACH

IV.I General Approach

This thesis aims to integrate Remote Sensing (RS), soil science and social science. The questions 'what do I see and what processes can I link to this?' are answered both with the knowledge gained from my technical soil science background, as well as with my knowledge of remote sensing analysis techniques. However, to understand underlying causes, for instance overgrazing as a result of pressure from urbanization, knowledge on sociological issues is crucial.

This research treats and analyses data with assistance of remote sensing software, ENVI. Here, changes in land surface properties can be detected. To be able to identify these changes (specific land use etc.) and the characteristics of the degradation processes at selected sites, so-called 'hot-spots', field visits will take place to gather qualitative data on the present and former land use, forest condition and so on, which will be used to analysed why and what degradation processes occur.

IV.II Causal relationships

In search for solutions to land degradation and desertification, one must identify the causes of these problems. By detecting changes in land surface properties and analysing the sites where these occur, insight can be gained about the causes for these changes and the assumption that these are caused by degradation processes will be tested. As discussed earlier, these changes, in land surface properties, will be assessed by analysing space-born images from MODIS Terra and Landsat MSS/TM/ETM.

The relation between driving forces, direct pressures, the state, impacts and responses are given in figure 9. However, these relations are often interlinked, and for instance urbanization is an effect of population growth in Rabat, but also assumed to be a cause for the intensification of land use in the Sehoul plateau.

This thesis will focus on the state of degradation and will link this to the direct pressures occurring in the area (figure 7). Mapping these linkages will provide such an overview that the overall driving forces of these pressures may become more visible and can be anticipated on in policies and interventions (response). The impacts of the degradation pressures will become clearer with the analysis of detection of change. It will be interesting to repeat this analysis after some years of intervention measures have been undertaken in the area, to monitor their effect (response → impacts) (CDE/WOCAT, FAO/LADA, ISRIC; 2008).

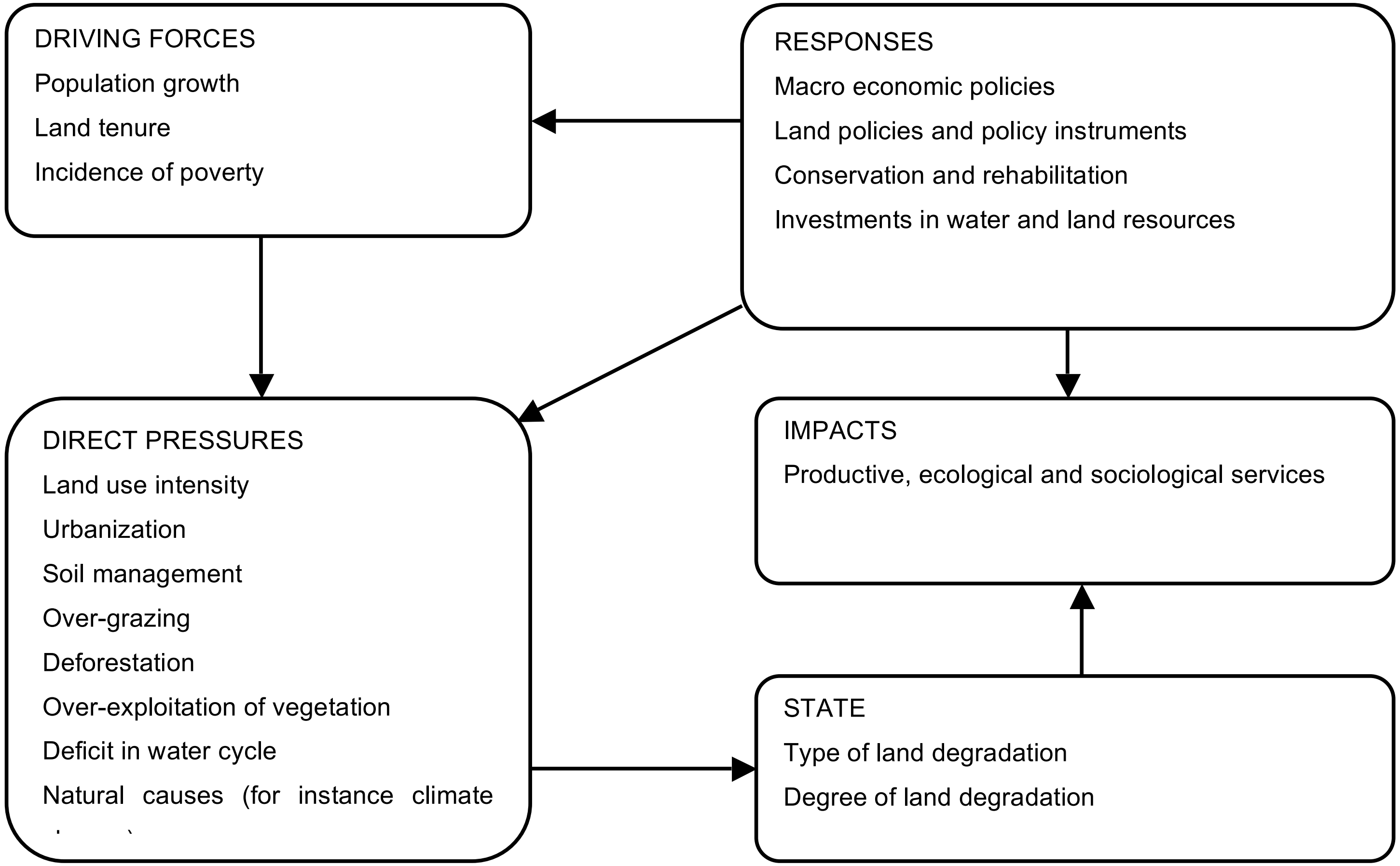


Figure 7 Drivers-Pressure-State-Impact-Response (DPSIR) DIAGRAMME (adapted from CDE/ WOCAT, FAO/LADA, ISRIC; 2008)

V. OBJECTIVES

The aim of this research is to assess changes in land surface properties and investigate links to degradation and desertification processes. Therefore, the main objective is:

Temporal mapping and analysis of changes in forest condition and land use in Sehoul, Morocco.

The four sub-objectives, through which the main objective is to be finalised are:

1. To detect specific areas of change – so called “hotspots” – in
    a. Land-use practices
    b. NDVI (Normalised Difference Vegetation Index)
    c. NDII (Normalised Difference Infrared Index)
    d. LST (Land Surface Temperature)
2. To analyse the nature of the degradation processes in these hotspots by determining the (change in) land use practices and socio-economic context with qualitative data.
3. To validate the methods of land-use classification.
4. To up-scale the results for the analysis of spatial and temporal trends.

The focus of this research lies on changes in land use in the Sehoul plateau over the past 30 years. Since the available temporal Landsat data are not continuous it is important to look especially into changes in land surface properties that suffer little change seasonally or even annually except when other factors play a role. For the Sehoul plateau, this applies in particular for forested areas and the present water bodies (the artificial lake and both rivers). Therefore, the aim is to detect and analyse changes especially in these areas, by analysing for instance the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST).

VI. RESEARCH METHODOLOGY

VI.I Objective 1 – Hotspot detection

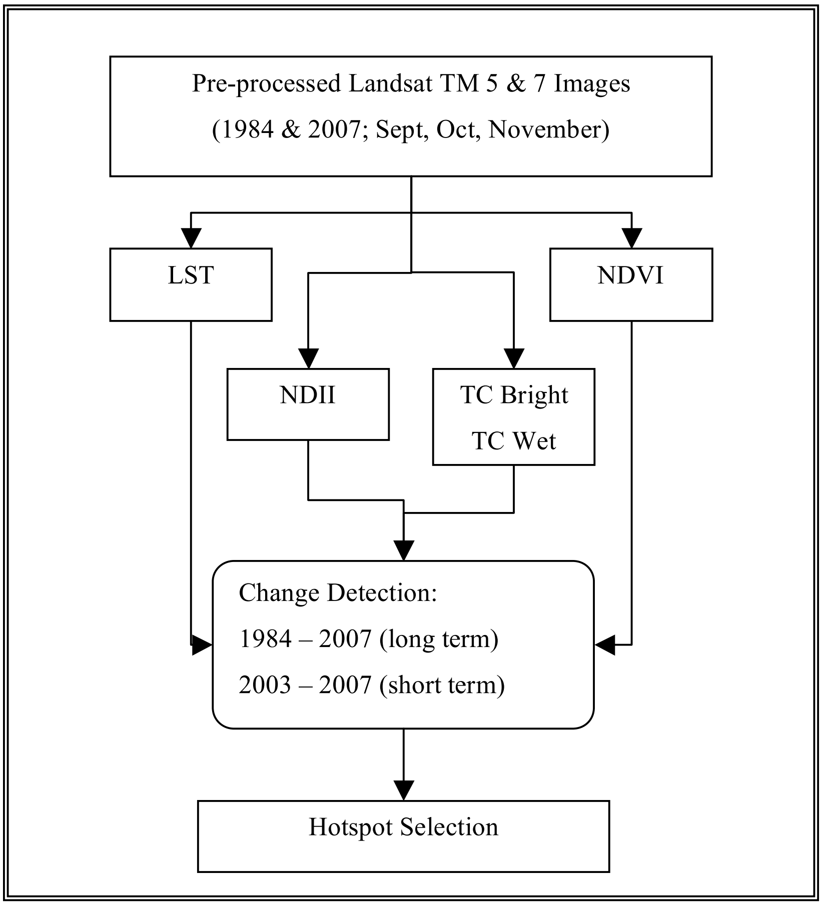


Figure 8 Research Methodology - Objective 1

To finalize this sub-objective an analysis of recent Landsat images in the Sehoul plateau has to be made, to detect land degradation and desertification hotspots (figure 8). Since the fieldwork has taken place from September until December, the recent images that are used here should originate from these months (of previous years) for validating the classification and analysing the outcomes of objective 2.

As data-input, pre-processed Landsat TM/ETM images are used in ENVI, resulting in maps of the research area showing hotspots of change in land use, land surface temperature and vegetation cover.

Table 1 Original data input files

Satellite	Sensor	Path-Row	Date
Landsat 5	TM	202-036	11-Sep-1984
Landsat 5	TM	202-036	15-Sep-2003
Landsat 5	TM	202-036	26-Sep-2007

Changes in NDVI were calculated, since they might provide a qualitative overview of the green biomass in the region.

[NDVI= (NIR- RED)/ (NIR+RED)]

Also, changes in LST are useful because they can be linked to changes in physical characteristics of land cover, like Sobrino and Raissouni (2000) did for seven different land cover zones for the whole of Morocco (e.g. desert, mountains etc.) to look at LST patterns within zones and the relation between NDVI and LST (Sobrino and Raissouni, 2000).

Changes in NDII were also calculated, as it estimates moisture content directly, i.e. for the NDII a ratio is calculated between the near infrared (R_{850}) and the shortwave infrared (R_{1650}). This ratio includes wavelengths that are closely associated to water absorption bands. Therefore, the NDII gives better results to interpret surface moisture content and cleared or stressed forest (Bruno et al. 2006; Hunt & Yilmaz 2007; Chuvieco et al. 2004).

$$[NDII = (R_{850} - R_{1650})/(R8_{50} + R_{1650})]$$

For land use changes, especially when focussing semi-arid, forested areas, the tasselled cap (TC) and principal component analysis (PCA) are best applicable. PCA, however, is scene dependent, which is why TC might give better results when the comparative dates are not the same. A post-classification comparison might also provide good results, but these are highly dependent of the training sample data that is used and needs a lot of time and expertise (Lu et al 2004). Therefore, land cover change detection results of TC bright and wet made by Dr. Eli Argaman were used additionally.

The Tasselled Cap Brightness index simulates Albedo and thus indicates the differences between (bright) soil surface reflection and (dark) dense vegetation. To make a good interpretation, the NDVI (also possible is TC Greenness index) should be taken into account as well. The Tasselled Cap Wetness index indicates vegetation biomass. Together they can give an indication if changes occurred in forest condition (biomass, TC wetness) or forest density/cover (TC brightness, in combination with NDVI) (pers. comm. Dr E. Argaman, 8 Aug. 2011).

VI.II Objective 2 – Analysis of the degradation processes

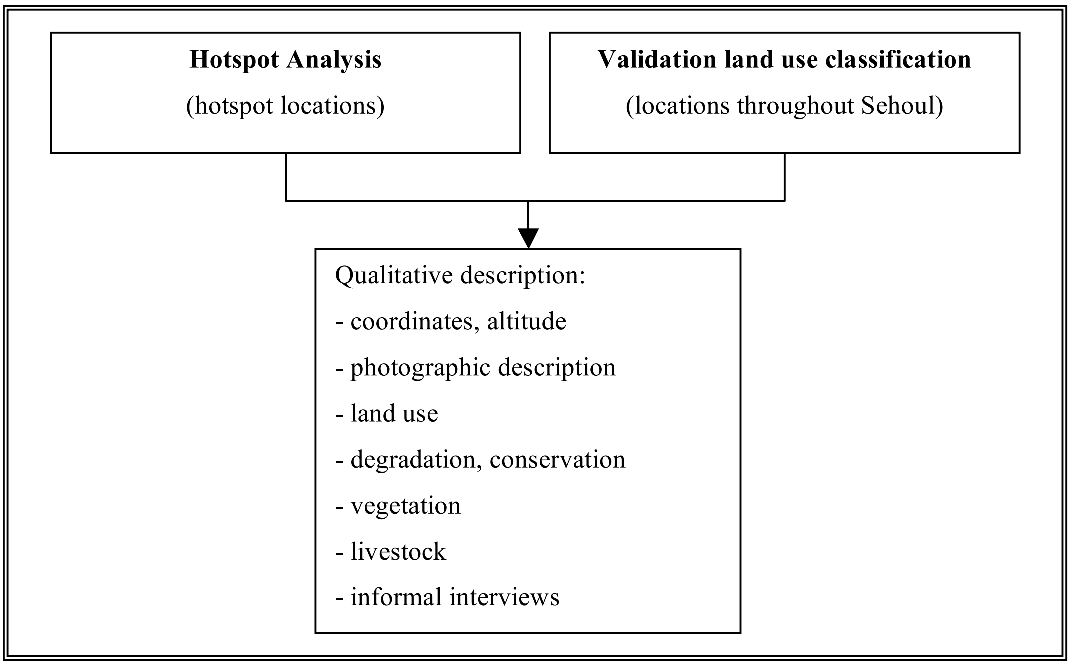


Figure 9 Research Methodologies - Objectives 2 and 3

In order not to overlook important observations from the field while gathering land use and degradation data, the questionnaire for mapping land degradation and SLM practices of CDE/WOCAT, FAO/LADA and ISRIC (2008) were adapted. This questionnaire was originally intended for detailed mapping. As the dataset for this research was to be less extended and detailed, the original questionnaire was adapted and reduced. This new document served primarily as a guideline in the field, as not to overlook certain issues when making observations and photographs.

By determining with qualitative data in which the socio-economic context the changes in land use took place, the environment in which degradation and desertification processes were able to originate will become clearer. Socio-economic context is here defined as the phenomena in society (local and regional) and economy (local – national) that are interrelated with changes of the environment of the Sehoul area (urbanization etc.).

Taking into account the amount of time available, this cannot be done for the whole Sehoul area. Therefore, this research will focus on one or a few specifically interesting hotspot locations. A literature study was done, and by visiting the hotspot areas, with observation, photography and informal interviews structured in field notes, additional data was gathered to explain the reason for and moment of change (figure 9).

Key-topics are: man induced changes in land surface properties, agricultural practices and land management policies.

VI.III Objective 3 – Validation of land-use classification methods

With assistance of coordinates and field notes, not only in the hotspot areas but also spread along other parts of the Sehoul research area, the land use classification methods can be validated (figure 9). In gathering these observations, a questionnaire regarding the mapping of land degradation and SLM practices was adapted and used as was explained in VI.II (CDE/WOCAT, FAO/LADA, ISRIC. 2008).

VI.IV Objective 4 – Up scaling results to analyse for temporal trends

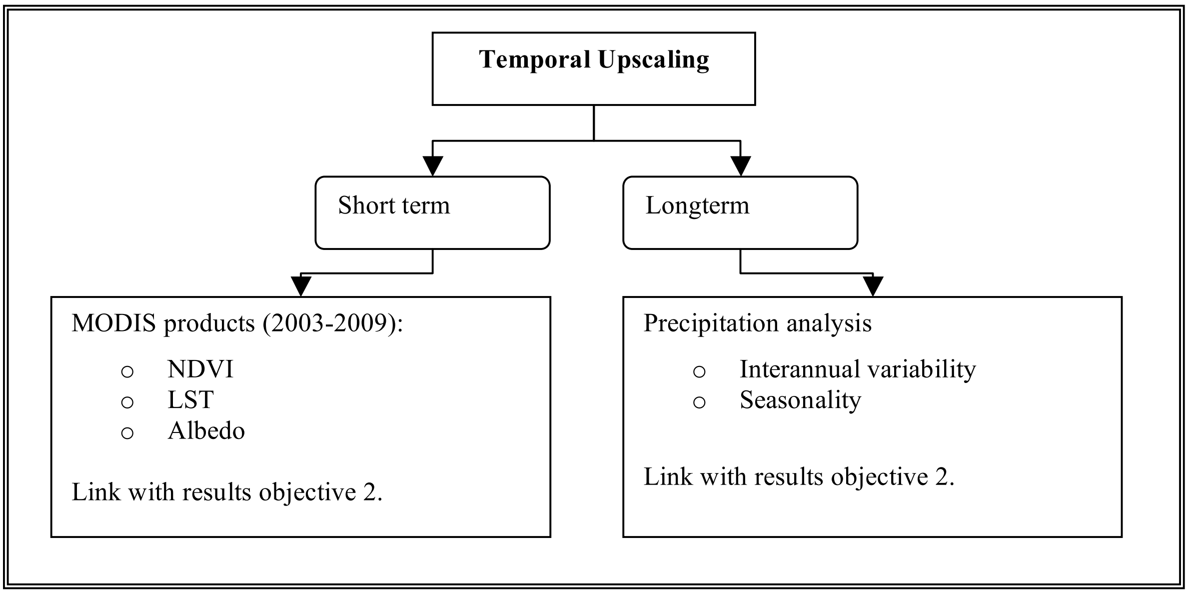


Figure 10 **Research Methodology - Objective 4**

For temporal upscaling on the short term, Moderate Resolution Imaging Spectroradiometer (MODIS) products were used (figure 10). MODIS is a key instrument on the Terra (EOS AM, since 2/2000) and Aqua (EOS PM, since 7/2002) satellites. In the morning, Terra passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS view the Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands. MODIS measures visible and infrared radiation and gathers data that are used to create products, e.g. vegetation cover (http://modis.gsfc.nasa.gov/about/ MODIS website; 11/8/11).

For this objective. MODIS Terra subsets were downloaded from the website of the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC; http://daac.ornl.gov/MODIS/). With the Global Tool, MODIS Land Product subsets for any site, area (from 1 pixel up to 201 x 201 km), and time period can be downloaded. This tool was used to gather the MODIS NDVI, Albedo and LST information.

For the short term temporal upscaling, the MODIS products mentioned above were compared with the results of objective 2, the analysis of the hotspots, i.e. the results of the Landsat TM image change detection and the gathered field data.

For the long term temporal upscaling, a precipitation analysis was done based on the data of the Rabat-Salé weather station (from www.tutiempo.net) and on the research of by Dr. Mostafa Antari (2007). Antari also used the same weather station data for a similar precipitation analysis for his research in Sehoul. This research however, takes into account the period of 1970 – 2002, while this study focuses on 1984-2002. Therefore, Antari's analysis was taken into account but data and findings were adjusted to this new time period and interpreted taking into account the purpose of this thesis.

VII. RESULTS – HOTSPOT DETECTION

VII.I Introduction

The first step in mapping and analysing the Sehoul area in terms of changes in forest condition and land use is to make an overview of the 'hotspot' areas of these changes, i.e. which parts of Sehoul have changed significantly in between present and thirty years ago, in terms of vegetation and land use.

In figure 11, an example is given of an output file for such change detection. The Landsat images from 1984 and 2007 were processed in ENVI, in order to indicate potential areas of change. With ArcGIS shape files, maps were made to display these results. These change detection images were aggregated into classes indicating the extension of change, i.e. the following five:

1. Much increase
2. Slight increase
3. No change
4. Slight decrease
5. Much decrease

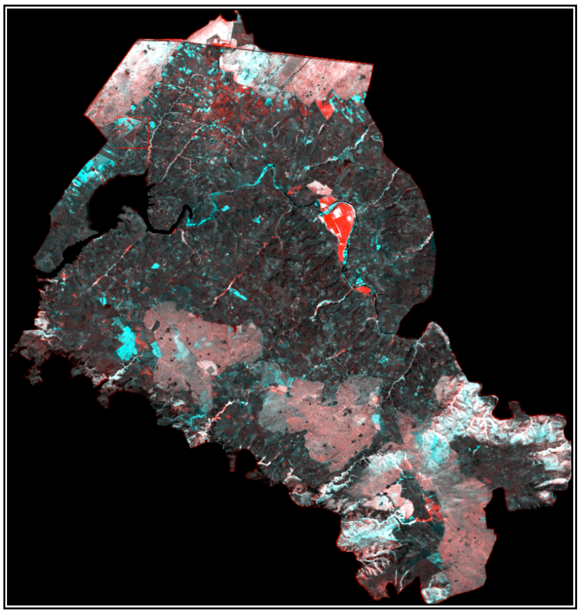


Figure 11 Example of ENVI - image of change in NDVI (Landsat: 1984 – 2007 (2CMV)) (Cyan = increase; red = decrease)

By setting a threshold for these classes, the ArcGIS map output can differentiate between much or no/little change rate. By giving "much increase/decrease" pronounced colours, the hotspots of change, i.e. where the biggest changes occurred, become clearly visible.

VII.I Selection of hotspots

In figure 12, the selected hotspots of change are presented. In the field, these were visited to analyse the processes and phenomena that caused or can explain these changes. Hotspot 1 indicates areas of change in Land Surface Temperature (LST); hotspots 2-6 represent long- (hotspot 2-4) and short-term (hotspot 5&6) changes in the Normalised Difference Vegetation Index (NDVI); and hotspot 7 for changes in the Normalised Difference Infra-red Index (NDII). In the following paragraphs is explained how the selection of these hotspots was made.

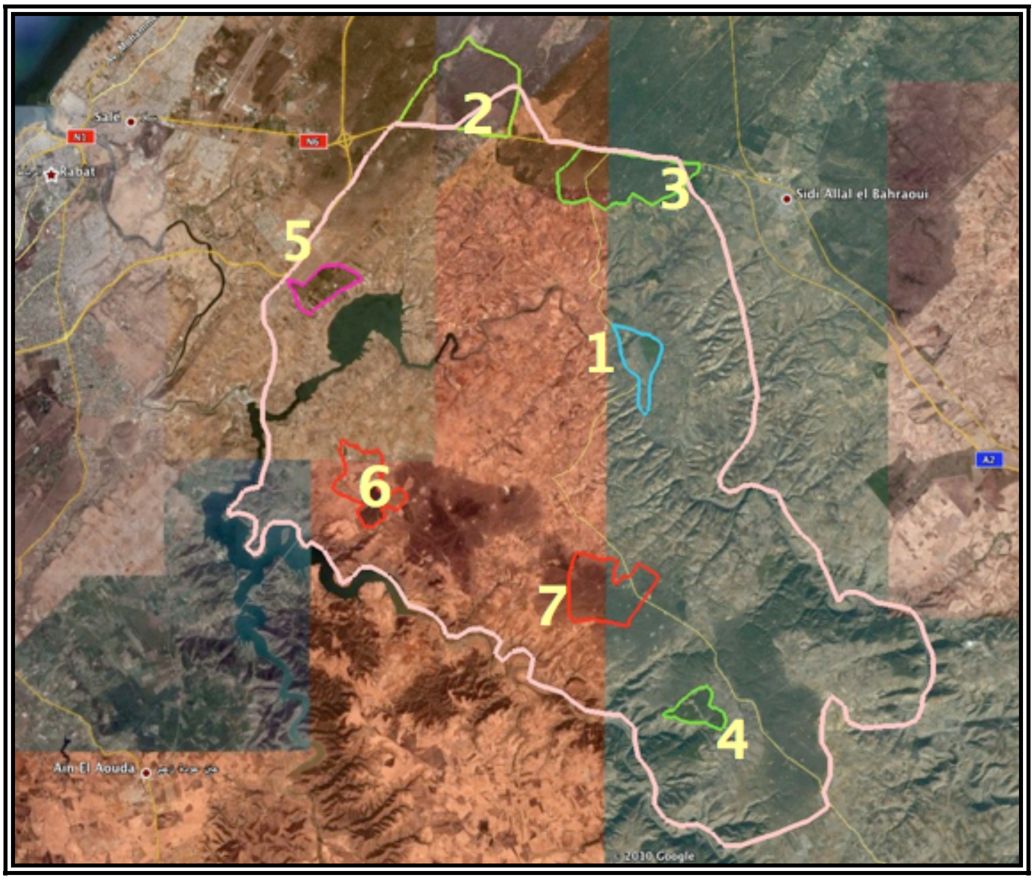


Figure 12 Selected Hotspots in Sehoul (Google Earth, 29-06-2010)

VII.II Changes in Land Surface temperature

From figure 13, it can be observed that the biggest change in Land Surface Temperature (LST) is an increase of LST (red area) located in a bend in the Bou Regreg River. This change took place in 1984-2003, and not very recent, as no similar pattern was visible in 2003-2007. This is hotspot no 1 (figure 14).

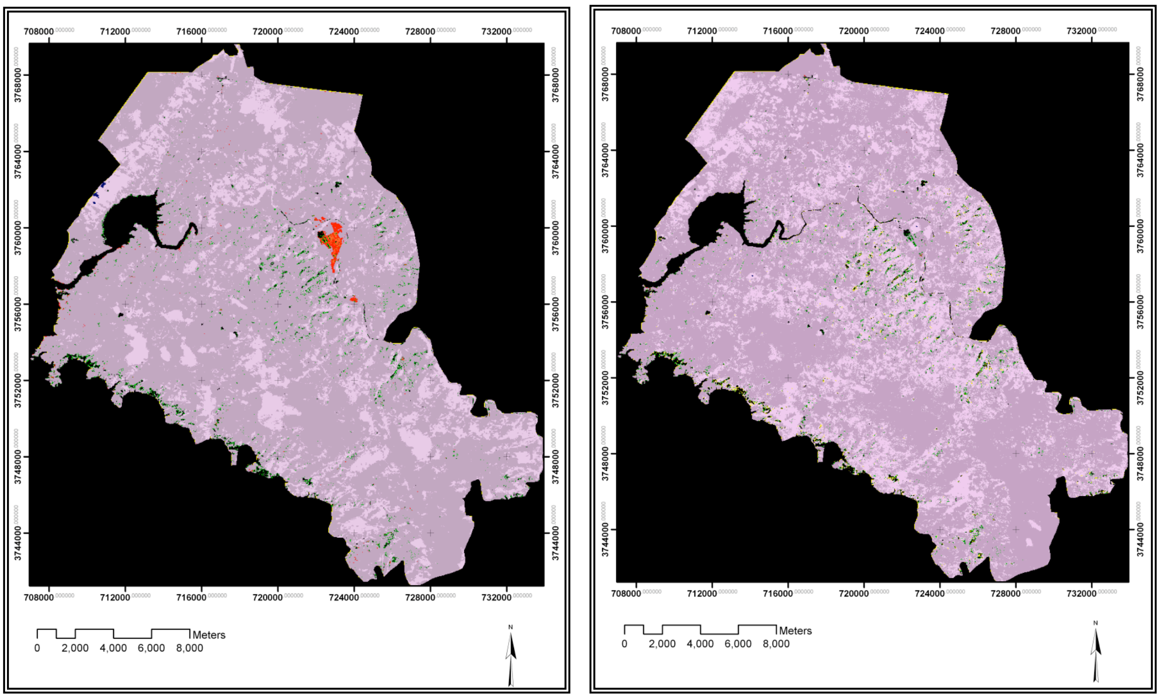


Figure 13 Changes in land surface temperature (LST), of 1984-2007 (left) and 2003-2007 (right) [Landsat product, red=increase; green=decrease]

VII.III Changes in NDVI

In figure 14, hotspot 1 can also be observed as change in NDVI. Other larger areas of change are seen in the north/northwest part of Sehoul and the southeast. In these areas, it is remarkable that in the long-term (1984-2007) the NDVI has decreased, but that in 2003-2007 an increase of NDVI can be observed. To investigate this, hotspot 2, 3 (northwest) and 4 (southeast) were selected to visit in the field (for hotspots, see figure 12).

In addition to this, two smaller hotspots can be observed: directly west-northwest of the lake (hotspot 5; figure 14) and somewhat further south of the lake (hotspot 6; figure 14). The latter has also a difference between long-term increase in NDVI, but a short-term decrease however.

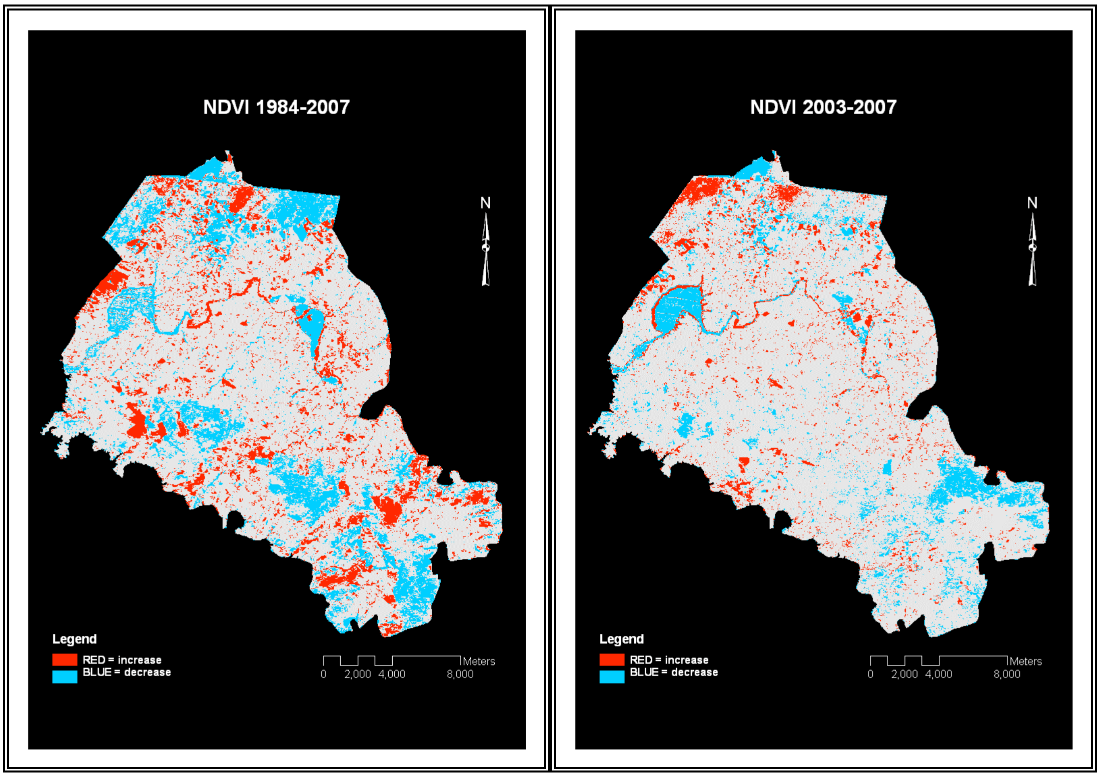


Figure 14 NDVI [Landsat: 84-07; 03-07 - Red for positive change; blue for negative change]

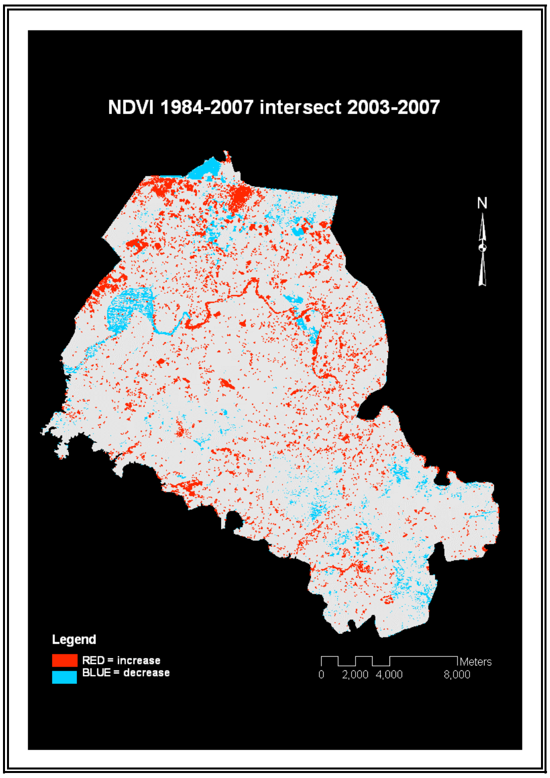


Figure 15 NDVI [Landsat: 84-07 intersected 03-07 – Red for positive change; blue for negative change]

VII.IV Changes in NDII

When looking at changes in NDII, and especially when intersected with NDVI, there is another area of change observed (hotspot 7; figure 12). A decrease in NDII (see figure 16) is seen south of hotspot 1, close to the southern border of Sehoul, the Bou Grou River.

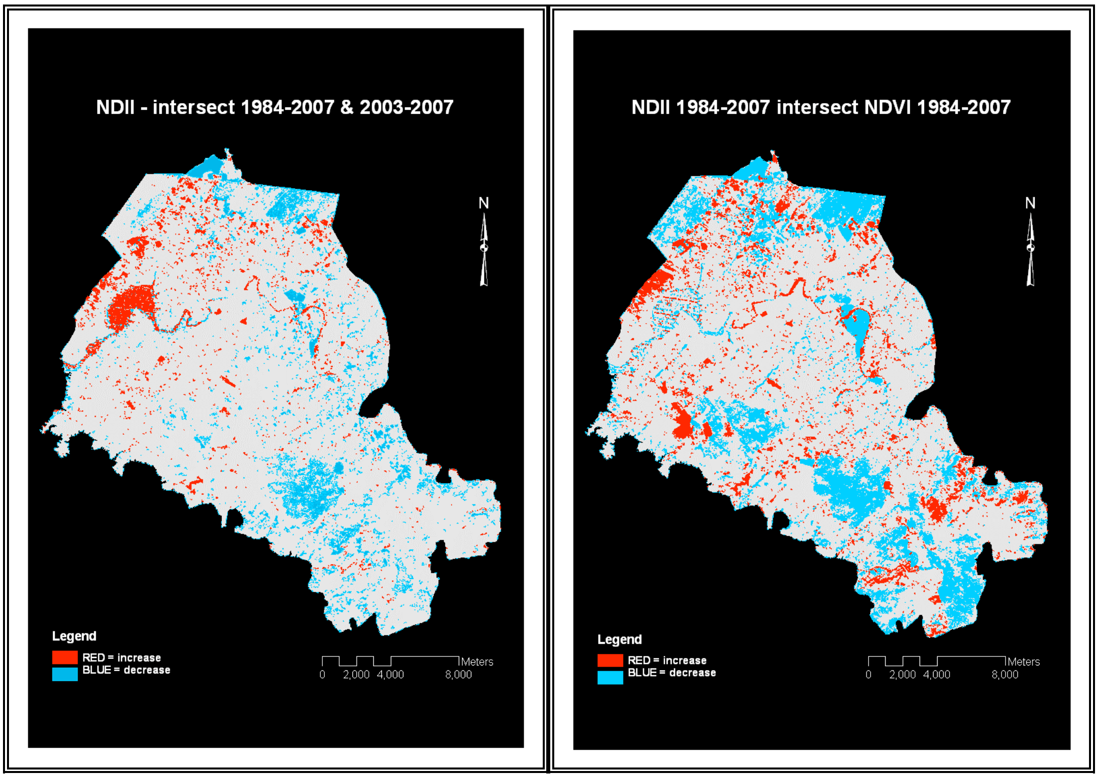


Figure 16 NDII 84-07 intersected 03-07; NDVI 84-07 intersected NDII 84-07
[Landsat 84; 03; 07 – Red for positive change; blue for negative change]

VII.V Change in Land Use

Although different land use classification methods can be used, TC (Tasselled Cap) is the most reliable method to use according to the literature (see 'Methodology'). Dr. Eli Argaman already executed change detection for Sehoul with the Tasselled Cap method. These are presented in figures 17 and 18, where all hotspots (no 1-7; figure 14) can be observed again. However, what is also visible here is that the changes are mostly long-term, as it is the figures on the left (1984-2007) that show the most distinctive change, whereas these changes cannot or only slightly be observed in the more recent change detection (2003-2007).

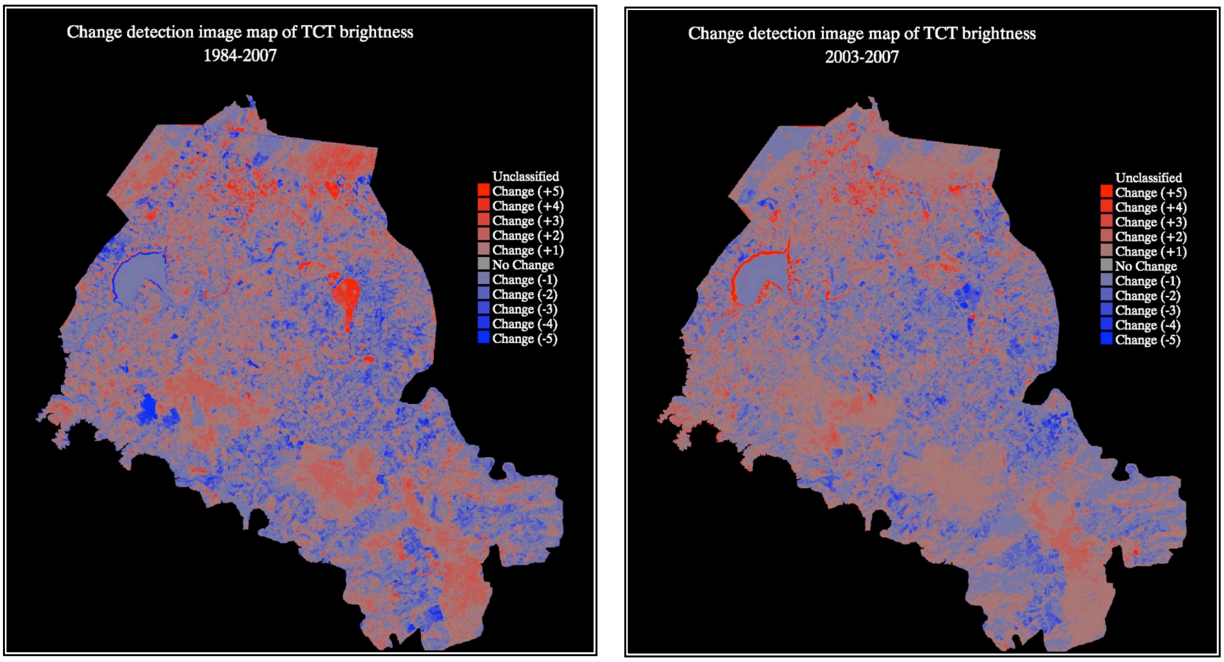


Figure 17 Land use Change by E. Argaman – TC Bright 1984-2007; 2003-2007.

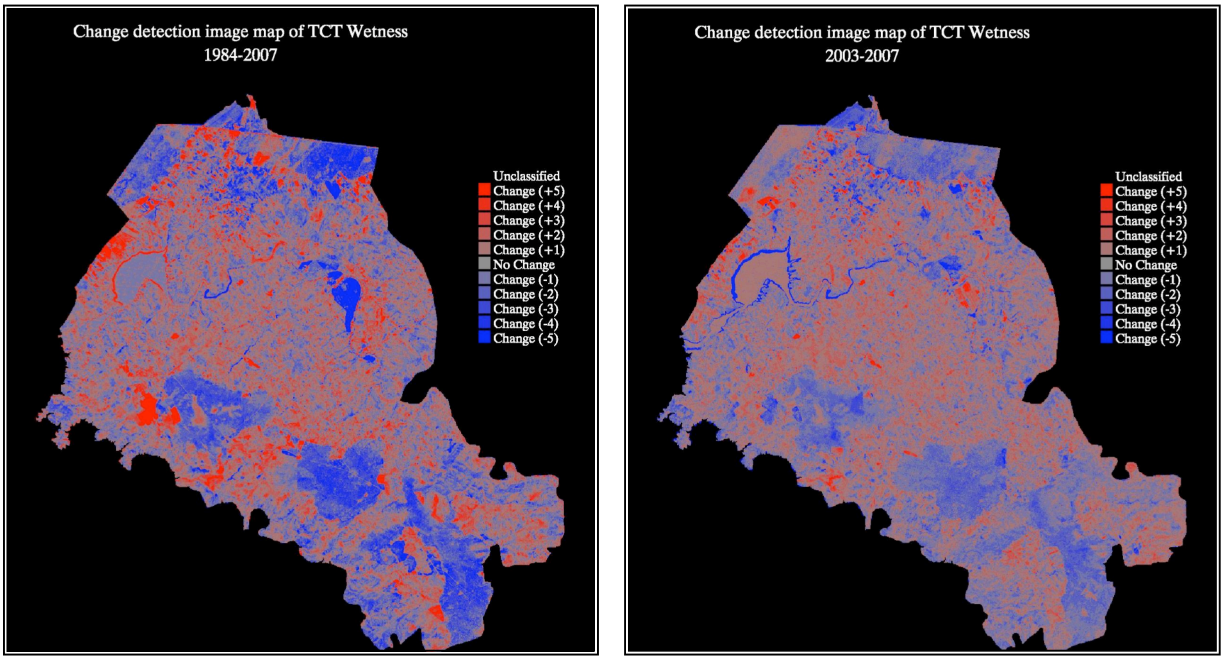


Figure 18 Land use Change by E. Argaman – TC Wet 1984-2007; 2003-2007.

VIII. RESULTS - ANALYSING HOTSPOTS OF CHANGE

VIII.I Comparing Landsat TM with field results

In order to see the background in which the comparison between the image processing results of the previous chapter and the results from the field was made, follows here the context of this comparison; i.e. what were the differences to take into account between the field situation from September to December 2009, and the Landsat imagery dating from September 1984; 2003 and 2007.

Figure 21 includes the total monthly precipitation for the period (August-December). These were the months in which the fieldwork was executed and includes the dates in which the Landsat TM images were taken (September 1984; 2003; 2007), that were used for this study (figure 19). What can be observed from these precipitation rates is that Sehoul was very dry during September-December 2009, which corresponds with the experiences from the field and staying in Rabat: only in December there were some small rainstorms, but in the months before, no significant rain occurred. Thus, it should be taken into account that the fieldwork was performed under relatively dry circumstances for soil and vegetation.

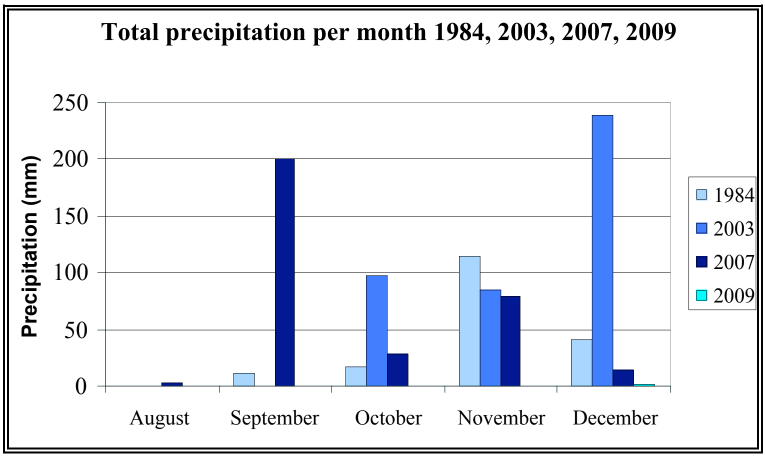


Figure 19 Total precipitation per month; 1984, 2003, 2007, 2009

Let us now compare the field situation to the conditions in which the Landsat TM images used for this research were taken (11-09-84; 15-09-03; 26-09-07). Looking at the precipitation condition of September months of these years, September 2007 stands out as extremely wet; while in 1984 and 2003 no/little rain was registered. Hence, the Landsat products from the latter two are comparable with the results from the field. The conditions in 2007, however, should be reviewed.

The exceptionally high amount of precipitation in September 2007 can be ascribed to a single rainstorm on the 11th of September 2007, two weeks before the used Landsat image was taken (26-09-07). An amount of 201mm was recorded on that day (source: tutiempo.net). This is an extremely high amount in comparison to normal precipitation in Sehoul and thus could be an error in the data from the weather station. If it is indeed an error, the month was further relatively dry and the weather and moisture conditions were similar for both Landsat TM images as fieldwork.

If the data is correct however, it is difficult to guess what the influence has been on the image processing products (higher NDVI for 2007 etc). Therefore, assuming the error but taking into account this uncertainty of data in the analysis is the best option.

VIII.II Observed changes in land properties at the hotspot areas

Following is an analysis of all selected hotspots, i.e. the nature of the change detection results that were found in the previous chapter are explained with field work data, literature and personal communications with experts from Université Mohammed V, Rabat.

"LT" indicates that the observed changes were long-term, i.e. between 1984 and 2007. "ST" indicates short term changes, i.e. in 2003-2007. Not all changes are discussed, as a decrease in TC wet is linked to an increase in TC bright (lower forest biomass, more soil reflection), etc.

<u>Hotspot 1 – a flooded river curve</u>

Summary of change detection results:

- LST increase (LT)
- NDVI decrease(LT)
- NDVI-NDII intersect decrease (LT)
- TC bright increase (LT)
- TC wet decrease (LT)

The changes that occurred in hotspot 1 are all of a long-term nature, i.e. took place before 2003. Decreasing NDVI and TC wetness indicate decreasing vegetation cover and biomass. Field work results and personal communications with experts explain that irrigated modern agriculture has replaced traditional agriculture in this area. However, after the Sidi Mohammed Ben Abdellah reservoir was full, this area completely flooded as has remained that way (figure 20). To clear the area for this purpose, the government has relocated the farmers in advance (pers. comm. Prof. M. Chaker, 30 Oct. 2009; pers. comm. N. Machouri, MSc, 17 Nov. 2009). Sources were not clear and varied on when this happened. Most probable is that it happened after 1996, which recorded a total annual precipitation of 1162.6 mm, exceeding the average with about a 100% (Antari, 2007).

Figure 20 Flooded agricultural land (M Schoolenberg, 17/11/09)

<u>Hotspots 2, 3 and 7 - Mamora & Sehoul forests</u>

Summary of change detection results:

- Hotspot 2:
  - NDVI decrease (LT + ST)
  - NDII decrease (LT + ST)
  - TC wet decrease (LT + ST)
- Hotspot 3:
  - NDVI decrease (LT)
  - TC bright slight increase (LT)
  - TC wet slight decrease (LT)
- Hotspot 7:
  - NDVI – NDII strong decrease (LT)
  - TC bright slight increase (LT)
  - TC wet slight decrease (LT)

Again, as for hotspot one, a long-term decrease in NDVI and TC wet, i.e. decreasing vegetation cover and biomass is observed. However, different than hotspot 1, these hotspots are all forested areas, i.e. the Mamora forest (hotspot 2 and 3) and "foret de Sehoul" (hotspot 7). There are several possible explanations for the detected changes in these forested hotspots.

Most likely, the detected changes in hotspots 3 and 7 can be ascribed to changes in forest density/condition, as an increase in TC bright was observed. This indicates a higher surface reflection, and as in Sehoul soil types are generally 'bright', an increasing TC bright most likely means that more soil reflectance is measured because forest density has decreased (pers. comm. Dr E. Argaman; 7 Aug. 2011).

Figure 21 Livestock grazing in Mamora and Sehoul forest (clockwise from top left: cows; donkeys; sheep)

A reason for this change in forest density could be overgrazing, which definitely creates serious pressure on the forest condition (figure 21), as the forest cannot regenerate when seedlings removed by grazing. Another cause for the difficulties for cork oak regeneration is the gathering of these oaks, in huge amounts, to be sold in Rabat by local inhabitants of Sehoul.

Additionally, it should be noted that the trees themselves are in worse shape nowadays. Inexperienced labour forces are hired to harvest the cork, whereas this has to be done by trained staff to prevent tree damage. Carelessly or due to a lack in skills, the cuts are made too deep into the tree stems, causing wounds, prone to diseases, fungus and parasites (figure 22) (pers. comm. N. Machouri, 17 Nov. 2009).

The changes in hotspot 2 indicate a decrease in biomass (NDVI, TC wet) and moisture content (NDII), but only a small decrease in TC bright was observed, unlike in hotspots 3 and 7. Thus, it is unclear what the nature of this change is. In Annex 2 the changed area from the NDVI, NDII and TC change detection results are shown for two selected images from Google Earth, dating July 2004 and August 2007 respectively. The difference between these pictures, the clearance of a small forest parcel and the decreased condition of a larger forest part in the southeast of the image, might be an indication that these kind of changes were also occurring between 1984 and 2007. There are no Google Earth results before May 2004 however of this area.

<u>Hotspot 4 - Eucalyptus plantation</u>

Summary of change detection results:

- o NDVI decrease (LT)
- o TC wet slight decrease (LT)

The changes indicate a decrease in biomass on the long-tem. In the field, the explanation for these changes is became clear. Hotspot 4 used to be natural forest, but is now covered by a Eucalyptus plantation (figure 23) that was constructed around 20 years ago (after the image from 1984). In order to harvest the wood, the Eucalyptus trees are cut every 8 years and then replanted (pers. comm. N. Machouri, 17 Nov. 2009; Prof. A. Laouina, 13 Nov. 2009; anonymous farmers, 17 Nov. 2009).

Figure 22 (left) Wounded cork oak, Sehoul forest

Figure 23 (right) Eucalyptus plantation

Hotspot 5 - Royal Domain

Summary of change detection results:

- NDVI increase (LT)
- NDVI-NDII intersect strong increase (LT)
- TC bright slight decrease (LT)
- TC wet slight increase (LT)

An (long-term) increase in biomass was observed in hotspot 5. As this area covers the royal propriety of King Mohammed VI, it was not possible to enter the domain or ask questions about it, and as guarded fences and tree rows surround it, it was also difficult to see what was cultivated (pers. comm. M. Sfa, 10 Dec. 2009). What could be observed from a distance, were orange trees. So it can be assumed that in at least a part of this area, fruit trees are cultivated. An explanation for the increase in NDVI cannot be given with certainty, through it is possible that the domain came under more intensive cultivation in 1984 to 2007.

Hotspot 6 - Agricultural land & Eucalyptus plantation

Summary of change detection results:

- NDVI increase (LT)
- NDVI decrease (ST)
- NDVI-NDII intersect strong increase (LT)
- TC bright strong decrease (LT)
- TC wet strong increase (LT)

As well as in hotspot 4, the natural forest that could be found in hotspot 6 has been replaced by a Eucalyptus plantation (figure 25), which was planted 12-15 years ago (pers. comm. N. Machouri, 17 Nov. 2009; Prof. A. Laouina, 13 Nov. 2009; anonymous farmers, 17 Nov. 2009).

The major part of hotspot 6 however is covered by a large enclosed farm (38 ha). Many years back, wheat was grown on this land, but since twelve years ago (1997) the farm changed its owner, who cultivated it with avocados, prunes and grapevines. This proved to be not productive enough, so crop types were changed again four years ago (2005) and at present Italian grapevines, potatoes, vegetables and olives are the dominating crops (pers. comm. anonymous farmer, 13 Nov. 2009). The story of the farm explains the increasing biomass on the long-term, i.e. the shift from wheat cultivation to grapevines and fruit trees, and the decrease in biomass on the short-term, when although the grapevines remained, the fruit trees were replaced with vegetable cultivation.

VIII.III General Trends

Apart from visiting these hotspots, coordinates, descriptions and general information were gathered, to gain a general impression of land cover and degradation in Sehoul. With this, the severity of overgrazing became clear: various types of livestock, or evidence of their presence, could be found throughout both the forest and the agricultural lands (figure 23). These agricultural lands are used as pastures, after harvest, as soon as herbaceous species are present. Therefore, both in the forest as also on these agricultural fields, the regeneration of vegetation and restoration of soil organic matter is much more difficult (pers. comm. I. Machmachi, 24 Oct. 2009).

A second trend was explained by Prof. Miloud Chaker during field excursions. He mentioned that a big change in Sehoul, regarding soil degradation, is the quick introduction and spread of modern, agricultural heavy machinery, causing severe soil compaction (pers. comm. Prof M. Chaker, 30 Oct. 2009). Research by van Dijck et al. (2006) confirm this, stating that modern agriculturalists use heavy machinery and irrigation systems, which cause respectively, soil compaction and salinization. Another drawback of the introduction of large-scale agriculture is their large contribution to inefficient water use and soil and ground water pollution (van Dijck et al, 2006).

Figure 24 Rill and gully formations along the Bou Grou River, Southern Sehoul (M Schoolenberg, 27/10/09)

A third phenomenon in the Sehoul area, linked to the previous matter, are the extensive degradation features along the river banks of especially the Bou Grou River which forms the Southern border of the Sehoul research area. Figure 24 shows a gully formation, with in the background an example of rill formation on the sloping riverbanks.

Feeding into the pressure on the land as well is the strong population growth in Morocco, which, due to the urbanisation of Rabat and its surroundings, has a particularly strong effect in Sehoul. This is confirmed by demographic data shown in table 2 and figure 25. The first shows that the total population of Morocco has more than tripled since 1950, which is confirmed by a trend shown in figure 25, where a similar pattern can be observed for the whole Maghreb.

Table 2 Total population (mln.) of Morocco (Puigdefábregas & Mendizabal, 1998; Sabagh, 1993; Navez-Bouchanine, 2003; CIA World Fact book, 2010-07-01)

Year	Population (mln)
1950	9
1960	11.5
1990	25
1994	28
2010	31.6

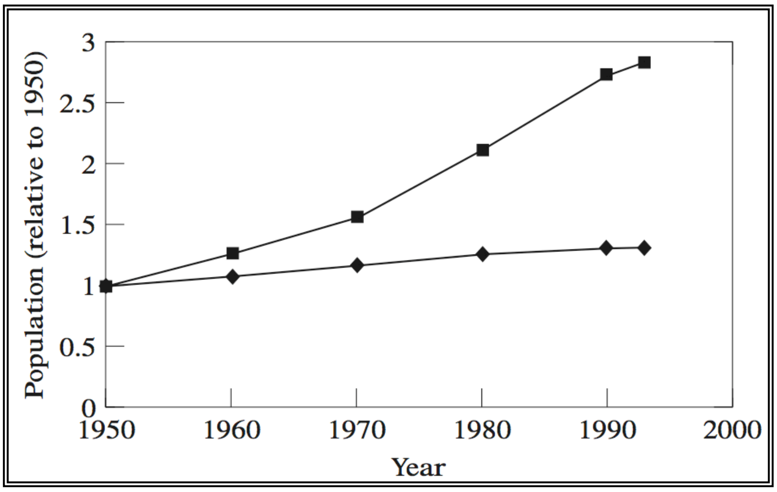


Figure 25 Demographic trends in Western Mediterranean countries (N-MED: (◆) Portugal, Spain, France, Italy; S-MED: (■) Morocco, Algeria, Tunisia) (Puigdefábregas & Medizabal, 1998)

In Sehoul, as it is located close to the capital city Rabat, urbanization adds to the pressure of population growth. The CIA World Fact book (2010-07-01) gives that in 2008, 56% of the population lived in urban areas, of which Casablanca and Rabat-Salé are the most important for administrative, economic and commercial reasons.

The tendencies mentioned above increase the pressure on the cultivated areas, as well as on the forest. The increase in modern agriculture can be linked to the combination of a larger population and increasing urban area, as with this, the demand for crop production per ha is rising, thereby stimulating the shift towards modern agriculture. This combination can also be linked to overgrazing. As the shifting cycle between pasture and crop cultivation has become shorter, a smaller amount of herbaceous species and fewer nutrients are available on these fields. Hence, the pressure for grazing in the forest is becoming even higher. A factor contributing to this is that with an increase in population, the amount of livestock is most likely to increase alongside of that.

Summary of results

Altogether it can be said that most of the changes are resulting from two main issues:

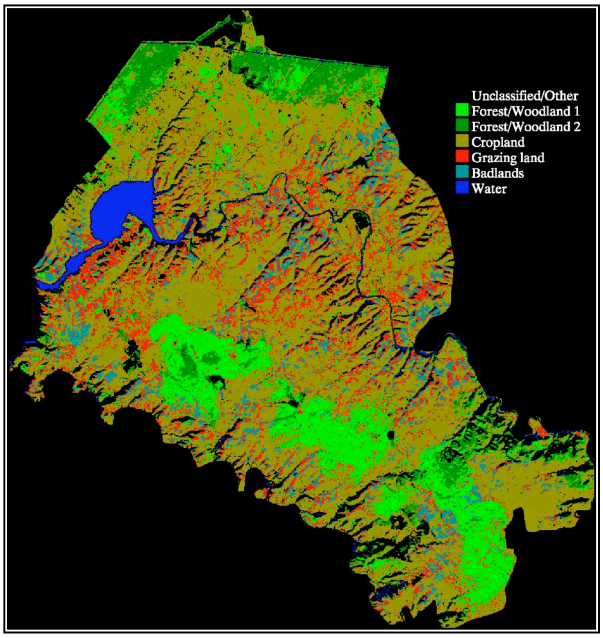
1. an increased pressure on the Sehoul region, resulting from demographic changes: the expanding city of Rabat, both in area and population, and the expanding population/urbanisation in Sehoul itself. This pressure results in forest degradation in:
    a. condition, due to overgrazing and oak harvesting (hotpots (2), 3 & 7)
    b. area, due to forest clearance for new agricultural land or Eucalyptus plantations (hotspots (2), 4 & 6).
2. the modernization and change of agricultural practices (hotspot 1, 5 & 6) , which could be:
    a. …beneficial as it enhances the economic productivity of the region, shifting from wheat cultivation to orchards and cash crops, e.g. vegetables.
    b. ...negatively influencing the environmental condition of the region, as the introduction of heavy machinery is causing severe soil compaction.

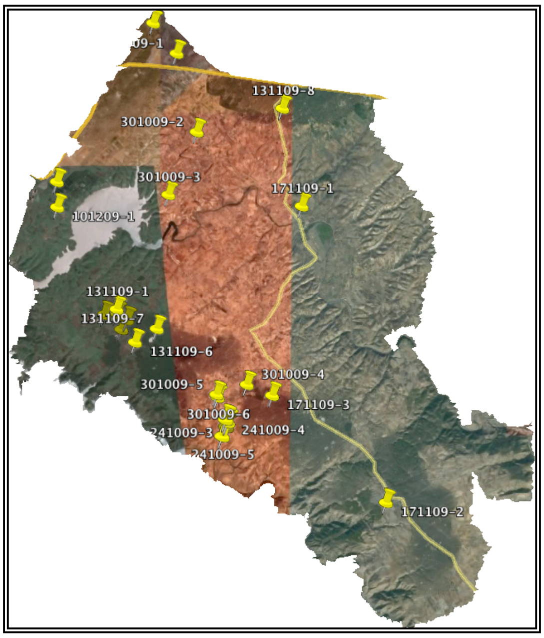
Apart from this, the overgrazing of pastoral lands and removal of forest along especially the Bou Grou river on the Southern border of Sehoul, cause enormous gully and rill formations on its river banks.

NOTE: for follow-up research it would be interesting to investigate in what amount the erosion of these river banks feeds sediment into these rivers, consequently filling up the Sidi Mohammed Ben Abdellah reservoir. In turn, this might be causing the overflow of water after heavy rainfall from the reservoir, leading to the flooding of agricultural land (hotspot 1) and thus replacement of farmers paid by the government.

IX. RESULTS - VALIDATING LAND-USE CLASSIFICATION

In context of the DESIRE Project, Dr. Eli Argaman made output maps with SAM (Spectral Angle Mapper) classification, according to the basic WOCAT land cover classes (see figure 26; CDE/WOCAT, FAO/LADA, ISRIC; 2008). When classifying without specific field data from field visits, the SAM classification method is preferable to other standard classification methods, as these compare each pixel to the signatures of training sites, while SAM compares each pixel with end-member of each class and assigns them a high (1) or low (0) resemblance value. End-members can





be selected directly either from the image itself or with use of lab/field data (Girouard et al. 2004).

Figure 26 Land cover SAM classification Sehoul (2007) according to WOCAT classes (E. Argaman, 2010

Figure 27 Coordinates taken in Sehoul (25/05/10 Google Earth; modified by M Schoolenberg)

In order to validate the output of the SAM classification of the Sehoul area, this output map was compared with the field results, in the form of observations and photography linked to coordinates. In addition to specific coordinates, tours throughout the area where made to get a general overview of the dominant land cover types in Sehoul and specific characteristics for the different parts of the study area.

Figure 27 shows the coordinates that were gathered across Sehoul. Apart from this, other parts of Sehoul were studied by taking field notes of general observations. Other parts, especially in the (south-) east were not possible to access.

WOCAT selected the land use classes on which this SAM classification was based, to be used globally. On national level, specific additions might be preferable. One of the goals of this research was to find out if and for what these additions are needed. This raises two questions:

- First of all, can a classification with these global land use classes, be carried out sufficiently from 'behind your desk' or is additional fieldwork necessary to provide valid results? And for which purposes would they be valid?
- Secondly, is this global classification method suitable for Morocco or is there a need for adjustments?

To answer, the first: yes, comparing the outcomes of the classification with the actual land cover in the field, this global classification system and method proved its worth. Cropland, grazing land and the natural cork oak forest were classified as such. Therefore, this classification is very useful to gain an immediate insight in how the area is generally covered: the pattern of the forest is clearly visible on the map and fits with reality. Also, the river incisions along its shores are noticeable.
Additionally, this straightforward classification method could be considered preferable to the use of local maps, which can be outdated, of unknown quality and/or not (easily) available abroad.

However, the classification does not provide more than a general overview of vegetation types. Following is provided a list with the most important shortcomings:

- **Orchards** are classified as cropland. In Sehoul there is a rotational use between agricultural and grazing land. The orchards, however, are cultivated on a long-term base and taking into account land degradation and SLM practices it might be good to distinguish these fruit trees from other crop types, considering their specific cultivation requirements.
- The various **Eucalyptus plantations**, which were also the nature behind the changes in hotspot 4 and (partly) hotspot 6, are not distinguished in the WOCAT classification. However, it is important to take these plantations into account separately when studying the area, due to their high water demand and the losses of nutrients after clearance for wood harvesting every 6-8 years.
- The **flooded river curve** in Sehoul was classified as agricultural land and partly unclassified, but not as water. Part of the explanation lies in the fact that the bigger part of this area was flooded after the image was taken in 2008 and no information could be found on the date this area was entirely flooded and the farms relocated.
- **Exposed bedrock** in incised streams, especially along the Bou Grou River: from field experience, it is known that the shores of the Bou Grou River are deeply incised by streams, gullies and rill formations towards the river. What is seen in the SAM classification is that these are shown as grazing land in an agricultural cultivated landscape, with some small spots of badlands. In field reality however, this slopes are indeed used as grazing land, but large parts are already severely

degraded, and the stream bottoms are grown by only an occasional fig tree but exposed bedrock can often be observed.

- **Pine tree plantations** and reforestations are found in small parcels in different parts of the area, for instance at the west border of la Forêt de Sehoul. Pine trees were planted as measure of reforestation. Plots of 20 to even 40-50 years old are found. When focussing on forest regeneration, degradation etc, it might be useful to distinguish for these too in a classification.
- As mentioned for the **streams and gullies** along the Bou Grou river but also applicable for other parts of Sehoul, the amount of badlands in the WOCAT classification output is relatively low. Of course it depends on which threshold was used for this classification, but some parts are classified as crop or grazing land, while in reality, although they are still used for cultivation and grazing, these lands are severely degraded and incised by sometimes very deep gully formations.

Summary of results

The (SAM) WOCAT classification is accurate and specific enough to indicate the main patterns of land use in the Sehoul research area. Therefore, it is a suitable method to use in the DESIRE project. Using this simple and similar classification for all study sites, quick overviews and comparisons can be made about the dominant land cover types in these areas.

However, for a more into-depth study of the Sehoul itself, a field visit was necessary to gain more specific information that distinguishes vegetation types from each other, especially between the natural cork oak forests and Eucalyptus plantations. Also, in Sehoul there is regular shift between using the land for agriculture or as grazing land and badlands are often intertwined with these land use types, which should be emphasised more in the reclassification. Also, badlands were underestimated in the WOCAT classification (figure 26). Altogether, it can be said that the information from the (SAM) WOCAT classification is not accurate enough when searching for information of specific locations within the research area.

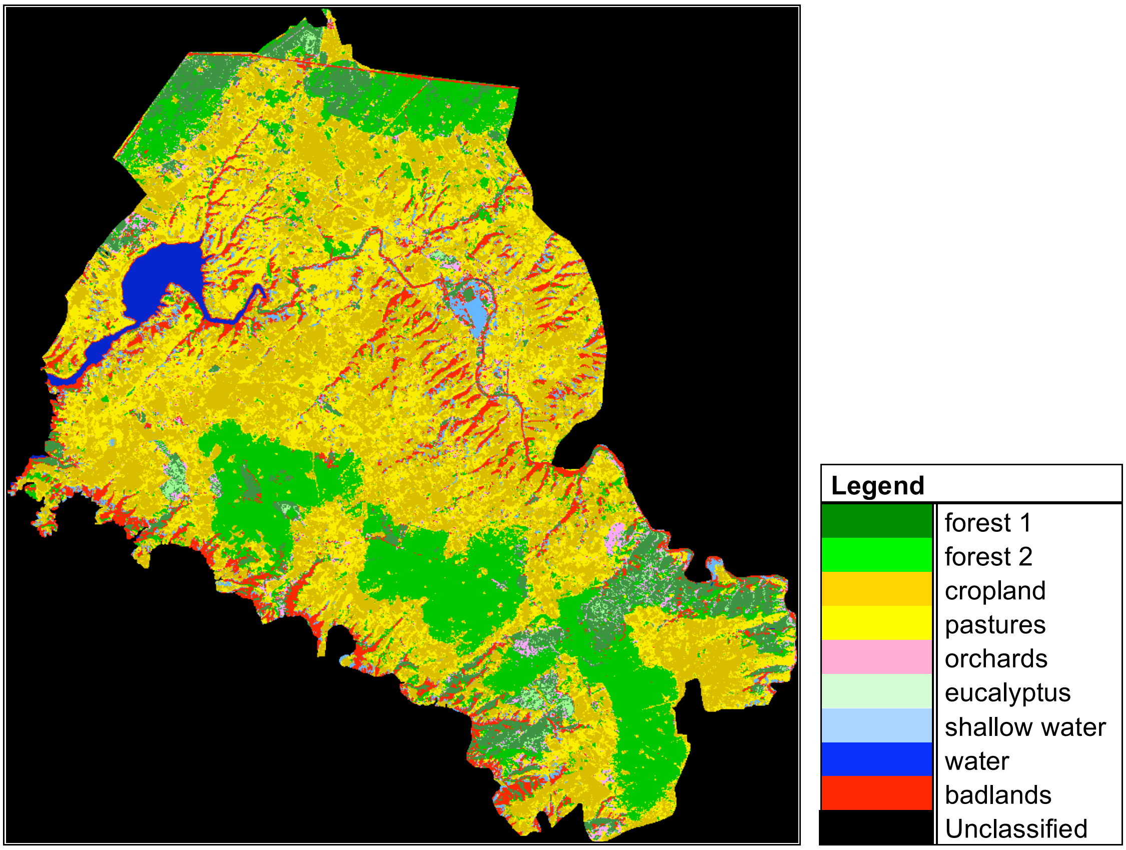


Figure 28 Land cover SAM reclassification Sehoul (2007)

Figure 28 shows an example of a Land cover reclassification of the Landsat 2007 image that was used for Argaman's SAM classification of the WOCAT classes. In this reclassification, the SAM classification method was used as well, based on Regions of Interest (RoI) that were selected according to training sites visited in the field, and corrected by resetting the thresholds of the different classes manually based on visual interpretation. Not all land covers (e.g. pine tree plantations) are included in this new classification, as only one training site was known which was not sufficient to produce an good result. The most important difference with the WOCAT classification is the increase in pasture land. As observed in the field, crop and grazing lands are interchangeable in Sehoul as their function rotates. Also, badlands are highlighted in figure 28, as in the field it was observed that not only along the river banks, but also along the streams feeding into these rivers, gully and rill formations are highly present. New classes are Eucalyptus and Orchards to differentiate these from the natural forest, and Shallow water in order to indicate the flooded areas in the curve of the Bou Regreg River.

X. RESULTS – UP-SCALING FOR TEMPORAL TREND ANALYSIS

In order to upscale this research to a temporal trend analysis, a change detection analysis comparing two single images, and present day field data are not enough to give a complete overview of the changes. To gain insight on the speed of these changes, i.e. abrupt or gradual, more insight is needed on the time between the date of the first image (September 1984) and the time of last field work (December 2009).

MODIS Terra satellite data provides free information on the different indices that were focussed on. However, the records date back from 2000 to present day, thus only short term changes can be analysed with this. Therefore, additionally, long term precipitation data (1984-2003) were used to gain more insight in the land use and vegetative changes by looking in to climatic variability of the region.

X.I Short term trend analysis

From the MODIS Terra Land subsets, NDVI, LST and Albedo data for three land use classes that MODIS differentiates (i.e. grassland, forest and cropland, classified by MODIS) were gathered to compare with the change analysis on Sehoul from the previous chapters. Albedo can be compared to TC bright according to Dr. E. Argaman (pers. comm., 7 Aug 2011). The data are shown in Annex 3 and give values between 1/2003 and 5/2009 which includes the same time period as the short term change detection for Landsat imagery (2003-2007) and the field work period (2009). The data in 2009 are shown until May 2009, which was at time of downloading this sub-set the most recent data.

The figures show:

- constant LST trend for all three land use classes.
- constant Albedo trend for cropland and grassland, but an increasing trend for forest.
- A decreasing trend in NDVI for all three land use classes.

The increase of Albedo that is observed from the MODIS data also coincides with the observation that forest condition and cover decreasing. As soils in Sehoul are relatively bright, the results is thus an increase in reflectivity when vegetation reduces (pers. comm. Dr. E. Argaman, 7 Aug. 2011).

Although the LST trend remained constant, looking into LST data is especially interesting for variation differences in seasonality. However, also the seasonal variability did not seem to have changed in this short time. From this it can be concluded, that the changes in Sehoul are, at least on in the short term, not a result of a higher variability in seasonality, i.e. more extreme seasons due to climate change.

The decrease in NDVI coincides with the observations from the Landsat data and the field. The short term changes that were observed in the hotspots in 2003-2007 were a decrease in NDVI in hotspot 6, were agriculture was modernized to the cultivation of vegetables, grapevines and olives, and in hotspot 2 were patches of forest were cleared (as shown in Annex 2).

X.I Long term trend analysis

Chapter "VIII. Results – Hotspot Analysis" concluded that the changes are the result of socio-economic changes, i.e. demographic changes increasing the pressure on the land of Sehoul, and the modernisation and change of agricultural practices. However, in order to get a more complete picture of the underlying causes of especially the decreasing NDVI in Sehoul, it is in addition interesting to see if there is also a link with the climatological environment of the area. Therefore, this paragraph focuses on long-term trends in precipitation, with data from Rabat-Salé weather station in 1984-2003, in both seasonality and interannual variability.

Antari focussed on the period from 1970 to 2002. However, as the first data included in this research dates from 1984, for this research only the data in the period of 1984-2002 was used in the analysis.

Interannual variability

The annual precipitation recorded in 1984-2002 shows interannual irregularity in a sawtooth pattern (Figure 29), with a maximum of 1163.6 mm in 1996 and a minimum of 249.6 mm 1994. Wet years have up to five times more precipitation than the dry years and standard deviations values reach from from 100% more to 52% less than average.

The average of the period 1984-2002 is 480,8 mm. The 5-year average trendline shows that during some periods, wet years are predominant, while for other periods it is vice versa with a predominance of dry years. A differentiation between the following periods can be made:

→ A less humid period, 1984-1995, where most values are below average, but where the rainfall standard deviation exceeded the average with 47% in 1994. This phase coincides with the exceptional drought experienced in Morocco during this long period.
→ An exceptional year was 1996 that recorded a total annual amount of 1162.6 mm precipitation. This exceeded the average with 145%.
→ Between 1997 and 2002 except 1998 (292mm) and 2002 (686mm), rainfall remained generally close to average.

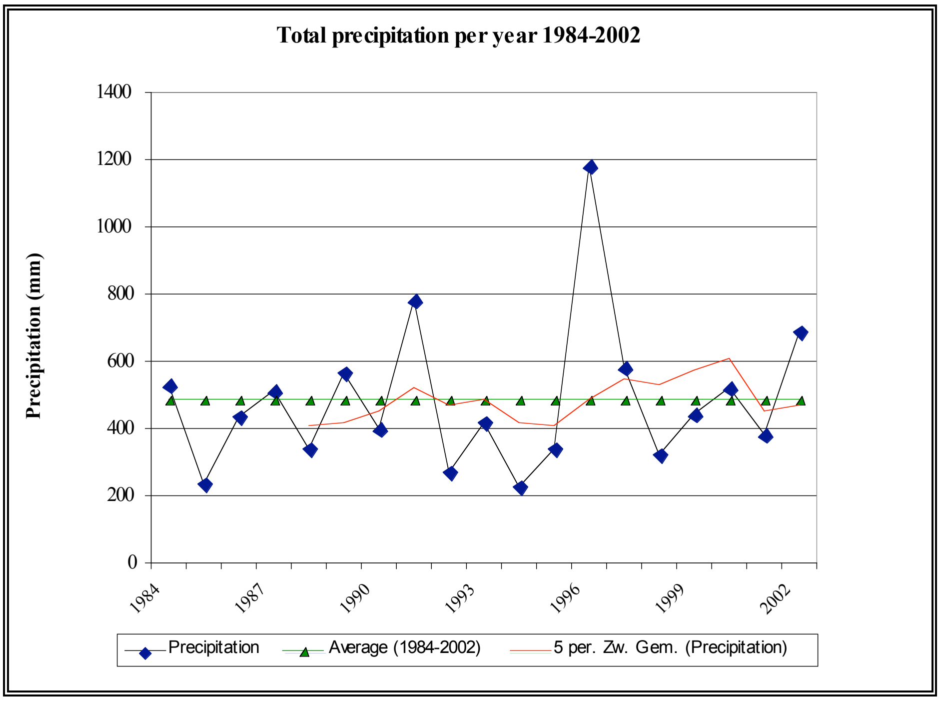


Figure 29 Variation in annual precipitation, Rabat-Salé weather station (1970-2003)

The annual number of rainy days (NRD) indicates a concentration of rainfall over part of the year. In 1984-2002, the NRD is highly variable (figure 30) and ranges between 47 and 118 days per year.

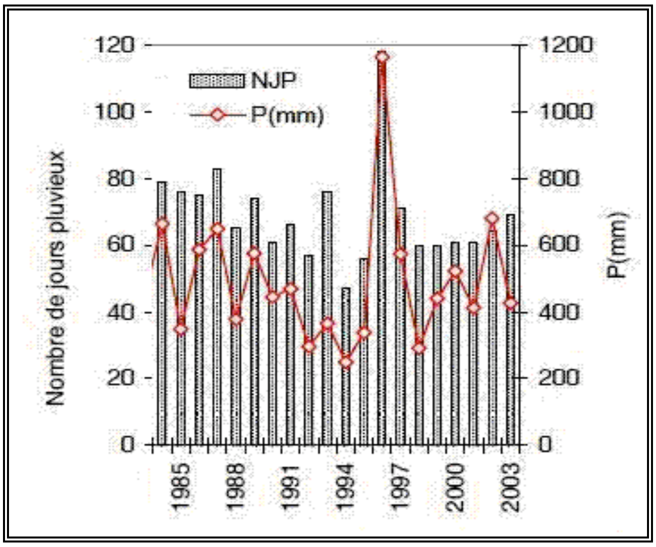


Figure 30 Annual variation in Number of Rainy Days, Rabat-Salé weather station (1970-2003) (Adapted from Antari, 2007)

Seasonal variability

According to Antari's analysis (2007), two seasons can be distinguished in the precipitation patterns of Sehoul. The dry season from May to October/November (5-6 months), and a wet season from October/November to April (5-7 months). The most critical of these wet months are (October,) November and December because, firstly, the precipitation of these months represents about 45% of the annual amount, and secondly because the physical conditions of the basin, e.g. bare soil, are the more vulnerable for erosion and runoff in this period (Antari, 2007). Thus, this concentration and long duration of precipitation and drought phases have a negative impact on both agriculture (yields decline), on vegetation (water stress) and soils (erosion, run off etc).

Summary of results

In the short term analysis, the MODIS data confirmed the conclusions from objective 2, i.e. that the decreasing NDVI (vegetation cover) is caused by changes in not only forest condition but also in land management practices. The fact that this decrease in NDVI is a trend for the whole of Sehoul not only on the long but also on the short term, makes it clear that these, i.e. the change in agricultural practices and the decrease in forest cover/condition, are ongoing processes that should be considered by policy makers in the environmental department.

The long term analysis (1984-2003) shows that the interannual variability is highly irregular, both in yearly precipitation as also in the number of rainy days. Wet and dry periods interchange and there is no clear decrease in annual precipitation that contribute to the decrease of NDVI in Sehoul. However, when looking at the seasonality of the rain, almost half of the annual precipitation is concentrated in (October,) November and December. As this is also the season when the soils are bare (van Dijck et al, 2006; Antari, 2007), this period is particularly prone to erosion.

VIII. DISCUSSION AND CONCLUSIONS

From analysing the hotspot locations of change, it can be said that most of these changes are resulting from the increased pressure on the Sehoul region due to demographic changes, and consequently, the modernization of agriculture and enhancement of using heavy machinery. Resulting from the first point, grazing by livestock has also become one of the most serious and most influential causes for degradation (both of forested and agricultural land) in Sehoul.

However, the relative influence and effect of the causes above is not known. They all contribute to certain problems with degradation in the region, but for instance the effect of Eucalyptus plantations (now seen as a solution to take pressure off the natural forest for wood cutting) on the groundwater levels is not clear. Also, the ratio between the costs and benefits for the regional community of modern agriculture might put a different light on the 'problems' of land and forest degradation in Sehoul.

Also, considering the research itself, is that in 2009, during the months of the fieldwork, Sehoul was very dry from August-December, compared to 1984, 2003 and 2009. Therefore, the conclusions linking field observation to image analysis focus on qualitative rather than quantitative analysis.

The other objective of this study was to validate the WOCAT classification, in this case using the SAM classification. It proved to be accurate and specific enough to indicate the main patterns of land use in the Sehoul research area, and is therefore a suitable method to use in the DESIRE project, as a starting point for studies on degradation and land cover changes. However, for a more into-depth study of a study site, field visits are a necessity to distinguish vegetation types from each other, in Morocco especially between the natural forests and tree plantations. Also, in Sehoul the shifting system for agriculture and grazing land that is used causes misclassifications of badlands in the WOCAT classification. Altogether, the information from the (SAM) WOCAT classification was not accurate enough when looking for more specific information. Therefore, a reclassification was made, based on the field data, which includes the missing features.

This reclassification could still be improved, as especially the distinction between orchards, eucalyptus and natural forest can be better defined, i.e. the classification is not yet perfect. However, the purpose was to show in what manner the image could be reclassified and which classes were to be added.

In the short term analysis confirms that the decreasing (vegetation cover) is caused by changes in not only forest condition but also in land management practices. Additionally, it became clear that the change in agricultural practices and the decrease in forest cover/condition are ongoing processes.
The long term precipitation analysis showed that interannual variability is high but there was not clear indication that this contributes to the decreasing NDVI in Sehoul. The seasonality analysis, however, showed that almost half of the annual precipitation is concentrated in 2-3 months (Oct-Dec). However, especially October and November are then especially prone to erosion, as the soils are dry/dusty from the summer and sometimes not yet ploughed and planted but still bare (Antari, 2007).

Summary of conclusions

Altogether, three phenomena were observed that should be taken into account by policy makers dealing with the environmental and socio-economic sustainability of Sehoul:

1. There is a shift going on from traditional agriculture to horticulture, orchard and vineyards. This results in the increased use of heavy machinery, leading to soil compaction, as well as a higher economic viability of the region.
2. Because of demographic changes, the pressure in and on Sehoul is increasing. This leads to overgrazing and clearance of forests and pastures, resulting in loss of forest, lower forest regeneration rates and water erosion along the river banks.
3. The seasonality of the climate in Sehoul is such that most precipitation is concentrated in 2-3 months of the year. This, in combination with land management practices, results in more erosion than perhaps necessary.

IV. RECOMMENDATIONS

Hereunder, some recommendations are given to take into account for future research and similar studies:

More research is needed on the relative impact of indirect contributors to degradation, before land conservation policies are written for and implemented in Sehoul.

For similar studies, after choosing your satellite images first analyse the precipitation patterns, as to know which differences might be caused by the context in which a specific image was recorded.

To strengthen conclusions and field results, similar data should be gathered during other growing seasons (for agricultural areas only), and field work should be repeated after several years in the same months as to update actual change and to verify if detected trends are indeed valid.

Also, if DESIRE has the wish to use the classification methods for other study sites as well, it is recommended that at least one other field validation is executed at another study site, and to compare the outcomes of both studies. Thereafter, adjustments to the method or additions to classes can be made before applying this for the other study sites.

As Girouard et al (2004) tested in Morocco, SAM classified Landsat TM images are useful especially for unfamiliar areas. However, for more detail, they recommend to use the SAM classification on Quickbird images.

Most important, to conclude, is that more research should be done especially on the third point: what can be change in agricultural practices/cultivation schemes to work around this bottleneck? As this is the most specific point to start working on, policy makers should think about investing in research related to this and how their policies can be adjusted to the changes that Sehoul is undergoing and will have in the future.

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ANNEX 1 – LEGENDS TRANSLATED

A: Legend figure 4 in English

	Quaternary fluvial terraces
	Plio-Quaternary dunes
	Pliocene: calcarenite and marine conglomerates, covered due to fluviatile late-Pleistocene alterations and "spreadings".
	Messinian marls
	Messinian: sandstone base
	Tournaisian and Visean: flysch
	Ordovician, Silurian: hard rock
	Fault

B: Legend Figure 5 in English

	Rough, mineral soils and soils little affected by erosion (Palaeozoic outcrops).
	Slightly developed soils "of the intake" on recent river terraces.
	Isohumic soils with organic horizon on sandy formations of Mamora.
	Isohumic soils
	Calcareous-magnesian soils on marl slopes.
	Fersiallitique leached stony soils on fluvial Plio-Quaternary formations.
	Brunifiés soil.
	Hydromorphic soils of interdune furrows and dayas, low in humic properties.

ANNEX 2 – ANALYSIS HOTSPOT 2

Part of hotspot 2 lies outside of the research area. In figures 31 and 32, the part of hotspot 2 is shown that was taken into account in the image processing results and the final hotspot analysis.

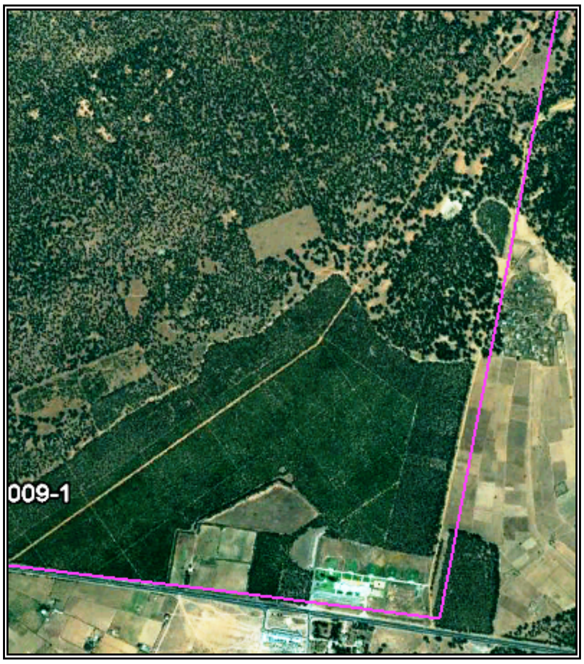

Figure 31 Hotspot 2 - 30/08/04 Google Earth

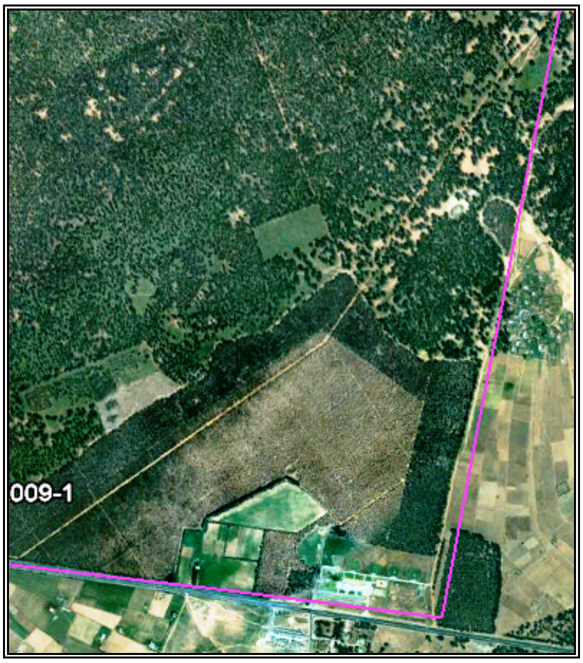

Figure 32 Hotspot 2 - 13/07/07 Google Earth

ANNEX 3 – MODIS DATA ON FOREST HOTSPOTS

The following graphs show the MODIS data for the forested areas of Sehoul, of respectively NDVI, LST and Albedo.

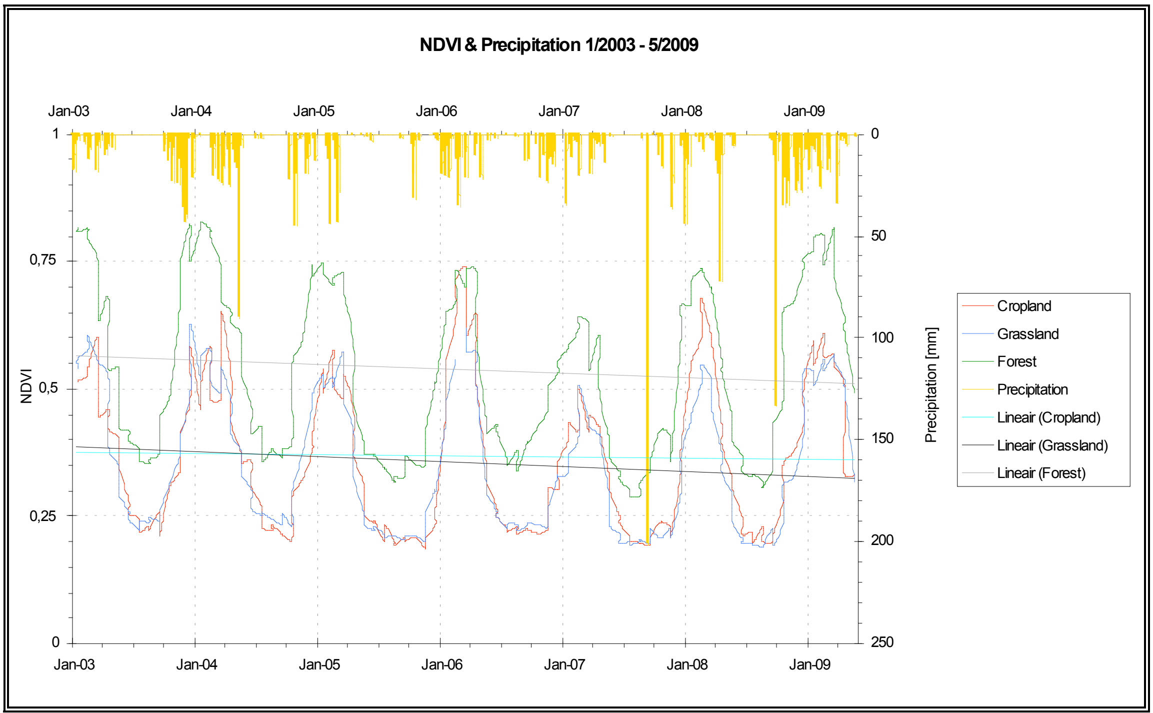

Figure 33 NDVI & P for September 2000-2008

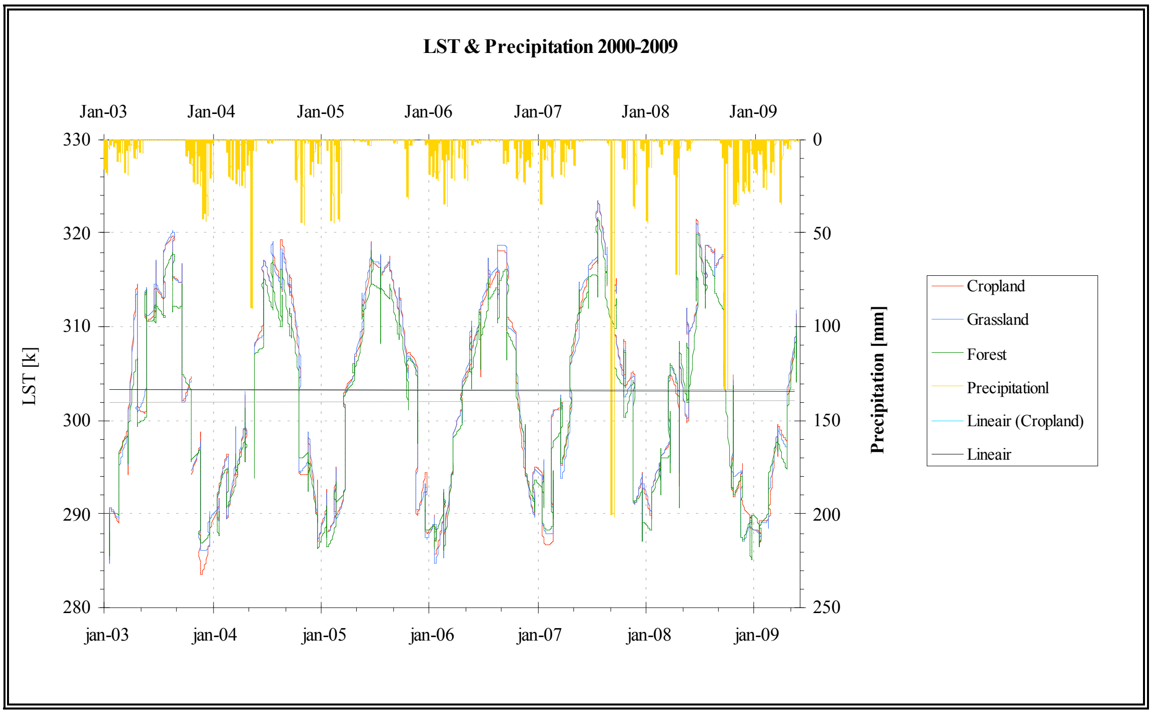

Figure 34 LST & P for September 2000-2008

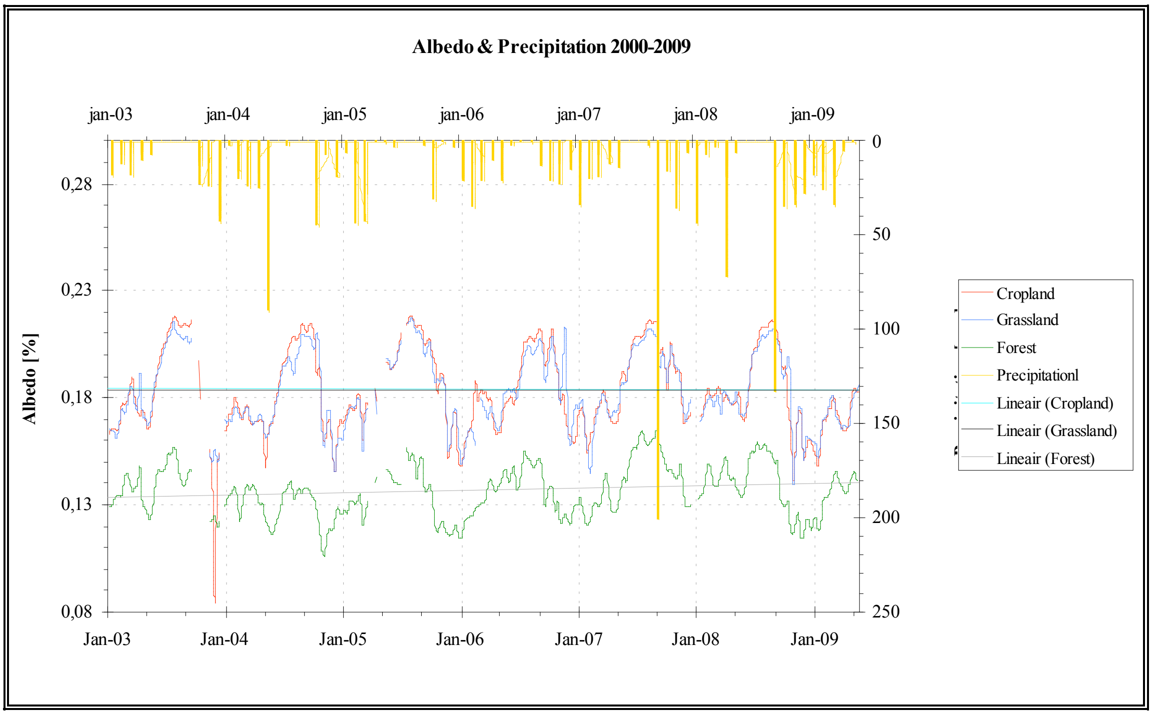

Figure 35 Albedo & P for September 2000-2008

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