Project

Impact Evaluation of the Sustainable Land Management Practices for achieving Land Degradation Neutrality in Tunisia

Technical report

Land cover changes in Tunisia using MODerate Resolution Imaging Spectroradiometer (MODIS) MCD12Q1 yearly products

April 2017

Badabate Diwediga

Abstract

Land cover is one of the important components of the global geosphere-biosphere-atmosphere continuum and equilibrium. Regular information on land cover is necessary for a continuous monitoring of the Earth's ecological balance. This study used the MODIS MCD12Q1 yearly data at 500 m resolution to evaluate the spatio-temporal changes in the national land cover of Tunisia. Land cover maps were generated for two years (2001 and 2013) and evaluated by other existing Global Land Cover data (Globcover, Google Earth) and field collected data sets. The overall evaluation accuracies were 63 % and 78 % for the maps of 2013 and 2001, respectively. Areal distribution analysis showed that barren/sparse vegetation areas were the most important LUC types in Tunisia for both years (68.07 % and 62.43 % in 2001 and 2013, respectively), indicating an area loss. Agricultural areas were of 2279722.04 ha (14.70 %) in 2001 and 2938599.54 ha (18.95 %) in 2013. The proportion of forests increased (more than double) from 0.27 % in 2001 to 0.57 % in 2013. Most important changes showed that the highest gain proportions occurred in the mosaic forest-savanna-grassland (7.22 %) and agricultural areas (5.15 %). Globally, there is a net increase of agricultural lands of about 659250 ha (4.25 % of the national lands) over the period 2001-2013. With the spatial resolution of the MODIS data, and the time window considered, caution should be given to the conclusions derived in this study. Further detailed studies using finer resolution satellite images could give more insights to the real changes occurred in specific land use/cover type at the country level.

Keywords: MODIS MCD12Q1, Land cover analysis, Change detection

TABLE OF CONTENTS

List of figures

List of tables

Acronyms and abbreviations

FAO	: Food and Agriculture Organisation of the United Nations
GDP	: Gross Domestic Product
GLC	: Global Land Cover
GPS	: Global Positioning System
HDF-EOS	: Hierarchical Data Format-Earth Observing System
IGBP	: International Geosphere-Biosphere Programme
KIA	: Kappa Index of Agreement
LADA	: Land Degradation Assessment in Drylands
LAI-FPAR	: Leaf Area Index and Fraction of Photosynthetically Active Radiation
LCCS	: Land Cover Classification System
LUC	: Land Use Cover Change
LUCC	: Land Use Cover
MCD12Q1	: MODIS Land Cover Type Product
MEA	: Millenium Ecosystem Assessment
MODIS	: MODerate-resolution Imaging Spectro-radiometer
NPP	: Net Primary Productivity
OA	: Overall Accuracy
PFT	: Plant Functional Type
SAEZ	: Socio-Agro-Ecological Zone
UMD	: University of Maryland
WGS	: World Geodetic System

1. Introduction

Over the early stage of the humanity, natural landscapes are being affected by human activities. Major transformations occurred during the last centuries, with large natural landscapes converted into multifunctional and more fragmented landscapes (Foley *et al.*, 2005; Ellis, 2011; Gaia, 2011). Occurring at different scales (local, regional or global, the factors influencing these landscape changes expand from the biophysical and socio-economic settings to the political, historical, and institutional environments (Geist and Lambin, 2002; Lambin *et al.*, 2003; Schulz *et al.*, 2011). Landscapes are managed for production (e.g. appropriation of land productivity), cultural (e.g. recreational and ritual landscapes), conservation (e.g. preservation of strategic areas and resources) and adaptation to new evolving environmental conditions (e.g. changes in land uses). From the tropics to the temperate and desert zones, landscape transformation still occurs at different rates and time scales.

As lands provide a wide range of ecosystem services (MEA, 2005), it is important to have a regular monitoring of the changes and processes affecting them. For instance, degradation and loss of natural vegetation reduce ecosystem services provision (e.g. water infiltration, runoff regulation, soil erosion control, recharge of groundwater, climate regulation, etc.) (Foley *et al.*, 2005; MEA, 2005)Nevertheless, it has always been a serious challenge to develop appropriate and timely data, especially at national, continental and even global scales, in order to monitor the land cover and ecosystem services. However, in the past decades, new and continuous efforts are developed to provide timely, free and reliable information at different spatial resolutions useful for monitoring the Earth surface processes (Zhang *et al.*, 2006; Zhao *et al.*, 2013), even though attention should be paid to the consistency, accuracy and suitability among different GLC products,(Dong *et al.*, 2012; Liang *et al.*, 2015), and with the local land cover patterns. The several GLC data include mostly Globcover (Bicheron *et al.*, 2008); MODIS (Friedl *et al.*, 2010); GLC2000 (Bartholomé and Belward, 2007), GlobeLand30 (Chen *et al.*, 2015), etc.

In Northern Mediterranean Africa, landscape change and land degradation are critical issues for landscape conservation, management and planning. Landscapes of the Mediterranean basin are undergoing crucial environmental problem manifest through soil degradation and desertification (Salvati, 2014; Salvati *et al.*, 2014). Human activities (e.g. land use changes, unsustainable crop intensification, poor rangeland management, etc.) and climate change are the main factors leading to the landscape transformation and desertification. Historical land uses coupled with harsh climatic conditions favoured these changes in the landscape architecture and surface cover. In Tunisia with 33.2 % of rural population (about 3.73 million of people) and agriculture representing 9 % of the total GDP (FAOstat, 2014), increasing pressures on land resources concerns mostly agriculture expansion and livestock overgrazing which expand the rate of land degradation process. Tunisia is known as one of the countries with high proportions of its lands under high degradation level. The usage of satellite imagery in the monitoring and evaluation of land conditions has gain a lot of attention. For instance, LADA project (2006 - 2010) analysed the land cover changes in Tunisia over the period 1990-2005 using Landsat data with a LCCS detailing 94 LUC types (LADA, 2010). Since MODIS MCD12Q1 is used widely for the monitoring of Earth surface, and has an annual updating cycle, the purpose of this paper is to investigate the usefulness of this data for land cover change analysis at Tunisian national scale. A quantitative analysis of landscape evolution between 2001 and 2013 was performed based on the yearly products. The motivation for this study is to discuss the potential usage of such free available data for quick monitoring of land cover change at national scale. This could be help for land degradation/improvement monitoring, biological conservation and climate-related studies, and national planning.

2. Methodology

2.1. Study area

Tunisia is in the Northern Africa in the Mediterranean basin between 32˚ - 38˚ N and 7˚-12˚ E. It covers an area of 163 610 km^2. The country is bordered by Mediterranean Sea at North and East, Libya Arab Republic at the South-Eastern parts, and Algeria Republic in the West (Figure 1). The biophysical and socio-economic information below are retrieved from the national environmental profile (Anonymous, 2012). The country has 24 governorates, which are the main administrative units, divided into 264 municipalities/delegations. The population is about 10.5 million inhabitants of whom 70% are settled in coastal areas. Tunisia has about 1300 km coastal line with the Mediterranean Sea. Great part of the national lands has arid climate. The climate is influenced by oceanic and Saharan winds as well as the mountain chain “Dorsale Tunisienne”. In the north, the climate is Mediterranean type, while it is semi-arid in the central part and arid in the south. Mean temperature over the country vary between 12 ˚C in December and 30 ˚C in July. Mean annual rainfall is 1000 mm in the north, about 380 mm in the centre, and 100 mm in the extreme south-west. The rainfall is mostly concentrated between October and March. Evapotranspiration is high and reaches 1200 mm in the north and 1800 mm in the south. Relief is multiform and elevation reaches 1544 m above sea level in the Dorsale Tunisienne. Terrestrial ecosystems comprise forest lands in the north, steppes in the south-central parts. In the southern areas, landscapes are dominated by sparse steppes with some isolated patches of humid vegetation specific to water points. This mosaic of landscapes in combination with the climate patterns define the land use systems across the country. The northern areas are mostly agro-sylvo-pastoral whereas the centre and the south are mostly agro-pastoral and pastoral, respectively. Main crops are cereals (wheat mostly), tree crops (olive, almond), forage crops, and market gardening. Animal husbandry concerns mainly small ruminants (sheep, goats) and some poultry and dairy cows. Fishing is highly developed with 41 fishing harbours and 165 fish transformation plants. The environmental risks in the country are mostly floods, droughts and forest fires. Tunisia is known as a country with high level of land degradation associated with the harsh climatic conditions.

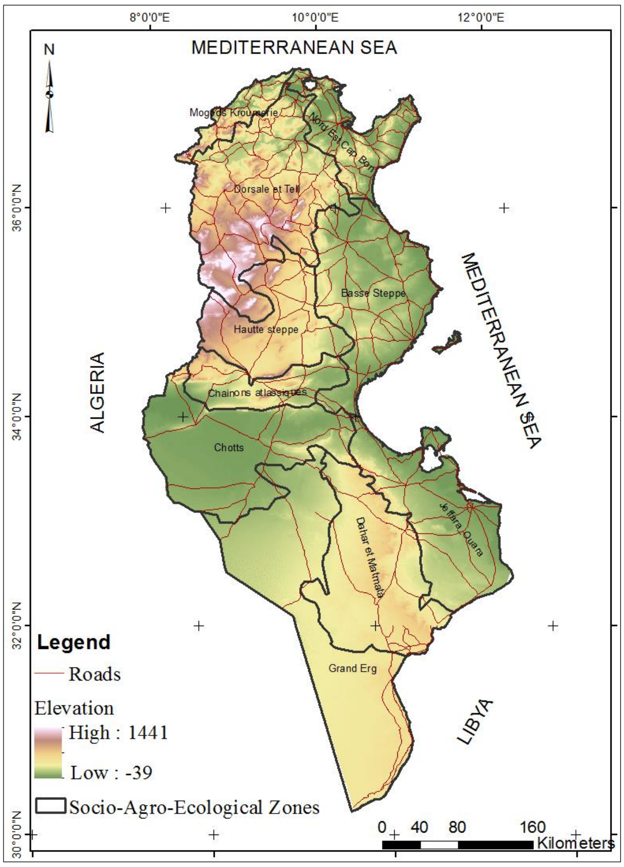

Figure 1. Map showing national lands of Tunisia

2.2. Overall work flow

This work is undertaken to provide broad LUC/LUCC classes for Tunisia in 2001 and 2013. It was basically developed following three steps:

- Dataset gathering and harmonization prior land cover mapping (see section 2.3). This step focused on the different data used in this work.

- Mapping and evaluation of the broad land cover types based on the retrieved datasets (Section 2.4). The methodological approach for achieving LUC mapping was the focus of this step.
- Post-classification analyses which comprises the accuracy assessment (confusion matrix) of the LUC maps, and the analysis of the broad categorical LUC changes (i.e. aggregation of LUCC directions) (Section 2.5).

2.3. Datasets

In this study, different data types were used, including land cover data (MODIS MCD12Q1, Globcover), satellite imagery (Google Earth) (Table 1). In addition, field data (GPS data) were collected during field works.

Table 1. Data used and sources

Data	MCD12Q1	GlobCover 2009	GoogleEarth
Format	HDF-EOS	Geotiff	
Projection	Sinusoidal	WGS84 (Plate-Carree)	Lat/Long
Acquisition dates	2001 and 2013; yearly observation data (01 Jan – 31 Dec)	2004-2006	2001 and 2013
Resolution	500 m	300 m	1 m
Sources	http://reverb.echo.nasa.gov	http://esa.gov	Google Earth (kh.google.com)

- **MODIS MCD12Q1 yearly data**

MODIS is an imaging spectroradiometer instrument that has data of spatial resolution ranging from 250 m to 1 km, depending on the spectral bands (Barnes *et al.*, 1998). The MODIS land cover type product (MCD12Q1), revised for inconsistency in previous release (Friedl *et al.*, 2010), was used in this study (Table 1). This dataset consists of processed yearly observations from the Terra and Aqua instruments. The MCD12Q1 product is generated by applying a decision tree algorithm on annual basis over a ten-year period (2001-2010) with about 2,000 training sites worldwide used to train the decision tree classifier (Friedl *et al.*, 2010). The MCD12Q1 dataset consists of five land cover classification systems: IGBP (International Geosphere-Biosphere Programme) global vegetation classification scheme; UMD (University of Maryland) vegetation classification scheme based on the modified IGBP classification system; LAI/FPAR scheme adopted by MODIS Leaf Area Index and Fractional Photosynthetically Active Radiation (LAI/FPAR) products (MOD15); NPP scheme adopted by the MODIS net primary productivity (NPP) product (MOD17); and Plant Functional Type (PFT) land cover classification scheme.

The global MODIS land cover product is mostly useful for global and continental applications (Park and Suh, 2014). However, this data available at 250 and 500 m can also be used to map broad and quick overview of the land cover dynamics at regional and national levels (Wessels, 2004; Kaptué Tchuenté *et al.*, 2011; Levin and Heimowitz, 2012; Liang *et al.*, 2015). The purpose of the MCD12Q1 is to provide reliable dataset for mapping human impacts on land cover at large scale (Wessels, 2004). As this MODIS MCD12Q1 has an annual updating cycle, the dataset provides more timely product for monitoring Earth surface through different applications (Wessels, 2004; Dong *et al.*, 2012; Liang *et al.*, 2015). For this research, interest was given to the MCD12Q1 data updated in 2014 for the year 2001 and 2013. The time period covered by the chosen data ranges from 1 January to 31 December of each of the selected year. The dataset used for this study is based on the IGBP classification scheme (Table 2), which provide more consistency with fine resolution dataset (Liang *et al.*, 2015). Full list of the MODIS data classification schemes is provided in Annex 1.

Table 2. MODIS yearly data MCD12Q1 IGBP and the legend of land cover types **(Sources: modis.gsfc.nasa.gov)**

Class	MCD12Q1 IGBP	Class	MCD12Q1 IGBP	Class	MCD12Q1 IGBP
0	Water	7	Open shrublands	14	Cropland/Natural vegetation mosaic
1	Evergreen Needleleaf forest	8	Woody savannas	15	Snow and ice
2	Evergreen Broadleaf forest	9	Savannas	16	Barren or sparsely vegetated
3	Deciduous Needleleaf forest	10	Grasslands	254	Unclassified
4	Deciduous Broadleaf forest	11	Permanent wetlands	255	Fill Value
5	Mixed forest	12	Croplands		
6	Closed shrublands	13	Urban and built-up		

- **Globcover dataset**

The datasets utilized are Globcover data (Bicheron *et al.*, 2008) (Table 1) used as the reference data in combination with Google Earth images. Schulp and Alkemade (2011) showed that this dataset has reasonable and good accuracy level for mapping ecosystem functions, and therefore could be used in land cover mapping. With the lack of high resolution satellite images for reference data, Globcover dataset are currently considered to be the most suitable GLC product for evaluating the consistency of MCD12Q1. In addition, Google Earth images were used to check the reliability of the MODIS MCD12Q1 data. The Globcover land cover product is the first 300 m global land cover map available for 2004-2006. This data was useful for iterating the verification (validation of the mapped land cover types from the MODIS MCD12Q1 data for the year 2001. This data has been used for its consistency at regional and global level, developed based on consistent reference data from all over the world. The primary legend file of the Globcover data is given in Table 3.

Table 3. Land cover types defined in the Globcover 2009 dataset (Bicheron et al. 2008).

Value	Label
11	Post-flooding or irrigated croplands (or aquatic)
14	Rainfed croplands
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
50	Closed (>40%) broadleaved deciduous forest (>5m)
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
70	Closed (>40%) needleleaved evergreen forest (>5m)
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
150	Sparse (<15%) vegetation
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
190	Artificial surfaces and associated areas (Urban areas >50%)
200	Bare areas
210	Water bodies
220	Permanent snow and ice
230	No data (burnt areas, clouds…)

- **Google Earth data**

GE images have been used for land cover mapping based on the interpretation of their spectral characteristics (Hu *et al.*, 2013; Jacobson *et al.*, 2015). Google Earth images are provided by the high resolution Quickbird satellite at a resolution of 1 m. In this study, Google Earth imagery (from Google Earth Pro; Table 1) was useful in collecting reference data for the evaluation of the MODIS-based reclassified images. The reference data was collected through visual interpretation of sampled sites.

- **Field datasets**

Field data were obtained through field campaigns during which GPS coordinates were gathered based on randomly across the visited sites. These points served as references to correct some of misclassified pixels of the MODIS reclassified data of 2013. Because the spatial resolution of the MODIS data (500 m) is very rough to be verified by the GPS points, care was taken to ensure that the GPS points are collected within large homogenous areas.

2.4. Mapping and evaluation of the broad LUC types

In this study, the MCD12Q1 yearly data of two dates (2001 and 2013) were used to give an overview of landscape changes at national level in Tunisia. Since the IGBP MODIS data are classification products, they were reclassified by aggregating the original classes. Based on the aggregation of the 94 LUC types national LUC scheme used by the LADA project (LADA, 2010), seven land cover types were defined and used to reclassify the original two datasets of MODIS (MCD12Q1 of 2001 and 2013). This allowed to have a broad overview of the LUC classes in Tunisia at large scale. The primary MODIS land cover types were aggregated into two categorical maps: 7 types and 10 types (Table 4).

The MODIS reclassified land cover products were evaluated by comparing with the selected training areas (based on Google Earth and GPS data) and with the homogenous areas of the Globcover data (Wessels, 2004). This was applied to provide some insights to the reclassification in terms of accuracy assessment and discussion purposes although the MODIS and the reference data (Globcover, Google earth and GPS truth data) are not of the same spatial resolution (Foody, 2002; Wessels, 2004). Broadly, the validation of MODIS data was performed with ground measurements (collected during field campaigns), Google Earth images and Globcover data (which are considered “truth” for this work even though there is less accuracy information of such data at the national level) (Hall and Riggs, 2007). The comparison is basically a matching approach through a confusion matrix in order to identify the mismatching or classification errors in MODIS data assuming the Globcover reliability is high enough based on its spatial resolution (0.3 km). The Globcover data was used to check consistency of the MODIS 2001 map for the Globcover data were developed for the year 2004 which is much closer to the evaluated year 2001.

The Globcover based LUC types were reprojected, resampled at 500 m, and reclassified to match the spatial resolution of the MCD12Q1 products (Table 4). Class consistency and agreement of Globcover data with MODIS data were firstly performed. Class merging to allow their matching with the MODIS data in order to facilitate better comparison. Resampling of Globcover to the MODIS resolution was necessary to ensure good sampling of the reference data for the validation of the reclassified MODIS data of 2001. In total, 526 pixels were randomly selected on the MODIS based map and Globcover map to perform the confusion matrix for the map of 2001. Further, samples were randomly generated from ArcGIS tool and used as ground truth data to evaluate the classification of MODIS data. Based on the samples, land cover information were collected from the visual interpretation of Google Earth images of March 2013 which often corresponds to the end of rainy season in Tunisia. Only point features were generated through on-screen digitising in the Google Earth engine, with care given to ensure a homogeneity of the features over large coverage. The 260-field collected GPS points were used to iterate on Google Earth and detect the corresponding broad cover types defined for this study.

Table 4. Reclassification scheme proposed for mapping the broad land cover types of Tunisia. Data used (MODIS MCD12Q1 at 0.5 km) evaluated by the Globcover 2009 data (at 0.3 km resampled to 0.5 km)

Order	Codes		Reclassifications (Codes + names)	
	Class codes in MCD12Q1 - IGBP	Codes in GlobeCover 2009	Reclassification 1 (7 classes)	Reclassification 2 (10 classes)
1	0-15	210	1 = Water	1 = Water
2	1	70	2 = Forests	2 = Needleleave forests
3	2	40	2 = Forests	3 = Broadleave forests
4	3	90	2 = Forests	2 = Needleave forests
5	4	50	2 = Forests	3 = Broadleave forests
6	5	100	2 = Forests	4 = Mixed forests
7	6-7-8-9-10	110-120-130	3 = Savanna-forest-grassland	5 = Mosaic forest-savanna-grassland
8	11	170	4 = Wetlands	6 = Permanent wetlands
9	12	14	5 = Agricultural lands	7 = Croplands
10	13	190	6 = Artificial areas	8 =Artificial areas
11	14	20-30	5 =Agricultural lands	9 = Mosaic croplands-natural vegetation
12	16	150-200	7 = Barren/sparse vegetation	10 = Barren/sparse vegetation

The overall accuracy – OA (i.e. the percentage of random points that are the same in both classified and reference images) and the Kappa Index of Agreement (KIA i.e. the percentage expressing whether the classification scheme achieved results better than by chance) were calculated for the 7-class land cover maps using equations 1 and 2. The Overall accuracy (OA) is the proportion of the well classified pixels from the reference data (n) to the total number of pixels used as reference data for the accuracy assessment (N).

$$\mathrm{OA} = \frac{\mathrm{n}}{\mathrm{N}} \qquad \text{(Equation 1)}$$

$$\mathrm{KIA} = \frac{\mathrm{Observed}-\mathrm{Expected}}{1-\mathrm{Expected}} \qquad \text{(Equation 2)}$$

where Observed is the overall accuracy as calculated above, and Expected is the proportion of the sum of the product matrix of all well classified pixels of all LUC types to the cumulative sum of all the product matrix.

2.5. Mapping the LUCC categories over the period 2001-2013

Land cover change (LUCC) was mapped and evaluated through post-classification procedure (Schulz et al, 2010). This allowed to obtain maps of change and the transition matrix among land cover types. LUCC (in ha) was calculated as the difference between the areas of each LUC type in both years. The relative proportion of LUCC (in %) for the period 2001-2013 ($LUCC_{2001-2013}$) was calculated based on the change relatively to the initial year (2001) considering the areas of a given LUC type *i* in 2001 (LUC_{2001}) and 2013 (LUC_{2013}), as in Equation 1:

$$LUCC_{2001-2013} = \frac{LUC_{2013} - LUC_{2001}}{LUC_{2001}} \qquad (1)$$

Furthermore, the spatial patterns of LUCC categories (*catLUCC*$_{2001\text{-}2013}$, where *cat* can be *gain*, *loss* or *unchanged*) were analysed in terms of gains, losses and unchanged of areas for the different LUC types. The statistics of each LUCC process were computed using the relative proportion of change based on the initial year (2001).

$$gainLUCC_{2001-2013} = (\sum_{i=n} LUCC_{i\to j})/LUCj \qquad (2)$$

where $LUCC_{i\to j}$ is the area gain of a targeted LUC type *j* in 2013 from the other LUC types *i* in 2001.

$$lossLUCC_{2001-2013} = (\sum_{j=n} LUCC_{j\to i})/LUCj \qquad (3)$$

where $LUCC_{j\to i}$ is the area loss of a targeted LUC type *j* in 2001 to the other LUC types *i* in 2013.

The *unchangedLUCC2001-2013* are computed as the relative percentage of the persistence areas of each LUC type to its initial area in 2001.

$$unchangedLUCC_{2001-2013} = (LUCC_{j\rightarrow j})/LUCj \qquad (4)$$

where $LUCC_{j\rightarrow j}$ is the area of a targeted LUC type j in 2001 which remained unchanged in 2013.

3. Results

3.1. Spatial patterns and areal distribution of LUC types in 2001 and 2013

The spatial patterns of the different land cover types are shown in Figures 2 and 3. Both maps showed that forest areas occurred in the northern along the coastal line in the two socio-agro-ecological zones (SAEZ) of Nord Est Cap Bon and Mogods Kroumerie. In the same northern areas, agricultural lands, mostly cereal crops are more dominant, especially in the Dorsale Tell and Nord Est Cap Bon. In the southern parts, the landscapes are dominated by bare soils and sparse vegetation, with some agricultural landscapes not captured through the MODIS images. This is the case of the Grand Erg, Dahar-Matmata, Jeffara-Ouarra, and Chotts.

The areal distribution of different land cover types is shown in Table 5. Barren/sparse vegetation areas were the most important LUC types in Tunisia for both years (68.07 % and 62.43 % in 2001 and 2013, respectively). Agricultural areas expanded from 2279722.04 ha (14.70 %) in 2001 to 2938599.54 ha (18.95 %) in 2013. This indicates an increase in agricultural areas between the two dates. The proportion of forests increased (more than the double) from 0.27 % in 2001 to 0.57 % in 2013. Water bodies, including both natural and man-made water bodies and permanent wetlands, experienced slight increase.

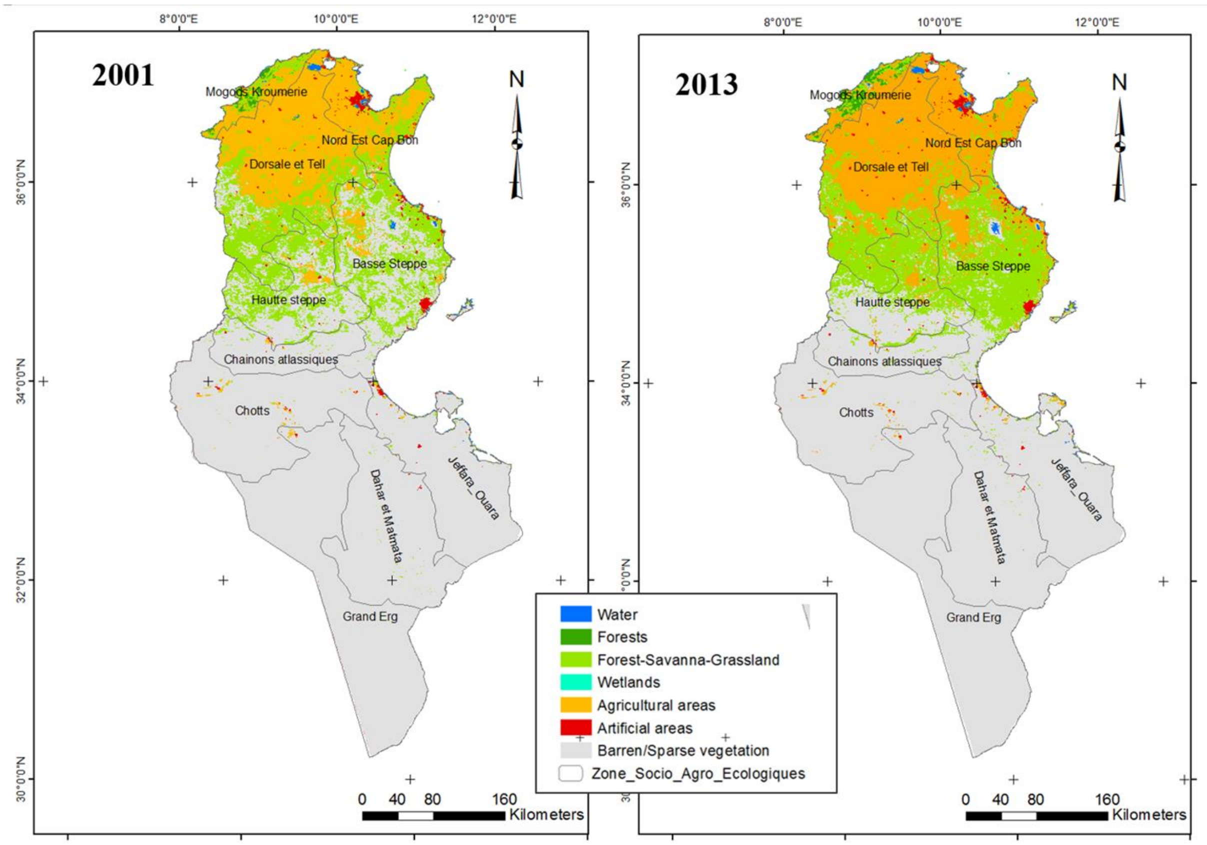

Figure 2. Land cover maps of the 7 categories based on MODIS yearly land cover data**.**

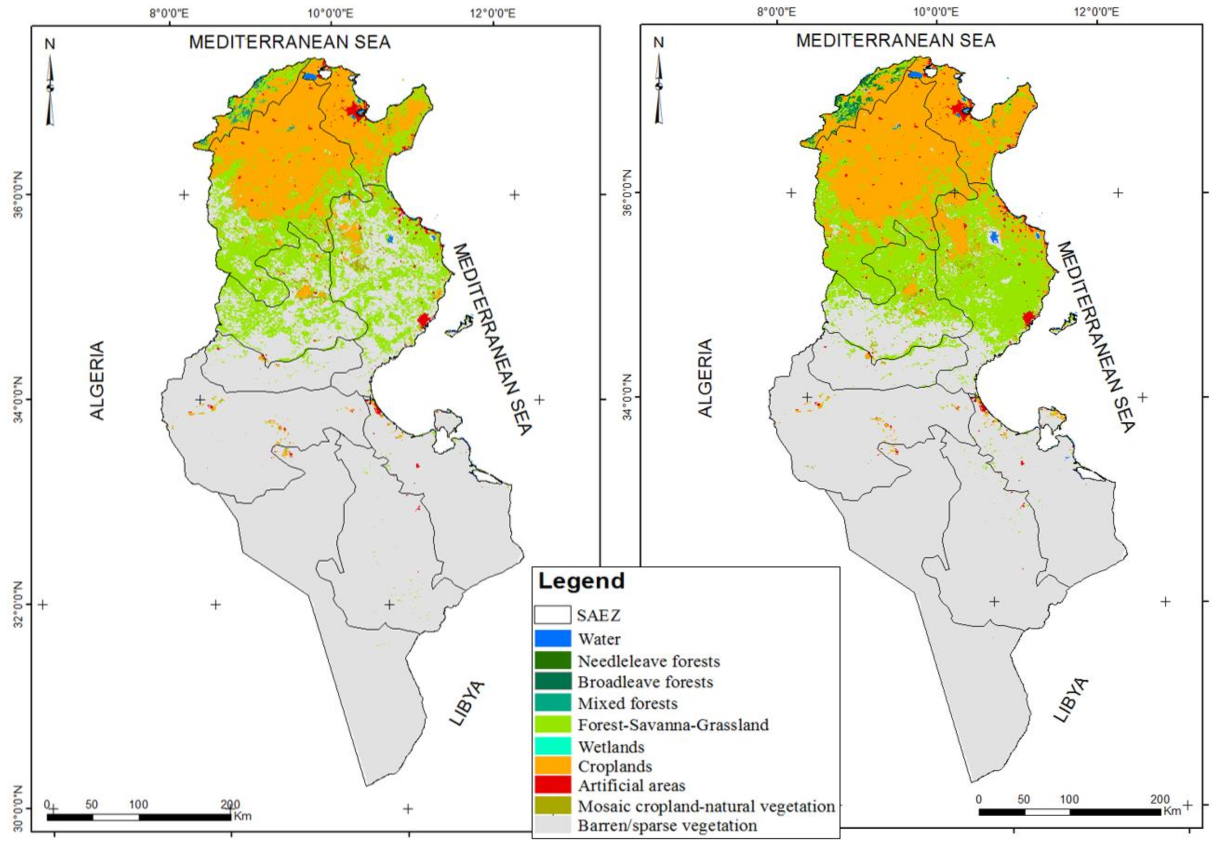

Figure 3. Land cover maps of 10- categories based on MODIS yearly land cover data.

Table 5. Areal statistics of the broad LUC types in Tunisia for 2001 and 2013

		LUC classes	Areas (in ha and %)				LUCC (in ha) for 2001-2013
			2001		2013		
			Area (ha)	%	Area (ha)	%	in ha
7 classes	1	Water	43777.37	0.28	45528.52	0.29	1751.15
	2	Forests	41094.96	0.27	88999.49	0.57	47904.53
	3	Forest-Savanna-Grassland mosaic	2464316.49	15.89	2625209.54	16.93	160893.05
	4	Permanent wetlands	1115.15	0.01	6069.97	0.04	4954.83
	5	Agricultural lands	2279722.04	14.70	2938599.54	18.95	658877.50
	6	Artificial areas	122087.67	0.79	121377.73	0.78	-709.94
	7	Barren/sparse vegetation	10554889.26	68.07	9681449.17	62.43	-873440.09
10 classes	1	Water	43800.10	0.28	45553.44	0.29	1753.35
	2	Needleleave forests	563.29	0.00	30744.63	0.20	30181.35
	3	Broadleave forests	10911.21	0.07	29445.92	0.19	18534.70
	4	Mixed forests	29088.06	0.19	27388.90	0.18	-1699.16
	5	Forest-Savanna-Grassland	2467331.02	15.91	2629644.49	16.90	162313.47
	6	Permanent wetlands	1115.15	0.01	15971.41	0.10	14856.26
	7	Croplands	2169411.93	13.99	2848086.04	18.31	678674.10
	8	Artificial areas	122238.83	0.79	131300.55	0.84	9061.72
	9	Cropland-natural vegetation mosaic	107165.44	0.69	107037.20	0.69	-128.24
	10	Barren/Sparse vegetation	10555383.25	68.07	9691473.94	62.30	-863909.31

Table 6. Evaluation outputs of the MODIS MCD 12Q1 reclassification for the year 2013

		Classified data 2013								OA	KIA
		LUC1	LUC2	LUC3	LUC4	LUC5	LUC6	LUC7	Total		
Reference data 2013	LUC1	2	0	1	0	3	0	0	6		
	LUC2	0	7	5	0	14	0	0	26		
	LUC3	0	0	12	0	12	0	23	47		
	LUC4	1	0	2	1	6	0	6	16		
	LUC5	0	0	15	0	55	0	37	107		
	LUC6	0	0	2	0	1	4	6	13		
	LUC7	0	0	4	0	0	0	149	153		
	Total	3	7	41	1	91	4	221	230		
OA										**0.63**	
KIA											**0.44**

Note: LUC1 = Water; LUC2 = Forests; LUC3 = Forests-savanna-grassland; LUC4 = Wetlands; LUC5 = Agricultural lands; LUC6 = Artificial lands; LUC7 = Barren/Sparse vegetation. KIA = Kappa Index of agreement; OA = Overall accuracy of the classification.

Table 7. Evaluation outputs of the MODIS MCD 12Q1 reclassification for the year 2001

		Classified data 2001									
Reference data 2001		LUC1	LUC2	LUC3	LUC4	LUC5	LUC6	LUC7	Total	OA	KIA
	LUC1	9	0	0	0	0	0	0	9		
	LUC2	1	3	1	0	5	0	0	10		
	LUC3	2	0	3	0	26	2	47	80		
	LUC4	4	0	0	0	0	0	0	4		
	LUC5	1	0	2	0	56	1	13	73		
	LUC6	1	0	0	0	3	4	2	10		
	LUC7	1	0	0	0	5	0	334	340		
	Total	19	3	6	0	95	7	396	526		
	OA									**0.78**	
	KIA										**0.54**

Note: LUC1 = Water; LUC2 = Forests; LUC3 = Forests-savanna-grassland; LUC4 = Wetlands; LUC5 = Agricultural lands; LUC6 = Artificial lands; LUC7 = Barren/Sparse vegetation. KIA = Kappa Index of agreement; OA = Overall accuracy of the classification.

According to Tables 6 and 7, the assessment of the classification outputs resulted in OA of 0.63 and 0.78 for 2013 and 2001, respectively. The values of KAI were of 0.54 and 0.44 % for 2001 and 2013, respectively. There was significant confusion between water (LUC1) and permanent wetlands (LUC4) for the two periods. Because of the class representativeness, the random sampling could not capture classes with small areal coverage. In the classified 2001 map, about 27 % of the mapped agricultural lands (LUC5) were mosaic Forest-Savanna-Shrubland (LUC3) in the reference data. This is mostly due to the high occurrence of tree crops in Tunisia which look like LUC3. Similar confusion was noticed for the year 2013. Furthermore, bare/sparse vegetation (LUC7) were confused to LUC5 and LUC3 for both years. In 2001, the confusion of water to other LUC types can be attributed to the MODIS spatial resolution (0.5 km) which does not allow to capture small patches easily datable by finer resolution images (Google Earth).

In sum, the overall accuracy of the 2001map look much better because the types of reference data used in validating the reclassified maps were almost of similar resolution (Globcover 0.3 km resampled to 0.5 km). Meanwhile, the accuracy of the 2013 map is low because coarse resolution of MODIS could not capture smaller pixels collected as reference data through GPS and google earth. There was a mixture of different land cover types within the coarse resolution of MODIS pixels of 500 m. This reveals the importance of considering scale and spatial resolution in the land cover classification process in order to avoid errors due to the mismatch between datasets.

3.2. Land use cover types per socio-agro-ecological zones of Tunisia

The spatial patterns of the land cover types per socio-agro-ecological zone of Tunisia are provided in Figures 3.1 to 3.10. The statistics of the different land cover types are provided in Tables 8 to 18.

- **Socio-agro-ecological zone "Haute Steppe"**

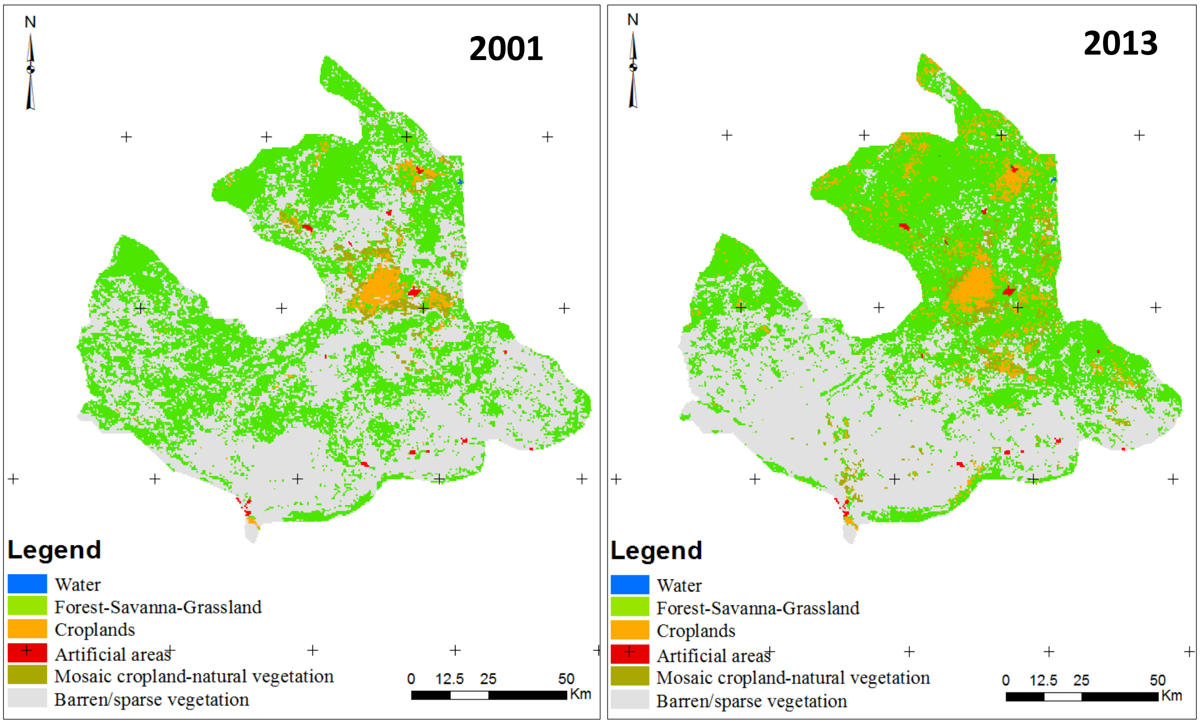

Figure 4.1. LUC maps for the SAEZ "Haute Steppe"

Table 8. Statistics of the land use/cover types in SAEZ "Haute steppe"

		2001	2013	[(2013-2001)/2001]
Haute Steppe	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	1	150	125	-0.17
	2	0	50	
	5	545125	565950	0.04
	7	28125	70150	1.49
	8	3750	3750	0.00
	9	21950	27325	0.245
	10	642500	574250	-0.11

- **Socio-agro-ecological zone "Basse Steppe"**

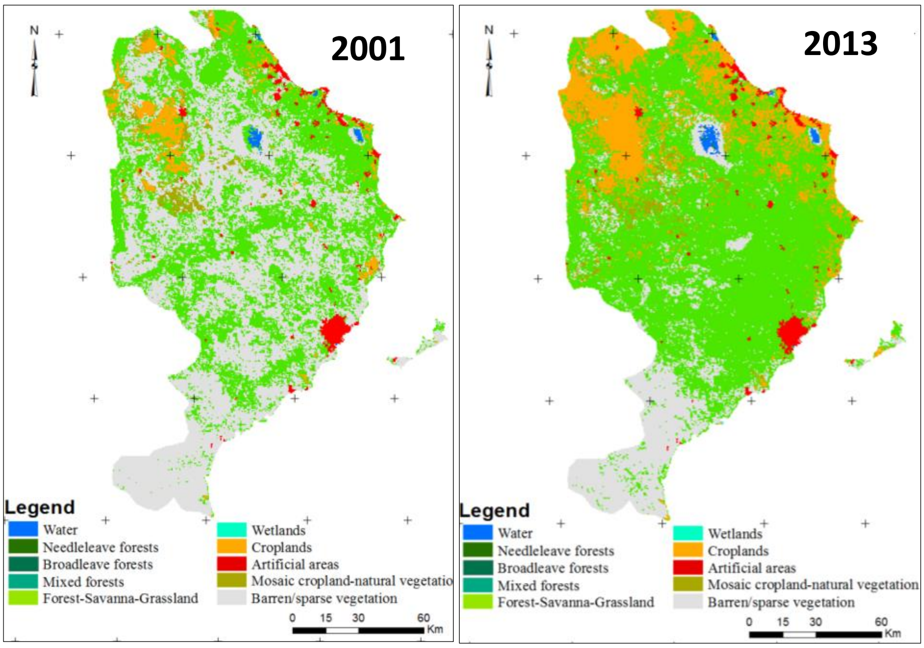

Figure 4.2. LUC maps for the SAEZ "Basse Steppe"

Table 9. Statistics of the land use/cover types in SAEZ "Basse steppe"

		2001	**2013**	**[(2013-2001)/2001]**
Basse steppe	**LUC**	**Area (Ha)**	**Area (Ha)**	**Relative change (%)**
	1	6275	10050	0.60
	2	0	625	--
	5	763100	1121575	0.47
	6	0	100	--
	7	83275	315775	2.79
	8	37825	37825	0.00
	9	38775	41375	0.07
	10	928400	330325	-0.64

- **Socio-agro-ecological zone "Chainons Atlasiques"**

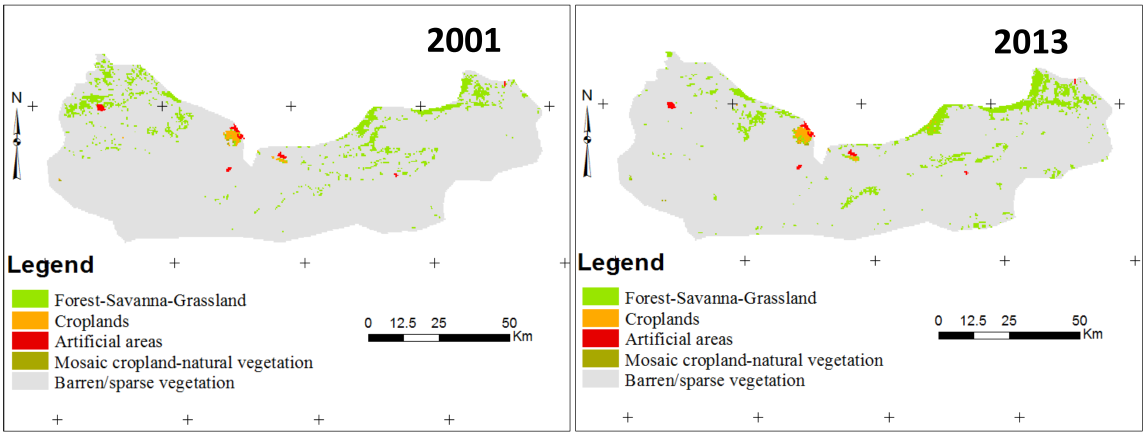

Figure 4.3. LUC maps for the SAEZ "Chainons Atlasiques"

Table 10. Statistics of the land use/cover types in SAEZ “Chainons Atlasiques”

		2001	2013	[(2013-2001)/2001]
Chainons Atlasiques	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	5	41000	44300	0.08
	7	2050	2750	0.34
	8	2125	2125	0.00
	9	225	425	0.89
	10	653025	648825	-0.01

- **Socio-agro-ecological zone “Chotts”**

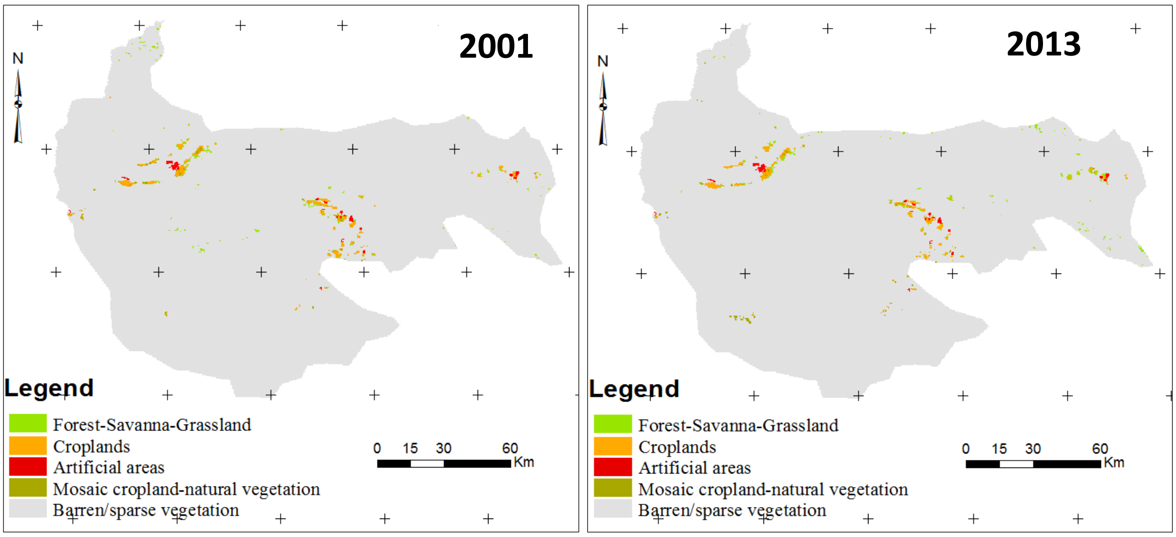

Figure 4.4. LUC maps for the SAEZ “Chotts”

Table 11. Statistics of the land use/cover types in SAEZ “Chotts”

		2001	2013	[(2013-2001)/2001]
Chotts	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	5	6475	7150	0.10
	7	13700	12375	-0.09
	8	3800	3800	0.00
	9	3025	3425	0.13
	10	1935725	1935975	----

- **Socio-agro-ecological zone "Dahar et Matmata"**

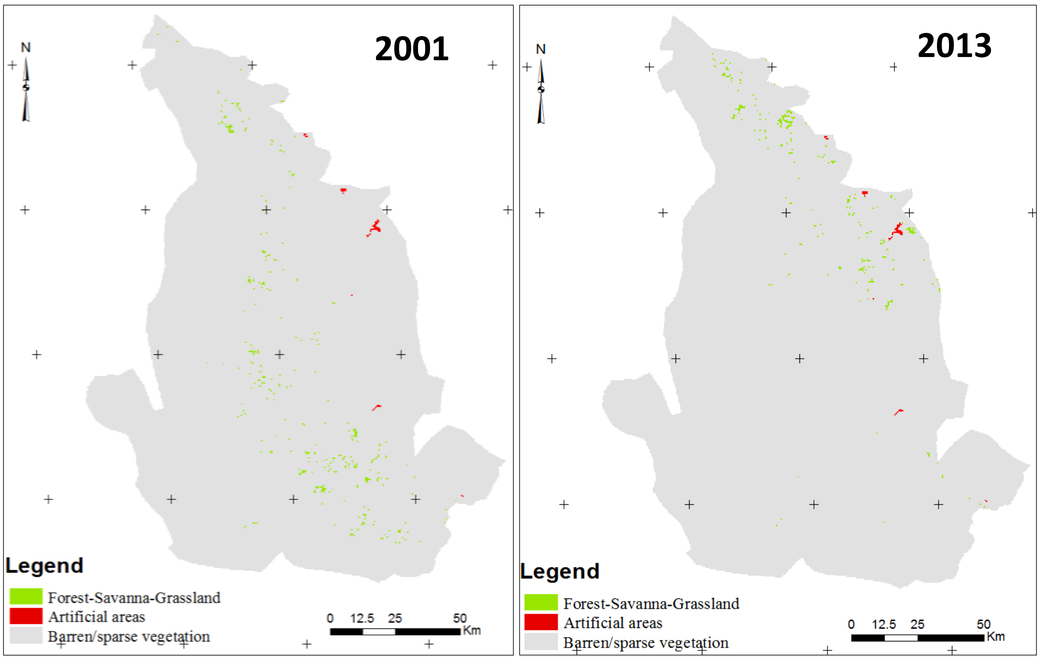

Figure 4.5. LUC maps for the SAEZ "Dahar et Matmata"

Table 12. Statistics of the land use/cover types in SAEZ "Dahar et Matmata"

		2001	2013	[(2013-2001)/2001]
Dahar et Matmata	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	5	9725	7825	-0.20
	8	1550	1550	0.00
	10	1866200	1868100	0.001

- **Socio-agro-ecological zone "Dorsale et Tell"**

Table 13. Statistics of the land use/cover types in SAEZ "Dorsale et Tell"

		2001	2013	[(2013-2001)/2001]
Dorsale - Tell	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	1	900	1350	0.50
	2	100	1425	13.25
	3	0	125	0.00
	4	775	550	-0.29
	5	760950	653225	-0.14
	6	0	50	0.00
	7	1349275	1642075	0.22
	8	14000	14000	0.00
	9	23350	12775	-0.45
	10	214300	38075	-0.82

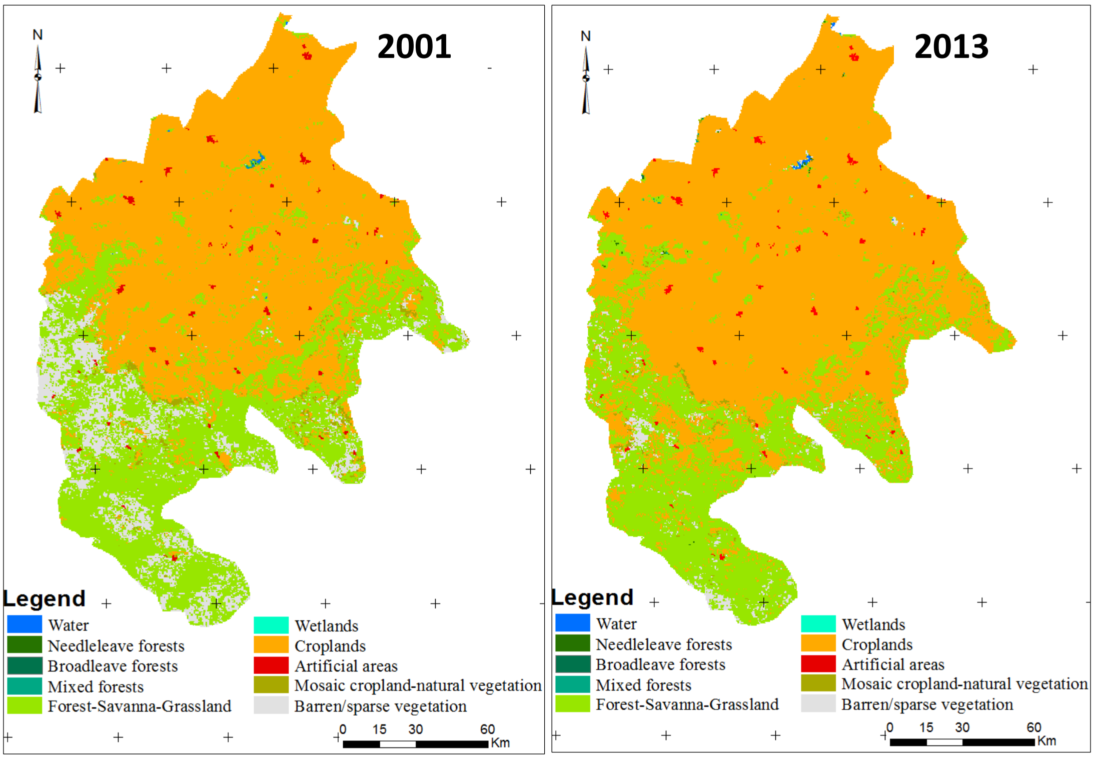

Figure 4.6. LUC maps for the SAEZ “Dorsale et Tell”

- **Socio-agro-ecological zone “Grand Erg”**

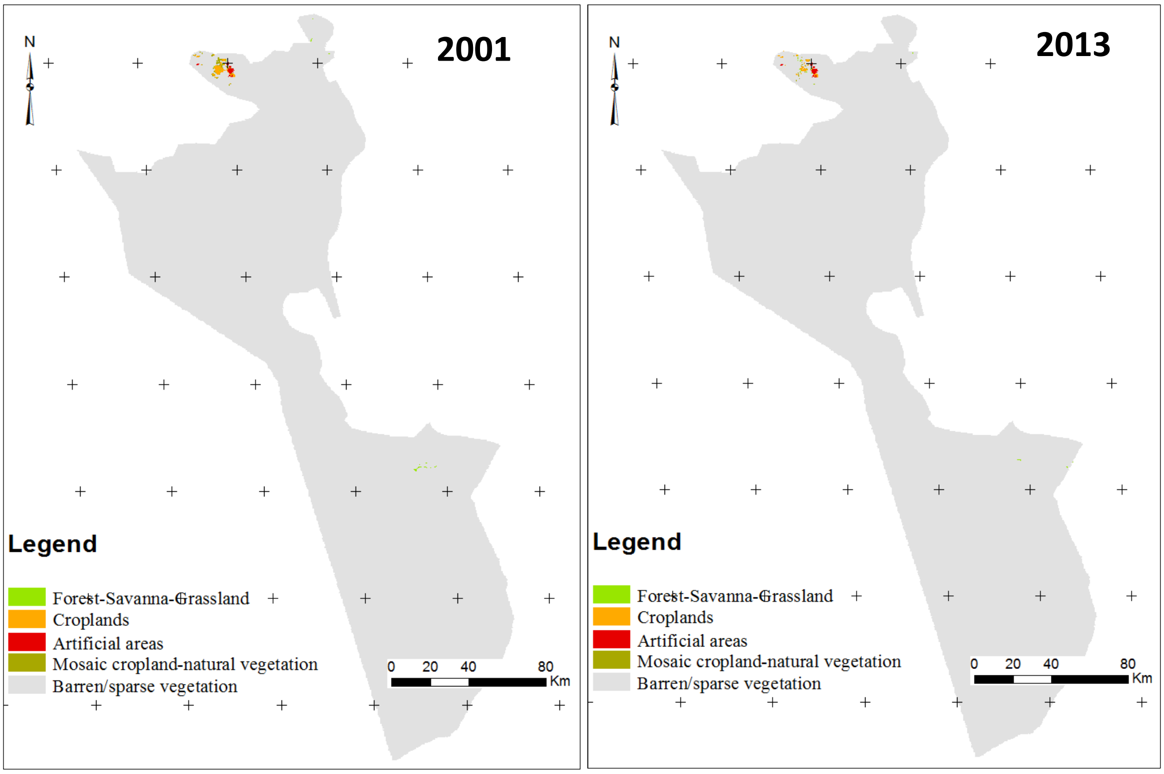

Figure 4.7. LUC maps for the SAEZ “Grand Erg”

Table 14. Statistics of the land use/cover types in SAEZ "Grand Erg"

		2001	2013	[(2013-2001)/2001]
Grand Erg	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	5	850	700	-0.18
	7	3150	1775	-0.44
	8	1225	1225	0.00
	9	1575	500	-0.68
	10	2711950	2714550	0.001

- **Socio-agro-ecological zone "Jeffara et Ouara"**

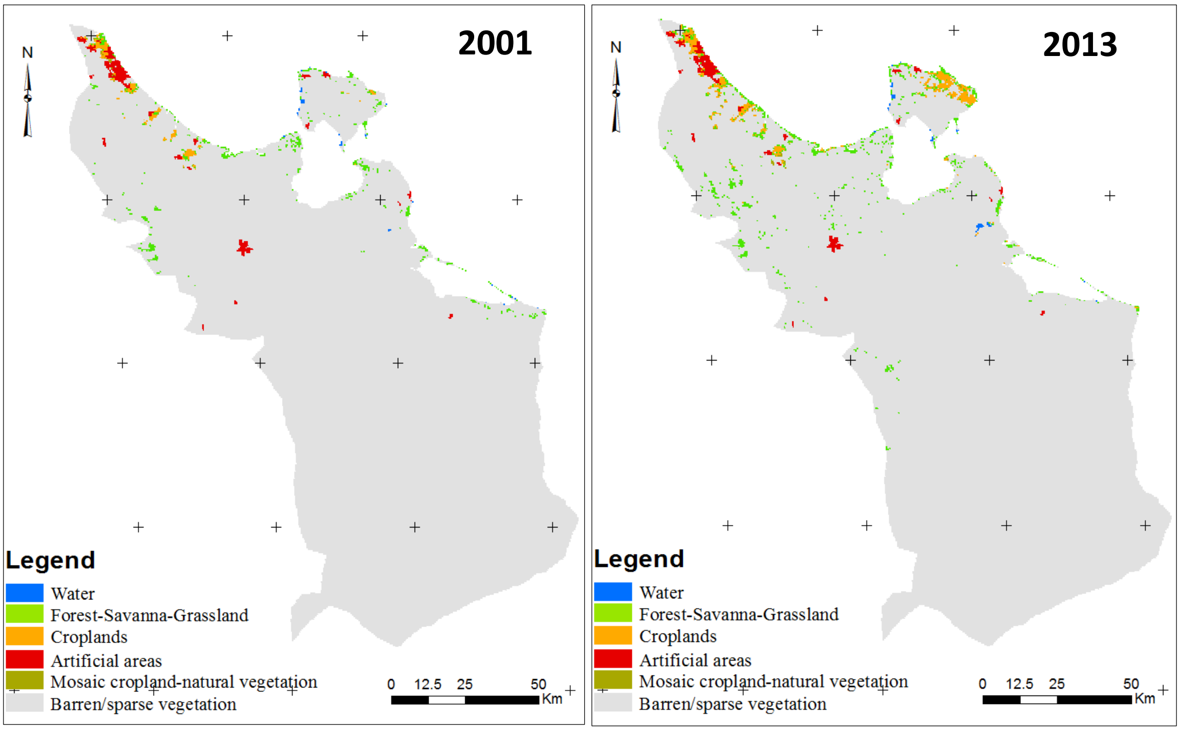

Figure 4.8. LUC maps for the SAEZ "Jaffara et Ouara"

Table 15. Statistics of the land use/cover types in SAEZ "Jeffara Ouara"

		2001	2013	[(2013-2001)/2001]
Jeffara Ouara	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	1	1025	1300	0.27
	5	13450	24375	0.81
	7	5575	14350	1.57
	8	9650	9650	0.00
	9	575	1150	1.00
	10	1549075	1528525	-0.01

- **Socio-agro-ecological zone “Mogods - Kroumerie”**

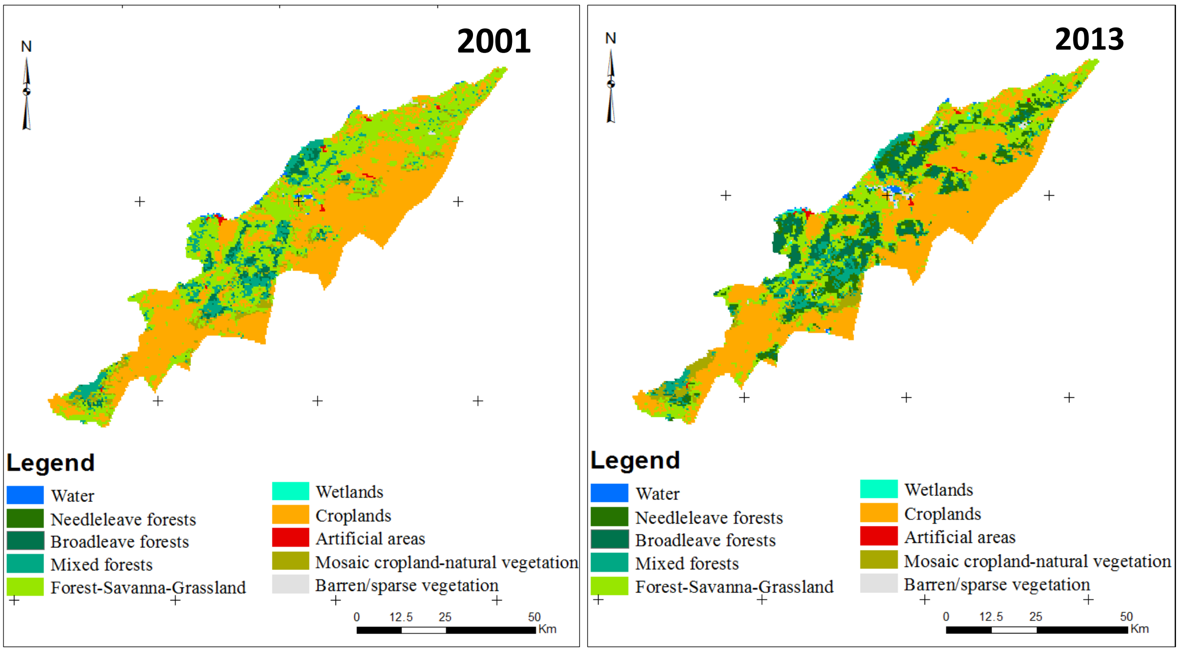

Figure 4.9. LUC maps for the SAEZ “Mogods – Kroumerie”

Table 16. Statistics of the land use/cover types in SAEZ “Mogods Kroumerie”

		2001	2013	[(2013-2001)/2001]
Mogods Kroumerie	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	1	1450	1725	0.19
	2	275	27400	98.64
	3	10925	28225	1.58
	4	26900	23875	-0.11
	5	110725	77675	-0.30
	6	175	1125	5.43
	7	151925	141700	-0.07
	8	1475	1475	0.00
	9	14575	13675	-0.06
	10	675	2225	2.30

- **Socio-agro-ecological zone “Nord Est et Cap Bon”**

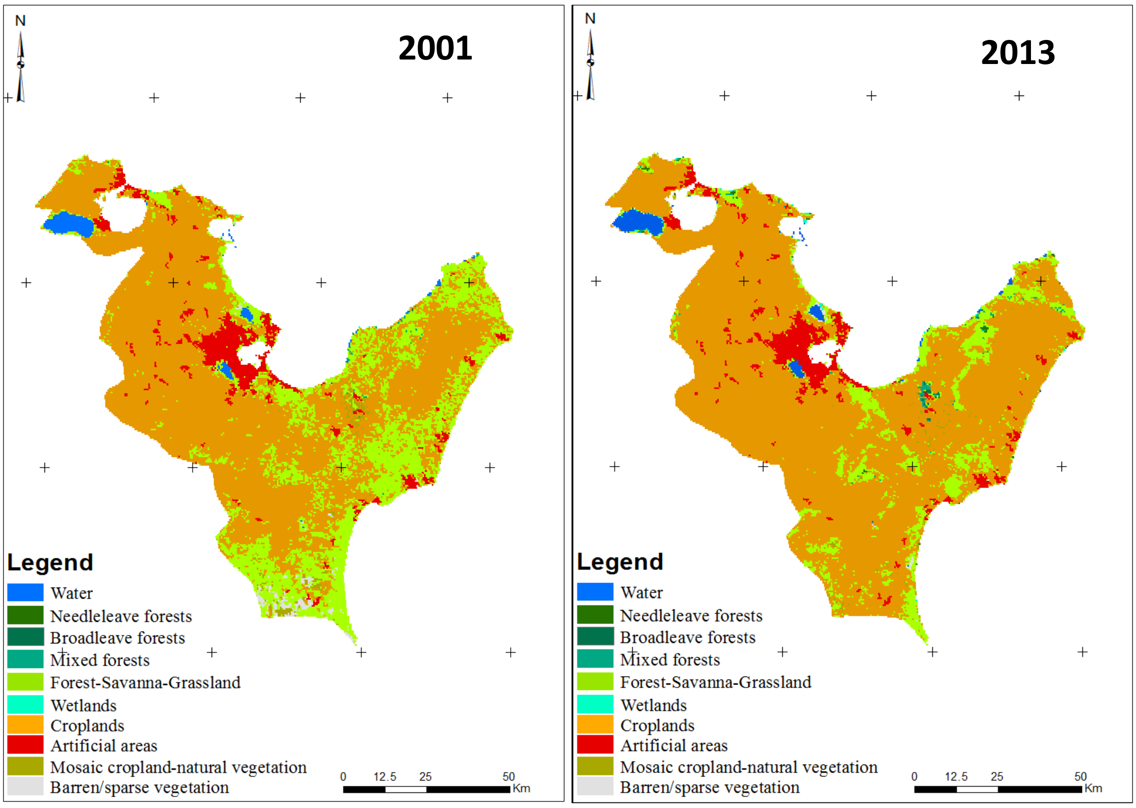

Figure 4.10. LUC maps for the SAEZ “Nord Est et Cap Bon’’

Table 17. Statistics of the land use/cover types in SAEZ “Nord Est et Cap Bon”

		2001	2013	[(2013-2001)/2001]
Nord Est Cap Bon	LUC	Area (Ha)	Area (Ha)	Relative change (%)
	1	10800	11450	0.06
	2	50	1525	29.50
	3	100	700	6.00
	4	700	2825	3.04
	5	203350	88375	-0.57
	6	125	1075	7.60
	7	523525	641950	0.23
	8	44975	44950	-0.001
	9	8225	3700	-0.55
	10	6800	2100	-0.69

3.3. Land use/cover changes over 2001-2013 in Tunisia

Between 2001 and 2013, the different LUC types experienced different changes (gains, losses and net changes) and stability in different locations (Figure 3). Most changes occurred in the northern and centre-north of the country. Even though, some changes might have occurred in between the two dates, this study assumes that there was no change in between the two dates. On this basis, Table 8 shows that the highest gain proportions occurred in the mosaic forest-savanna-grassland (7.22 %) and agricultural areas (5.15 %). These proportions are relatively calculated regarding the national total area. As far as the area losses are concerned, the most important loss was in the barren/sparse vegetation (7.89 %) and forest-savanna-grassland mosaic (6.22 %). Agricultural areas lost only little proportion (less than 1 % of the total national area) probably imputable to land abandonment. Globally, there is a net increase of agricultural lands of about 659250 ha (4.25 % of the national lands) over the period 2001-2013. This proportion was the highest positive net change that has affected the different LUC types. During the same period, the area of barren/sparse vegetation reduced by 5.61 % (approximatively 870087.41 ha). This could be due to agricultural expansion or vegetation improvement in these lands with less vegetation.

Table 18. Areal statistics of the LUCC types in Tunisia for the period 2001 - 2013

LUC TYPES	GAINS		LOSSES		NET CHANGE		UNCHANGED	
	Area (ha)	%	Area (ha)	%			Area (ha)	%
Water	9922.79	00.06	8315.03	00.05	1607.77	0.01	35196.79	00.23
Forests	54545.16	00.35	8104.65	00.05	46440.51	0.30	32902.76	00.21
Forest-savanna-grassland	1119201.35	07.22	964137.34	06.22	155064.02	1.00	1455727.54	09.39
Wetlands	5416.35	00.03	532.02	00.00	4884.33	0.03	591.01	00.00
Agricultural lands	797997.88	05.15	138747.38	00.89	659250.50	4.25	2141810.25	13.81
Artificial areas	141.01	00.00	103.11	00.00	37.90	0.00	122460.26	00.79
Barren/sparse vegetation	353332.54	02.28	1223419.95	07.89	-870087.41	-5.61	9319547.14	60.10
Other changes	13166781.11	84.91	13163920.45	84.89	-----	-----	2399031.61	15.47

Note: Negative values in net change column mean there was an overall decrease of the calculated area

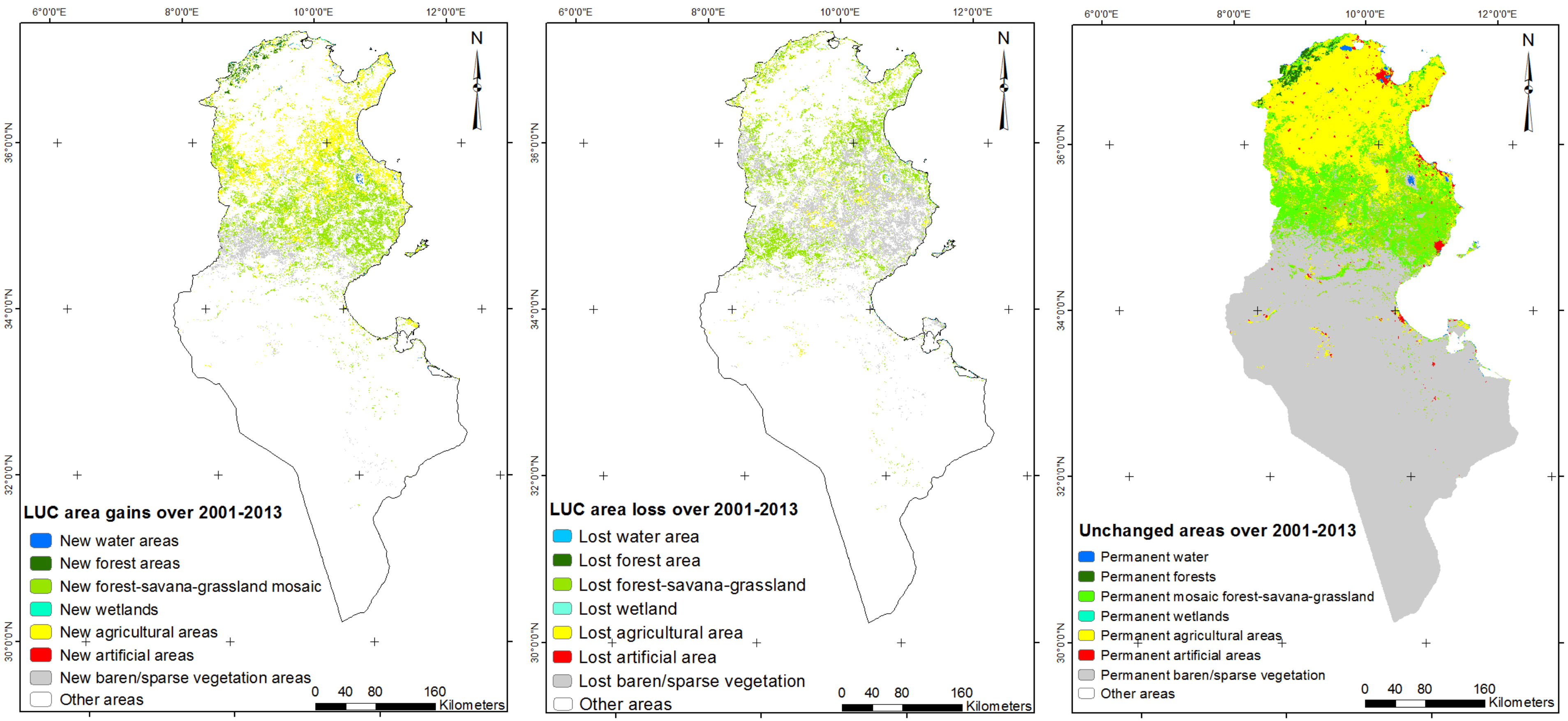

Figure 5. Spatial patterns of LUCC over 2001-2013 in Tunisia

4. Conclusions

Based on the dynamic monitoring of land cover in 13 years (2001-2013) using MODIS MCD12Q1data, the results showed that land cover in Tunisia underwent different changes between 2001 and 2013. The most important changes were the expansion of agricultural lands, and the mosaic forest-savanna-grassland, and the shrinking of the bare/sparse vegetation areas. Even though, one can argue that there was not a real decrease of the bare/sparse vegetation areas because of the class confusion, the usefulness of MODIS to capture landscape dynamics over very large areas has been shown through this study. Mostly, smaller patches of LUC types (e.g. wetlands, small water bodies such as dams and lakes, and forests, etc.) were probably under evaluated for they were not mapped through the MODIS data (0.5 km resolution). These details of land cover types provide basics for understanding landscapes functional typology, their resilience and fragmentation level as well as biodiversity/ecosystem service assessment. Regarding the spatial patterns, high proportions of changes occurred in the central north and northern parts of the country which concentrate high population density.

Based on MODIS MCD12Q1 IGBP dataset, the mapping of broad land cover types at large scale (national level) was successful to some extent. As indicated by Wessels et al. (2004), land cover mapping using MODIS dataset provides cheaper and faster monitoring tool although some limitations exist regarding the used coarse resolution to monitor landscape change. In addition to the biases generated by the poor resolution of MODIS data, the usage of multi sources of data with different scales could have introduced other inconsistencies in the land cover change analysis. Furthermore, the complexity of landscapes, and the differences of class definition among different classification schemes of the land cover products used in this study, also affects the agreement/overall accuracy of the produced maps (Hao and Gen-Suo, 2015). However, this combination provided insight into the possibility of relying on multi-source data to address historical reference data scarcity. This study also was helpful to quickly have an overview of the land cover dynamics for national land monitoring purposes.

With the numerous factors inducing uncertainty in the classification of satellite images into land cover types, cautious should be given to the classification outputs. For land monitoring over large scales, this study has shown the potential of available coarse resolution imagery and datasets. In line with previous studies (LADA, 2010), this study has demonstrated the perpetual changes occurring in Tunisia. However, for conservation initiatives, and local development projects, it will be valuable to conduct deeper studies using medium to finer resolution (e.g. Landsat, Sentinel, Aster, etc.) to depict the inner details of different land cover types. (Kaptué Tchuenté *et al.*, 2011) showed the limitations related to the usage of global land cover datasets in mapping areas with heterogenous landscapes. In this case, while MODIS serves at mapping broad cover types at national level, specific studies could use detailed land cover classification schemes such as the national validated one used by LADA project (2006-2010), for local and more targeted areas. This could allow the analysis and better understanding of the contribution of different factors to the land degradation and improvement towards the enhancement of land degradation neutrality efforts.

5. References

Anonymous, 2012. Profil environnemental de la Tunisie. European Union, p. 182.

Barnes, W.L., Pagano, T.S., Salomonson, V.V., 1998. Prelaunch characteristics of the Moderate Resolution Imaging Spectroradiometer (MODIS) on EOS-AM1. . IEEE Transactions on Geoscience and Remote Sensing 36, 1088-1100.

Bartholomé, A.S., Belward, E., 2007. GLC2000: a new approach to global land cover mapping from Earth observation data. Int. J. Remote Sens. 26, 1959-1977.

Bicheron, P., Defourny, P., Brockmann, C., Schouten, L.V., C., Huc, M., Bontemps, S., Leroy, M., Achard, F., Herold, M., Ranera, F., Arino, O., 2008. Globcover products description and validation report. Medias-France, Toulouse, France, p. 47 pp.

Chen, J., Chen, J., Liao, A., Cao, X., Chen, L., Chen, X., He, C., Han, G., Peng, S., Lu, M., 2015. Global land cover mapping at 30m resolution: A POK-based operational approach. ISPRS J. Photogramm. Remote Sens. 103, 7-27.

Dong, J., Xiao, X., Sheldon, S., Biradar, C., Duong, N.D., Hazarika, M., 2012. A comparison of forest cover maps in Mainland Southeast Asia from multiple sources: PALSAR, MERIS, MODIS and FRA. Remote Sensing of Environment 127, 60-73.

Ellis, C.E., 2011. Anthropogenic transformation of the terrestrial biosphere. Phil. Trans. R. Soc A 369, 1010-1035.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, S.F., al., e., 2005. Global consequences of land use. Science 309, 570-573.

Foody, G.M., 2002. Status of land cover classification accuracy assessment. Remote Sensing of Environment 80, 185-201.

Friedl, M.A., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A., Huang, X., 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. Remote Sensing of Environment 114, 168-182.

Gaia, V., 2011. An epoch debate. Science 334, 32-37.

Geist, H.J., Lambin, E.F., 2002. Proximate causes and underlying driving forces of tropical. Bioscience 52, 143-150.

Hall, D.K., Riggs, G.A., 2007. Accuracy assessment of the MODIS snow products. Hydrological Processes 21, 1534-1547.

Hao, G., Gen-Suo, J., 2015. Spatial and Quantitative Comparison of Satellite-Derived Land Cover Products over China. Atmospheric and Oceanic Science Letters 5, 426-434.

Hu, Q., Wu, W., Xia, T., Yu, Q., Yang, P., Li, Z., Song, Q., 2013. Exploring the Use of Google Earth Imagery and Object-Based Methods in Land Use/Cover Mapping. Remote Sensing 5, 6026-6042.

Jacobson, A., Dhanota, J., Godfrey, J., Jacobson, H., Rossman, Z., Stanish, A., Walker, H., Riggio, J., 2015. A novel approach to mapping land conversion using Google Earth with an application to East Africa. Environmental Modelling & Software 72, 1-9.

Kaptué Tchuenté, A.T., Roujean, J.-L., De Jong, S.M., 2011. Comparison and relative quality assessment of the GLC2000, GLOBCOVER, MODIS and ECOCLIMAP land cover data sets at the African continental scale. International Journal of Applied Earth Observation and Geoinformation 13, 207-219.

LADA, T., 2010. Land cover change analysis Tunisia.

Lambin, E.F., Geist, H.J., Lepers, E., 2003. Dynamics of land use and land cover change in Tropical Regions. Annu. Rev. Environ.Resour. 28, 205-241.

Levin, N., Heimowitz, A., 2012. Mapping spatial and temporal patterns of Mediterranean wildfires from MODIS. Remote Sensing of Environment 126, 12-26.

Liang, D., Zuo, Y., Huang, L., Zhao, J., Teng, L., Yang, F., 2015. Evaluation of the Consistency of MODIS Land Cover Product (MCD12Q1) Based on Chinese 30 m GlobeLand30 Datasets: A Case Study in Anhui Province, China. ISPRS International Journal of Geo-Information 4, 2519-2541.

MEA, 2005 Ecosystems and Human Well-Being. Current Status and Trends: Findings of the Condition and Trends. In: Assessment), W.G.M.E. (Ed.), Washington, DC.

Park, J.-Y., Suh, M.-S., 2014. Characteristics of MODIS land-cover data sets over Northeast Asia for the recent 12 years (2001-2012). Korean Journal of Remote Sensing 30, 514-524.

Salvati, L., 2014. Towards a sustainable land degradation? Vulnerability degree and component balance in a rapidly changing environment. Development and Sustainability 16, 239-254.

Salvati, L., Kosmas, C., Kairis, O., Karavitis, C., Acikalin, S., Belgacem, A., Solé-Benet, A., Chaker, M., Fassouli, V., Gokceoglu, C., Gungor, H., Hessel, R., Khatteli, H., Kounalaki, A., Laouina, A., Ocakoglu, F., Ouessar, M., Ritsema, C., Sghaier, M., Sonmez, H., Taamallah, H., Tezcan, L., de Vente, J., 2014. Unveiling soil degradation and desertification risk in the Mediterranean basin: a data mining analysis of the relationships between biophysical and socioeconomic factors in agro-forest landscapes. Journal of Environmental Planning and Management 58, 1789-1803.

Schulp, C.J.E., Alkemade, R., 2011. Consequences of Uncertainty in Global-Scale Land Cover Maps for Mapping Ecosystem Functions: An Analysis of Pollination Efficiency. Remote Sensing 3, 2057-2075.

Schulz, J.J., Cayuela, L., Rey-Benayas, J.M., Schröder, B., 2011. Factors influencing vegetation cover change in Mediterranean Central Chile (1975-2008). Applied Vegetation Science 14, 571-582.

Wessels, K., 2004. Mapping regional land cover with MODIS data for biological conservation: Examples from the Greater Yellowstone Ecosystem, USA and Par� State, Brazil. Remote Sensing of Environment 92, 67-83.

Zhang, X., Friedl, M.A., Schaaf, C.B., 2006. Global vegetation phenology from Moderate Resolution Imaging Spectroradiometer (MODIS): Evaluation of global patterns and comparison with in situ measurements. Journal of Geophysical Research 111, G04017.

Zhao, X., Xu, P., Zhou, T., Li, Q., Wu, D., 2013. Distribution and Variation of Forests in China from 2001 to 2011: A Study Based on Remotely Sensed Data. Forests 4, 632-649.

Annex 1. MODIS Land Cover Types Description (1 through 5 classification schemes)

Class	IGBP (Type 1)	UMD (Type 2)	LAI/fPAR (Type 3)	NPP (Type 4)	PFT (Type 5)
0	Water	Water	Water	Water	Water
1	Evergreen Needleleaf forest	Evergreen Needleleaf forest	Grasses/Cereal crops	Evergreen Needleleaf vegetation	Evergreen Needleleaf trees
2	Evergreen Broadleaf forest	Evergreen Broadleaf forest	Shrubs	Evergreen Broadleaf vegetation	Evergreen Broadleaf trees
3	Deciduous Needleleaf forest	Deciduous Needleleaf forest	Broadleaf crops	Deciduous Needleleaf vegetation	Deciduous Needleleaf trees
4	Deciduous Broadleaf forest	Deciduous Broadleaf forest	Savanna	Deciduous Broadleaf vegetation	Deciduous Broadleaf trees
5	Mixed forest	Mixed forest	Evergreen Broadleaf forest	Annual Broadleaf vegetation	Shrub
6	Closed shrublands	Closed shrublands	Deciduous Broadleaf forest	Annual grass vegetation	Grass
7	Open shrublands	Open shrublands	Evergreen Needleleaf forest	Non-vegetated land	Cereal crops
8	Woody savannas	Woody savannas	Deciduous Needleleaf forest	Urban	Broad-leaf crops
9	Savannas	Savannas	Non-vegetated		Urban and built-up
10	Grasslands	Grasslands	Urban		Snow and ice
11	Permanent wetlands				Barren or sparse vegetation
12	Croplands	Croplands			
13	Urban and built-up	Urban and built-up			
14	Cropland/Natural vegetation mosaic				
15	Snow and ice				
16	Barren or sparsely vegetated	Barren or sparsely vegetated			
254	Unclassified	Unclassified	Unclassified	Unclassified	Unclassified
255	Fill Value	Fill Value	Fill Value	Fill Value	Fill Value