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Detecting changes in cropland extent

A case study within the Lake Chad Basin using classified remote sensing data

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Abstract

Access to fresh water is essential for the lives of organisms and for human activities. However, with a growing population that strives after a higher standard of living, the pressure on already limited resources will rise. Lake Chad is one out of many diminishing lakes in the world where the call for action is urgent to prevent ecosystem degradation, famine, and outbreak of war. The lake has shrunk by more than 90% since the 1960's due to decreasing levels of precipitation and changes in water consumption. As most dwellers in the Lake Chad Basin are farmers and the agricultural sector consumes the largest proportion of all water resources, change in irrigation patterns is a likely cause for this decrease. Analysis of the change in cropland extent using classified remote sensing data acquired between 1992 and 2009 could possibly delineate areas where this change has occurred. The result could later be used to guide further studies on where suitable measures should be implemented to stop the current degradation.

Thus the main objective of this thesis is to delineate areas of change in cropland between 1992 and 2009 that could possibly explain the increased water consumption in the Lake Chad Basin. The study also aims to discuss the suitability and reliability of using classified land cover datasets to detect these changes.

Classified land cover datasets are generated based on multispectral images that are acquired by monitoring sensors onboard satellites. The spectral characteristic of a cell reviles properties of the observed surface and this information can be used to classify each cell in an image into a unique land cover type. Three types of datasets are used in this analysis: the MCD12Q1, the Globcover and the GLCC. They are all based on data acquired during different time periods, from different sensors and with different spatial resolution.

The datasets from 1992-1993, 2007 (GLCC and MCD12Q1 respectively) and the two Globcover datasets (2004-2006 and 2009) are found to not be suitable for this type of analysis. The MCD12Q1 datasets, on the other hand, were produced on an annual basis from 2001 to 2007 and give a clear indication of the expansion of cropland in certain areas in the basin. A constant intensification of cultivated land near Lake Chad’s northern pool and a migration of cropland from the upper KYB downstream the rivers could be detected. The flood and recession farming along the lower KY also seem to have increased between 2001 and 2007.

Despite the convenience in using classified remote sensing datasets to detect changes in cropland extent within the Lake Chad Basin, there are several drawbacks. Unique conditions in every observation, spectral resolution, spatial resolution and classification method are some of the reasons why different land cover datasets are not compatible with each other. Local conditions in the Sahel, such as almost permanent cloud cover and mixed vegetation, limit the possibilities to acquire useful data from this region.

The lack of classified land cover data from 1960 to 1980, when the largest retraction of the lake occurred, limits the possibilities of finding factors that can explain the decreased water resource. Studies using Landsat multi-spectral images should therefore be carried out to delineate areas where change in cropland extent has occurred since 1972. This could possibly be a better indicator of the reasons to the increased water consumption since the 60’s.

Keywords: Lake Chad, irrigation, cropland, classified remote sensing data, KYB, Chari-Logone, GLCC, MCD12Q1, Globcover, bi-temporal analysis, multi-temporal analysis

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Abbreviations and Acronyms

AVHRR	Advanced Very High Resolution Radiometer
ENVISAT	Environmental Satellite
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographic Information System
GLC2000	Global Land Cover 2000
KYB	Komadugu Yobe Basin
LCBC	Lake Chad Basin Commission
LCCS	Land Cover Classification System
MCD12Q1	MODIS Land Cover Type product
MERIS	Medium Resolution Imaging Spectrometer
MSS	Multispectral Scanner
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
RBV	Return Beam Vidicon Camera
SPOT	Satellite Pour l'Observation de la Terre
TM	Thematic Mapper
WGS84	World Geodetic System 1984
UNEP	United Nations Environment Program
USGS	U.S. Geological Survey

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1 Introduction

Only a tiny fraction of the world's water resources consist of fresh water found in rivers and lakes, and access to these resources is essential for the life of all organisms. However, not only animals and plants in ecosystems consume fresh water, human activities such as domestic and industrial activities along with agricultural production also depend on fresh water. As more people in the world reach a higher standard of living and the world population grows, the competition and pressure on this limited resource will rise. Without proper management the risk of ecosystem degradation, famine, desertification, epidemics and war outbreak in certain regions of the world will increase. Lake Chad is one of many examples of diminishing water bodies where the call for action is urgent to protect ecosystems and the lives of the poorest people in the world (UNEP, 2008). The lake has shrunk from a size of 25 000 km^2 in 1960 to less than 10% of that area today, see figure 1. With an expected population growth of 2.6%, 37 million people already living in the region, and a large influx of migrants to the Lake Chad body and its tributaries, the stress on surface water will rise. (UNEP, 2004). Thus, a research team at Lund University, in collaboration with the Lake Chad Basin Commission (LCBC) and the Red Cross, is carrying out a study that aims to design an inter-disciplinary assessment tool (IDA). This tool would be advisory in nature for future decisions made concerning the management of water resources within the Lake Chad Basin.

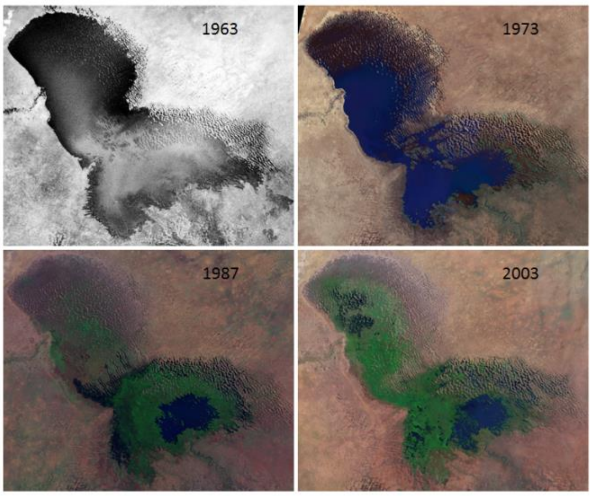

Figure 1 Images of the shrinking Lake Chad from 1963 to 2003 taken by Argon and Landstat 1, 5, 7 satellites respectively, Source: USGS, 2014

Despite a trend of reduced rainfall in the Sahel-region over the past centuries, Zilefac's (2010) study of the correlation between rainfall and stream flow trends showed that this pattern only partially explains the retraction of Lake Chad that began in the 1960's. Changed water consumption patterns in the basin, causing increased water withdrawal, is another factor that has decreased stream flow in the tributaries between 1948 and 1988 (Zilefac, 2010). Exactly in what part of the basin these changes have occurred and what is causing the increased water consumption is not fully surveyed yet. However, such information would be important when guiding future investigations of the area and finding suitable measures that could stop the current development. As most people in the basin live in remote areas and agricultural activities generate the largest share of the region's income, this sector is known to be the main consumer of accessible water (UNEP, 2004). Still, the lack of "on the ground" withdrawal data and unregulated irrigation activities makes it difficult to delineate regions of expansion of irrigated cropland. For this reason, remotely collected data on land cover, that is available from 1992 to 2009, could be useful in detecting areas exposed to increased irrigation during this time period.

1.1 Objectives and delimitations

The objective of this thesis is to use classified remote sensing data to detect areas exposed to extension in cropland between the years of 1992 and 2009. This change could possibly explain the increased water consumption in the Lake Chad Basin. The study also aims to discuss the suitability and reliability of using classified land cover datasets in detecting these changes.

Due to lack of information concerning groundwater resources within the Basin (UNEP, 2004), the interaction between surface and groundwater is disregarded in this study. Additional investigations of the use of alternative water sources for irrigation such as treated wastewater or harvested rainwater falls outside the scope of this study and therefore only surface water is accounted for. Nor are the changes in irrigation intensity or the variation in crop type regarded in the study. Moreover, water consumed by livestock is not considered due to a lack of a land cover classification system accounting for pastures and difficulties in delineating these areas from other areas of similar types of vegetation. Existing cropland might rely on rain for its water supply. Thus, no verification of the true cropland extent is carried out and only the change in cropland extent is analyzed on the basis of increased water requirements for irrigation.

2 Background and theory

2.1 Study area

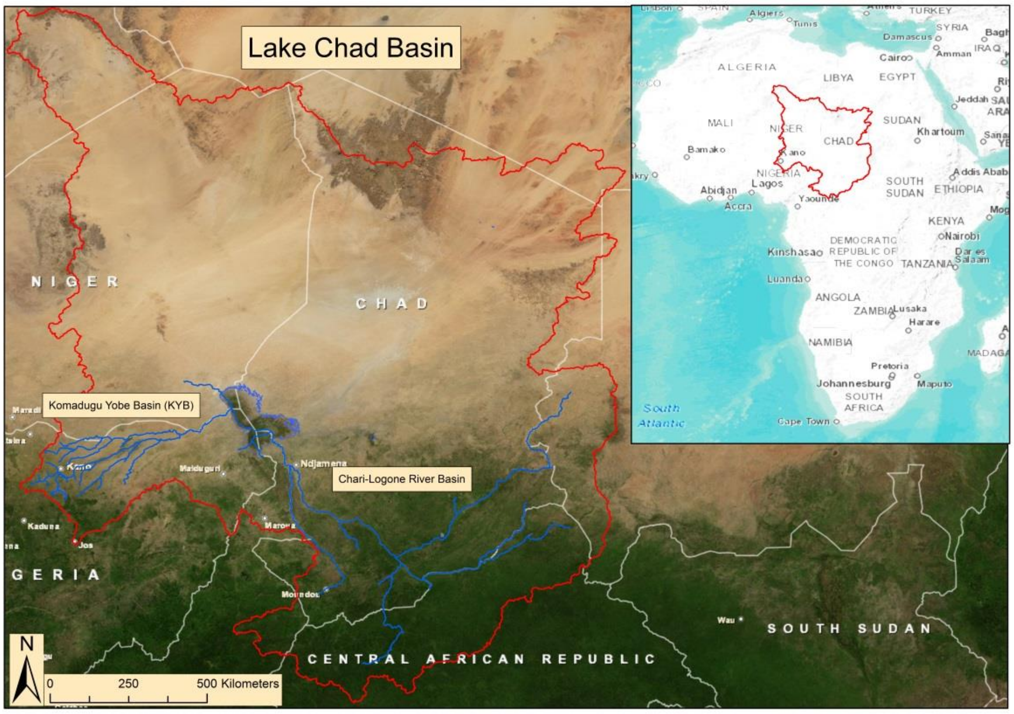

Figure 2 Lake Chad Basin with the former shoreline of Lake Chad and its tributaries, Source: Arc GIS base map, see chapter 8.2 Hydrological datasets for references to the hydrological datasets.

The Lake Chad Basin stretches from Libya and Alger in the north to the tropics in the south, see figure 2, and is comprised of four climatic zones with descending precipitation levels from south to north: Sudanese-Guinean (600-1500 mm), Sahelian-Sudanese (400-600mm), Sahelian-Saharan (100-400mm), Saharan (<100 mm) (LCBC, 2013). However, only the southern 1 million km^2 of the basin contribute to the lake's hydro balance during the rainy months of May through September. The Chari-Logone River originates in Central African Republic passing Cameroon and Chad before it discharges into Lake Chad and contributes with up to 95% of the lake's water resources. Most of the remaining water comes from the Komadugu Yobe Basin (KYB), constituting a border between Niger and Nigeria and recharging the lake's northern pool during six out of twelve months of the year. Extreme drought in the 1970's reduced the size of the lake significantly thus dividing it into a southern and a northern pool, see figure 1. However, this significant change in surface extent is not a new phenomenon. Geological investigations have discovered the occurrences of five dry ups of Lake Chad during the last millennium and have found that the lake body covered a substantially larger area 5000 years ago. Due to the shallowness of Lake Chad, it is very vulnerable to variance in recharge from the Chari-Logone River, thus creating a seasonal, annual and decadal fluctuation of the lake's size and depth.

However, this somewhat natural flow regime has been modified since the construction of major dams and reservoirs along the tributaries that started in the late 1970’s (UNEP, 2004).

2.1.1 Agriculture and Irrigation schemes in the Lake Chad Basin

Traditional farming systems are still the most commonly practiced cultivation methods within the Lake Chad Basin. In the absence of agro-chemicals, high technical equipment and financial support, crops are harvested by hand and depend on rain or the flooding of wetlands and floodplains for its water supply. However since the 1970’s, irrigation schemes have been seen as the solution to the low and unreliable rainfall that is causing severe food insecurity, especially during the drought years of 1973 and 1983-1984. The construction of dams and reservoirs was given founding to increase food production by diverting water from the main river channels to areas intended for irrigated cultivation. Twenty of these dams are found in Nigeria supporting irrigation schemes near the Lake Chad body and along the KYB. Meanwhile, only the Maga Dam is located in Cameroon and is recharged by the Chari-Logone River. Presented below are the main dams and irrigation schemes within the catchment.

- Maga Dam (Cameroon) constructed in 1979 in the upper Waza-Logone floodplain, supplying water to the SEMRY irrigated rice scheme and a fish farm, see figure 3.

Figure 4 Maga dam, Source: Google Earth accessed 2014-05-19

- South Chad Irrigation Project (SCIP) and Baga Polder Project both located on the Nigerian side of the Lake Chad body.
- Tiga Dam (Nigeria) constructed in 1974, feeding the The Kano River Irrigation Project (KRIP), see figure 4.

Figure 3 Tiga dam, Source: Google Earth accessed 2014-05-19

- Challawa Gorge Dam (Nigeria) constructed in 1992, feeding the Hadejia Valley Irrigation Project

Furthermore, Tiga Dam and Challawa Gorge Dam were both designed to supply fresh water to Kano City (UNEP, 2004). For a more accurate location of these and other minor dams in the basin see figure 10.

The improved water management that was expected from the modifications of the river morphology did not occur. Instead, the diversion of stream flow into unlined irrigation channels and the retention of water in the reservoirs resulted in even more water being lost to evaporation and percolation. Also, the seasonal flooding and recession of both the river banks and the Lake Chad shoreline, that the traditional cultivation method requires, was disturbed. This resulted in lower crop yields. Hence, less water reaches Lake Chad and a smaller area is irrigated today than what was anticipated when the projects were initiated

However, a reduced surface area of Lake Chad occurred even before the construction of large irrigation schemes, see figure 5. The same trend has also been taking place in the main tributary (Chari-Logone) with a 55% reduction between the average stream flow in 1950-1970 to the average in 1970-1990 (UNEP, 2004).

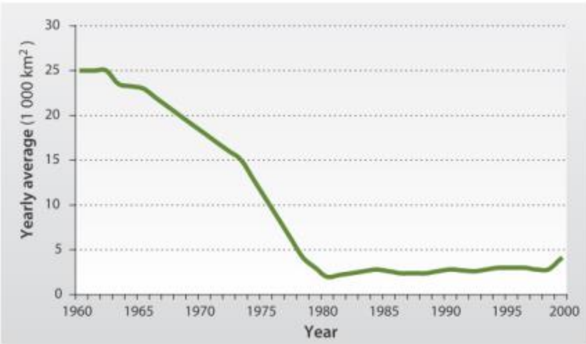

Figure 5 The surface area of Lake Chad 1960-2000, Source: UNEP, 2004

2.1.2 Legal agreements and Governance

Lake Chad Basin Commission was founded in 1964 comprised of Cameroon, Chad, Niger, Nigeria and Central African Republic which joined in 1994. The purpose of the organization was to control and regulate the use of water and natural resources and coordinate projects and research within the basin (Lake Chad Basin, 2014). At the time of the establishment of the Lake Chad Basin Commission, all member states signed the Fort Lamy Convention. However, this convention is ineffective and it does not contain any agreements regarding water allocation strategies. Also, it is not a legal instrument which means that the riparian states are not obliged to enforce water laws that could uphold a sustainable management of the water resources in the basin (UNEP, 2004)

2.2 Remote sensing

Electromagnetic energy conveys information about the surface it is radiated from, the so called spectral characteristic. This data can be used to monitor natural resources and the extension of urban areas around the globe. Sensors mounted on airplanes and satellites register the intensity of radiation both within the visible spectrum and in wavelengths, not detectable by the human eye, see figure 6.

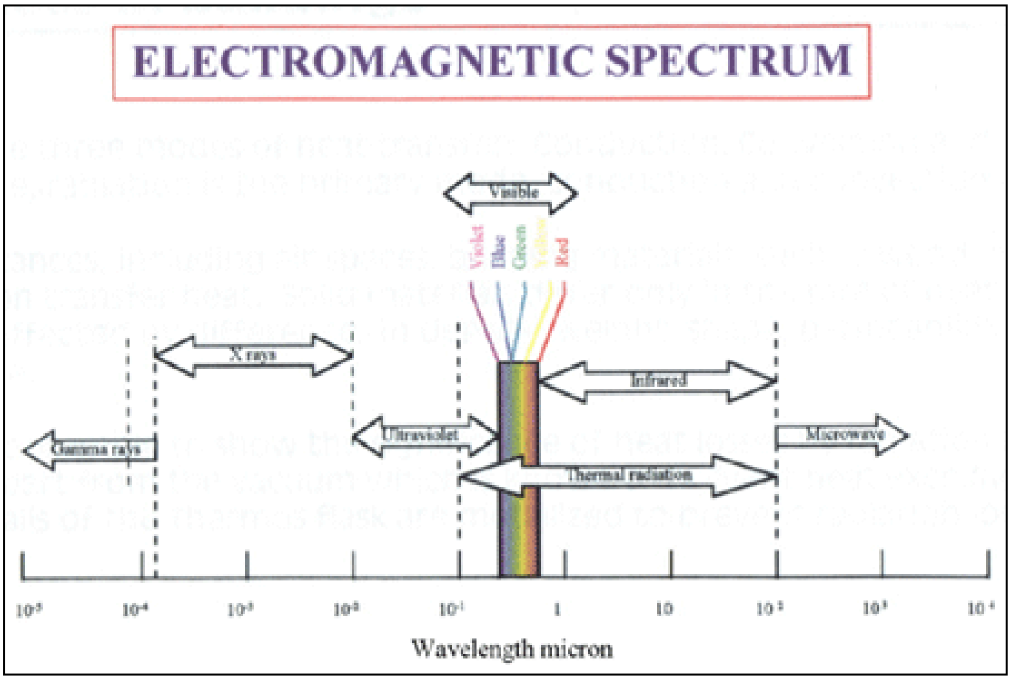

Figure 6 The electromagnetic spectrum and different types of radiation, Source: IPS, 2007

Registration of visible, infrared and thermal light is accomplished using a passive remote sensing technique that operates on solar energy. This so called optical light (visible- and infrared) is generated by the reflectance of solar radiation and can describe the moisture, pigment and cellular properties of vegetation, mineral and moisture content in soils. Thermal radiation on the other hand emits thermal energy and indicates the thermal properties and heat capacity of the material. Finally, microwaves convey information about the roughness of the surface of objects but require an active remote sensing method where radar is actively illuminated on the area of investigation and the reflected intensity is then recorded (Richards and Jia, 2006).

2.2.1 Preprocessing and enhancement of data

Before further analyses can be carried out the raw data has to be corrected for distortions and faults. Such distortions are caused by sensor noises and scattering of radiation that are specific to the satellite and concentration of large gas molecules in the atmosphere at the time of acquisition. In order to improve the appearance of the images, a difference in illumination and viewing geometry also have be corrected for as well as an improvement of contrasts, in order to define homogenous features (Canada Centre for Remote Sensing, 2014).

2.2.2 Normal Difference Vegetation Index (NDVI)

The graph representing the spectral signature of green vegetation in figure 7 shows a particularly high level of reflectance in the near infrared wavelength (700-1000 nm) while the intensity is much lower in the red band (600-700 nm). Green vegetation absorbs red light as part of its photosynthesis and that is why the level of reflected energy in this part of the electromagnetic spectrum is very low compared to in the infrared part of the spectrum. The Normal Difference Vegetation Index (NDVI) combines these characteristics by subtracting the level of reflected red light (red) from the near infrared light (NIR) and normalizes the result. The higher the index is the healthier the plant is, where as a negative index indicates an absence of or wilted vegetation, see equation 1.

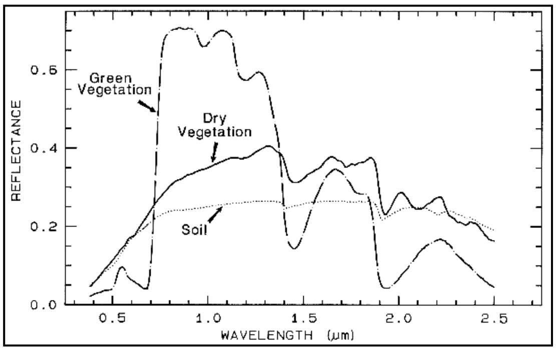

Figure 7 Spectral signature of green vegetation, dry vegetation and soil, Source: Clark, 1999

$$NDVI = \frac{NIR - red}{NIR + red}$$

$$-1 \leq NDVI \leq 1$$

Equation 1 The calculation of NDVI, Source: Price and Price, 2009

By doing this for each pixel in a series of images, the conditions of the vegetated areas and their specific growing period can be defined. When classifying the earth into different land cover types this information is valuable as it enables the type of vegetation to be determined and changes in ecosystems to be detected (Meneses-Tovar, 2011). The Enhanced Vegetation Index (EVI) and the Normalized Difference Water Index (NDWI) are other tools used in the classification of spectral statistics into land cover types (Levizou *et al.*, 2007).

2.2.3 Classification methods

In order to fully assimilate and make use of the information contained in multispectral images, each pixel is labeled with a land cover type that is a general representation of reality, see figure 8. The classification methods most commonly used are either supervised or unsupervised and are unique for each specific dataset. In a supervised classification, an operator teaches the classification algorithm to recognize the spectral characteristics of a certain class. A few pixels of a well-known land cover type are selected and their spectral signature, see figure 7, will represent a certain class in the dataset. This so called training data will then guide the algorithms in grouping the remaining pixels in each image into suitable land cover types. In unsupervised classification procedures, the number and names of the classes that the pixels will be assigned to is unknown to the operator beforehand. Instead, a clustering algorithm groups the pixels into different spectral and textural classes that will later be labeled based on thematic maps and local surveys (Richards and Jia, 2006).

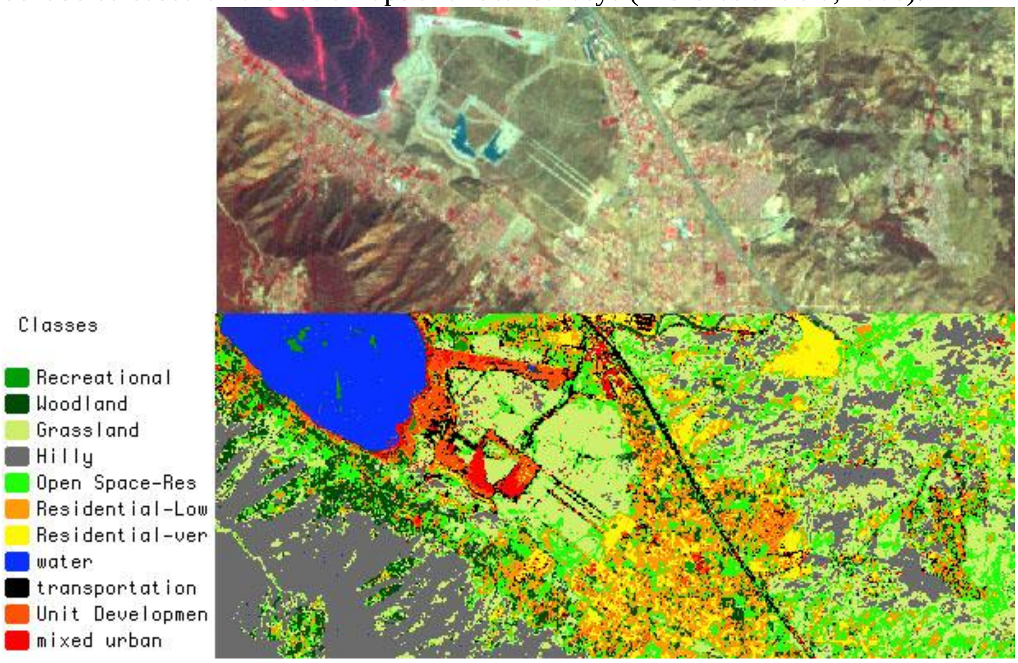

Figure 8 Classification of multispectral remote sensing images (Band 1=Green – Orange, Band 2=Red, Band 3=Near Infrared) into 11 different classes, Source: Bresciani, 2014

Despite the convenience of using data acquired from remote platforms, the methods used to convert electromagnetic signals into land cover classes still require a manual analysis of images in addition to the use of automatically preforming algorithms. This is time and cost consuming and limits the number of observations actually processed into classified land cover datasets (Volker, 1998).

2.3 Main land cover dataset

Availability of adequate land cover datasets is essential for research on global change such as: biodiversity conservation, ecosystem assessment, and modeling in environmental and climate change (Giri *et al*., 2005). During the past few years global land cover datasets have become available to the general public with the main purpose of improving knowledge about the extent and distribution of different land cover types (Strahler *et al*., 2006). However, the available land cover datasets differ in terms of resolution, legends, source of data and methodologies used in the classification process (Giri *et al.,* 2005). Below is a description of four well-known land cover products that are free of charge for non-commercial users.

2.3.1 Global Land Cover Categorization (GLCC)

The U.S. Geological Survey (USGS) was the first to publish a global and a continental land cover dataset, so called Global Land Cover Characterization (GLCC), (Giri *et al.*, 2005). The data was acquired between April 1992 and March 1993 by the AVHRR sensor mounted on NASA's satellite NOAA. Through an unsupervised classification process based on the maximum 10-day NDVI for each month, elevation and eco-regions, a 1-km resolution layer was generated. In order to fulfill the usage for various types of applications, the global dataset was classified into seven different legends, see Appendix 1. The continental and global datasets were also projected in different systems, the Lambert Azimuthal Equal Area and Interrupted Goode Homolosine systems on the continental level and Interrupted Goode Homolosine and Geographic systems for the global datasets (USGS, 2008). The impact these differences in projections have on the representation of the Lake Chad body is clearly presented in figure 9.

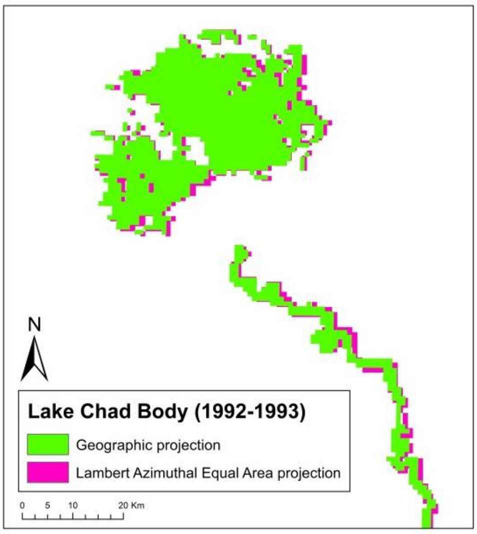

Figure 9 The difference between a presentation of Lake Chad in a Geographic and a Lambert Azimuthal Equal Area projection

2.3.2 Global Land Cover 2000 (GLC2000)

The European Commission's Joint Research Center (JRC) in cooperation with other organizations produced GLC2000 representing the land cover of Africa and other continents. The African 1 km- resolution dataset was based on four main data sources out of which each data source was used to map a particular land cover type or ecosystem:

- Daily data from the VEGETATION-sensor on the SPOT-4 satellite (CNES) acquired between 1999 and 2001 was used to detect vegetation. This multi-spectral mosaic consisted of blue, red, NIR and SWIR (Short wave infrared) wavelengths together with the maximum daily and ten- day NDVI and NDWI value.
- SAR (Synthetic Aperture Radar) data from both the JERS-1 satellite in 1996 and ERS 1 and 2 satellites in1994 and 1996, made it possible to detect seasonal variation in humid tropical ecosystems.
- Operational Linescan System (OLS) with low light sensing capabilities delineated human settlements.

- The digital elevation model of GTOPO30 enabled the topography to be described.

This data was then classified into 100 spectral classes, using an unsupervised approach, and was presented in a geographic coordinate system. Each specific class was later labeled based on visual interpretation and knowledge of growing seasons and other ancillary data (Mayaux et al., 2003). The classification system used is presented in Appendix 3 and has the structure of LCCS.

2.3.3 MODIS Land Cover Type product (MCD12Q1)

The MODIS instrument mounted on the Terra and Aqua satellites acquired global data every 8th day in the 1–7 (wavelength 620- 2155nm) spectral interval. Together with registration of Land Surface Temperature by the same instrument and the calculated NDVI and EVI, images are produced with 32-day intervals. By the use of a supervised classification method, land cover layers with a 500 m resolution were produced annually from 2001 to 2007 (Friedl *et al.*, 2010). The MCD12Q1 land cover product is presented in a geographic coordinate system with five different legends, all designed to satisfy different end users, see Appendix 2 (DAAC, 2014).

2.3.4 Globcover

There are two versions of the Globcover dataset, one produced based on data acquired from December 2004 to June 2006 and a second one based on data from 2009. However, both datasets have the same 300m resolution and originate from the MERIS Full Resolution sensor on board the ENVISAT satellite (ESA). Radiation from 15 spectral bands (412.5-900nm) was recorded globally ever third day and composed into multispectral images every second month. A supervised classification method was applied on urban and wetland areas while the remaining pixels were classified by an unsupervised classification method where local experts where involved. One regional fine-tuned legend with 51 land cover classes and a global with 22 classes were produced with the same structure as the LCCS, see Appendix 3, (Bicheron P. et al., 2008).

Information about the websites where these datasets have been downloaded from is presented in chapter 8.1. Additional information about other datasets that have been derived through processing these main datasets and the availability of scanned maps is also found in chapter 8.1.

2.4 The Landsat Program

In 1972, NASA launched the first Landsat satellite with the mission to observe the earth by using two different sensors (MSS and RBV). Since then, new satellites with updated instruments have been put in orbit and cover the earth every 16th day. Each sensor has the ability to register radiation in different bandwidths where the most recent instruments (TM and ETM+) have a higher spectral resolution. The spatial resolution of the Landsat instruments ranges from 30m to 120m which makes it an important data source when detecting human and naturally induced changes in the global landscape (USGS, 2013). Landsat imagery is commonly used in the detection of forest extent and change, while urban areas and cropland are harder to discriminate from other land cover types (Hansen and Loveland, 2012). Up until today the detailed Landsat images have not yet been used as the main data source to generate global classified land cover datasets. However, the method of classifying Landsat data is used when mapping smaller regions for specific purposes (Kovalskyy and Roy, 2013).

2.5 Considerations

Despite the time and economic efficiency in using classified remote sensing data to detect changes in cropland distribution, several studies indicate drawbacks in the use of this method.

Studies have been carried out comparing different global land cover products to find discrepancies between them. However, differences are often explained by inter-annual variability and low accuracy in the classification rather than an actual change in land cover (Giri C., 2012, *Reed et al*., 2010). Moreover, due to the various end users of the products, each land cover dataset is produced for different purposes, which results in different classification systems being applied to the datasets (Herold *et al.,* 2006). The suitability of using classified land cover to detect land cover changes is therefore questionable (Giri C., 2012). However, in order to enhance the possibilities to evaluate, monitor and compare land cover classes and data, UNEP and FAO have launched a global Land Cover Classification System (LCCS). This hierarchical system is applied both to the GLC2000 and Globcover datasets and is designed to satisfy a variety of users without compromising the compatibility of the classification system (Gregorio, 2005). Still the presentation of the classification systems of Globcover and GLC2000 in Appendix 3 shows a difference in their labels.

There are certain drawbacks in the application of classified remote sensing data when tracking cultivated land. Mayaux (2003) and You (2008) point out that the heterogenic character of natural vegetation creates a risk of misinterpreting agricultural land for natural grass and scrubland. Sensors on the earth observing satellites are also tuned to detect natural vegetation rather than discovering cropland or land used for other human activities. Moreover, the number of classes and level of detail assigned to these classes are not as specific as for natural ecosystems (Mayaux *et al*., 2003, Leff *et al.*, 2004). Despite the convenience of using remote sensing data to delineate land cover types, this technique lacks the ability to convey information about crop type, the use of fertilizer or irrigation and the yield - all important features in agricultural activities (Leff *et al.*, 2004).

A close to permanent presence of clouds over west and central Africa limits the number of images that can be acquired and used in compiling the land cover dataset. The possibilities of recording the seasonality that is characteristic to the African vegetation is thereby limited, which can decrease the reliability of the product (Mayaux *et al*., 2003).

3 Data

All datasets are freely available for non-commercial use and presented in a Geographic Coordinate System (WGS84 ellipsoid). Websites where the following datasets are available are presented in chapter 8, Dataset sources.

3.1 Land cover datasets used in the analysis

When selecting the land cover datasets that are suitable for this analysis the following criteria are accounted for:

- Temporal Resolution: To reduce the risk of misinterpretation due to extreme meteorological events that are not representative of the overall trend, a multi-temporal analysis of the cropland extent is carried out. MCD12Q1 is the only dataset that is produced on an annual basis between 2001 and 2007 and is therefore suitable for this type of analysis. Further, in order to find reasons for the annual variation in cropland extent, the result is compared to statistics on precipitation anomalies in Sahel from the rainy season during the same years.

- Spatial resolution and level of detail: The Globcover dataset is produced in two versions, one based on data from 2004-2006 and the other from 2009. These datasets have the finest spatial resolution (300m) and the highest number of classes related to agricultural land, see table 2. A bi-temporal change analysis between the Globcover datasets is therefore included in this study.

- Temporal Coverage: A comparison between the cropland extent from a date as far back in time as possible and today could enable long-term changes to be detected. Thus the cropland extent presented in the GLCC dataset from 1992-1993 and the MCD12Q1 dataset from 2007 are compared.

A summary of the properties of each dataset is presented in table 1.

Table 1 A summary of the land cover datasets used in the study, for further details see chapter 2.3 Main land cover dataset.

Land cover dataset	Satellite/Sensor	Spatial resolution	Year of acquisition
GLCC	NOAA/AVHRR	1 km	1992-1993
MCD12Q1	TERRA & AQUA/ MODIS	500 m	2001, 2002, 2003, 2004, 2005, 2006, 2007
Globcover	MERIS/ENVISAT	300 m	2004-2006 and 2009

Land cover products have proven to label cropland areas differently, see table 2 and 3. In order to minimize the discrepancies due to a difference in classification systems, changes in cropland distribution is detected using land cover datasets classified with the same system.

3.1 Dams and irrigation datasets

Due to the large size of the Lake Chad Basin, changes in cropland extent on a smaller scale can be hard to detect. Thus knowledge of the location of irrigation schemes and dams can be valuable in guiding studies on a detailed level. The two datasets used for this purpose are presented in figure 10 and described below:

- The Dams v1.01 dataset that was compiled by Lehner (2011) and shows the location of dams associated with reservoirs larger than 0.01 ha.
- The Digital Global Map of Irrigated Area version 5 dataset shows the percent of each 5 arc minute-cell that is equipped for irrigation. The information is based on sub-national irrigation statistics, national surveys and from reports available from FAO, World Bank and other international organizations around 2005. The GLCC and GLC2000 land cover datasets were used to support areas where data were missing (Siebert *et al.*, 2013).

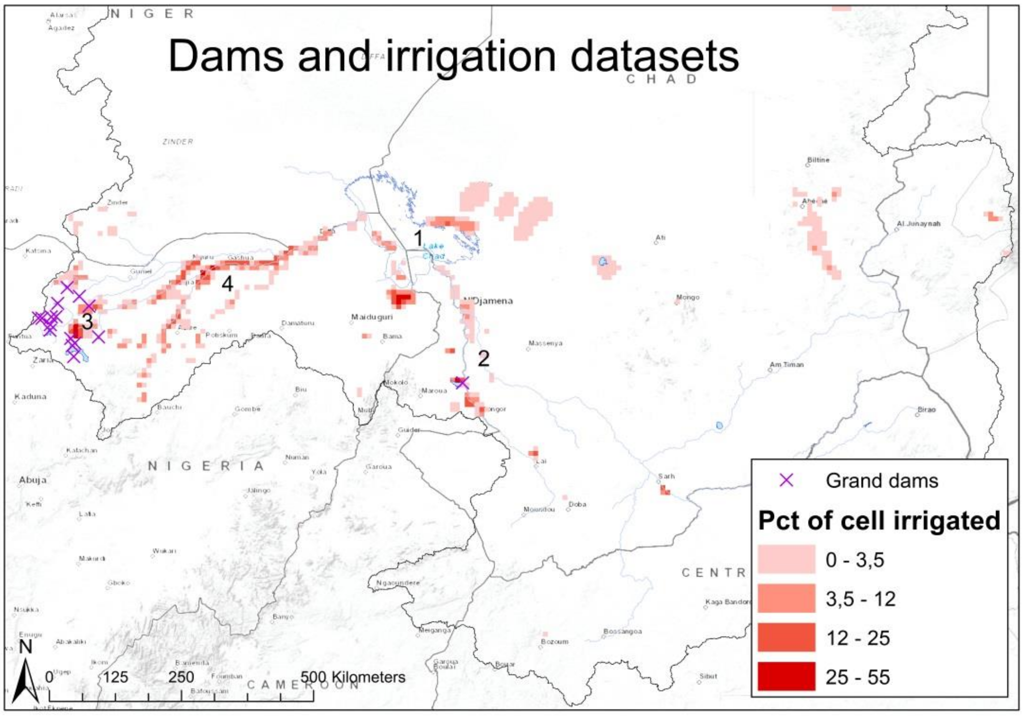

Figure 10 Dams and irrigation datasets used to delineate regions of interest, Source: ArcGIS base map, dams see Lehner 2011, irrigation see Siebert, 2013

References to the datasets that are used to delineate the Lake Chad Basin, rivers, reservoirs and lakes are found in chapter 8.2 Hydrological datasets.

4 Methodology

In order to detect changes in cultivated land within the Lake Chad Basin, analyses in ArcGIS were carried out using datasets from different years. The pixels assigned with the highlighted names in table 2 and 3 were extracted from each land cover dataset and aggregated into a single cropland class. Only datasets with the same classification applied to them were compared.

Table 2 Legend of the Globcover datasets (LCCS), classes counted as cropland are highlighted in yellow, Source: Bicheron, 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)

Table 3 Legend of the MCD12Q1 and GLCC datasets (IGBP), classes counted as cropland are highlighted in yellow, Source: DAAC, 2014

Value	Label
0	Water Bodies
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Close Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland-Natural Vegetation Mosaics
15	Snow and Ice
16	Barren or Sparsely Vegetated

When evaluating the suitability of using different types of land cover datasets in a bi-temporal change analysis, the cropland distributions of Globcover (December 2004-June 2006) and MCD12Q1 (2005) are compared. This comparison was carried out in ArcGIS by subtracting the reclassified datasets from each other.

The same procedure was carried out to detect temporal changes in cropland and the cells of the output layer were assigned a specific color that made the areas of decreased, unchanged and an extension of cropland possible to find. The result from the multi-temporal analysis of the MCD12Q1 datasets (2001-2007) and the precipitation anomalies in Sahel during the same years were compared to find explanations to the changes.

For subtle changes to be detected, regions where irrigation most likely takes place were studied in detail. These areas are labeled 1-4 in figure 11 and are located close to large dams, or where the Digital Global Map of Irrigated Area-dataset indicates that more than 10% of the cell is irrigated.

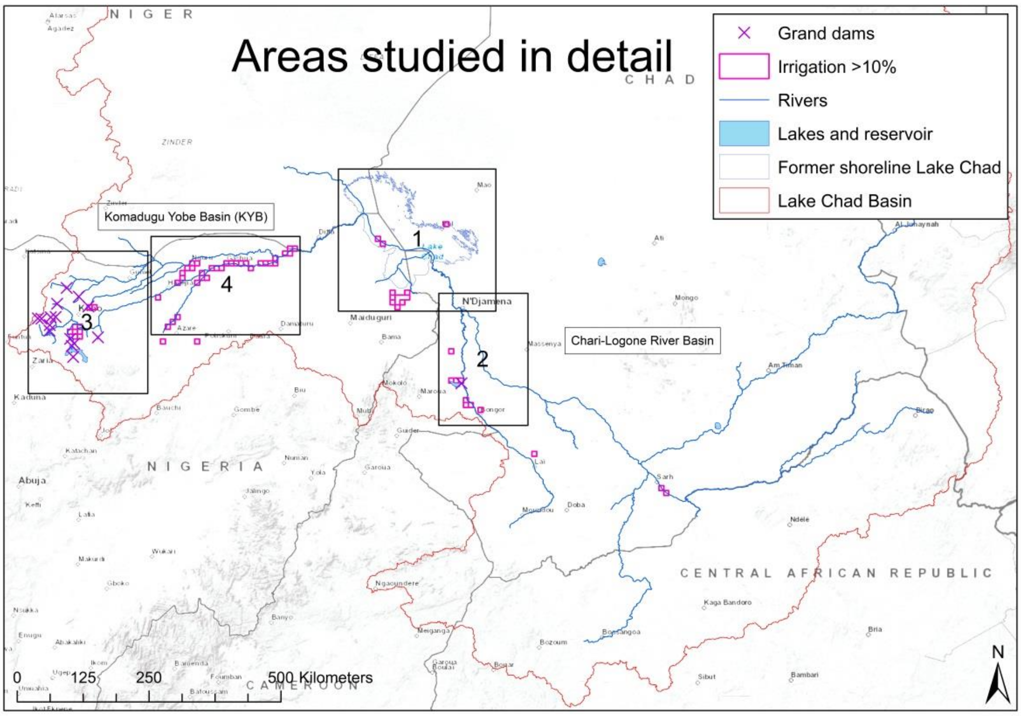

Figure 11 Delineated regions (1-4) located close to irrigation schemes and dams that are studied in detail. Source: ArcGIS base map and hydrological datasets for further detail see Chapter 8.2 Hydrological datasets

5 Result

5.1 Suitability analysis

Figure 12 shows how two different land cover datasets describe the distribution of cropland in the same region, during almost the same time period. These two datasets have been produced in different ways with different spatial resolution and different classification systems. The Globcover dataset is based on remote sensing data from December 2004 to June 2006, has a resolution of 300m and is classified into the LCCS, see table 2, while the MCD12Q1 dataset is based on remote sensing data acquired in 2005, has a resolution of 500m and is produced in the IGBP classification system.

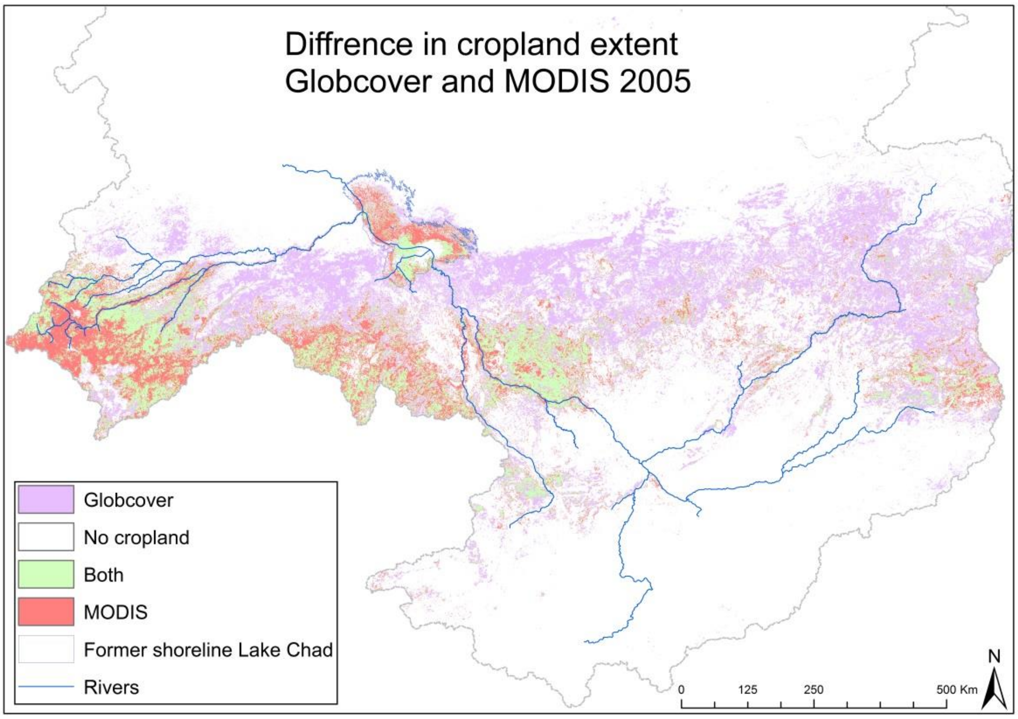

Figure 12 Difference in cropland extent due to classification systems and data sources. The figure is based on data from almost the same time period (2005) presented in the Globcover and MODIS datasets

5.2 Multi-temporal change in cropland extent 2001 to 2007

The figures presented below show the multi-temporal trend in cropland extension within the Lake Chad Basin between 2001 and 2007. Each image illustrates the change in cropland extent from one year to the next according to the 500-m resulted MCD12Q1 datasets. Areas where obvious changes occur have been marked with a letter and are commented on.

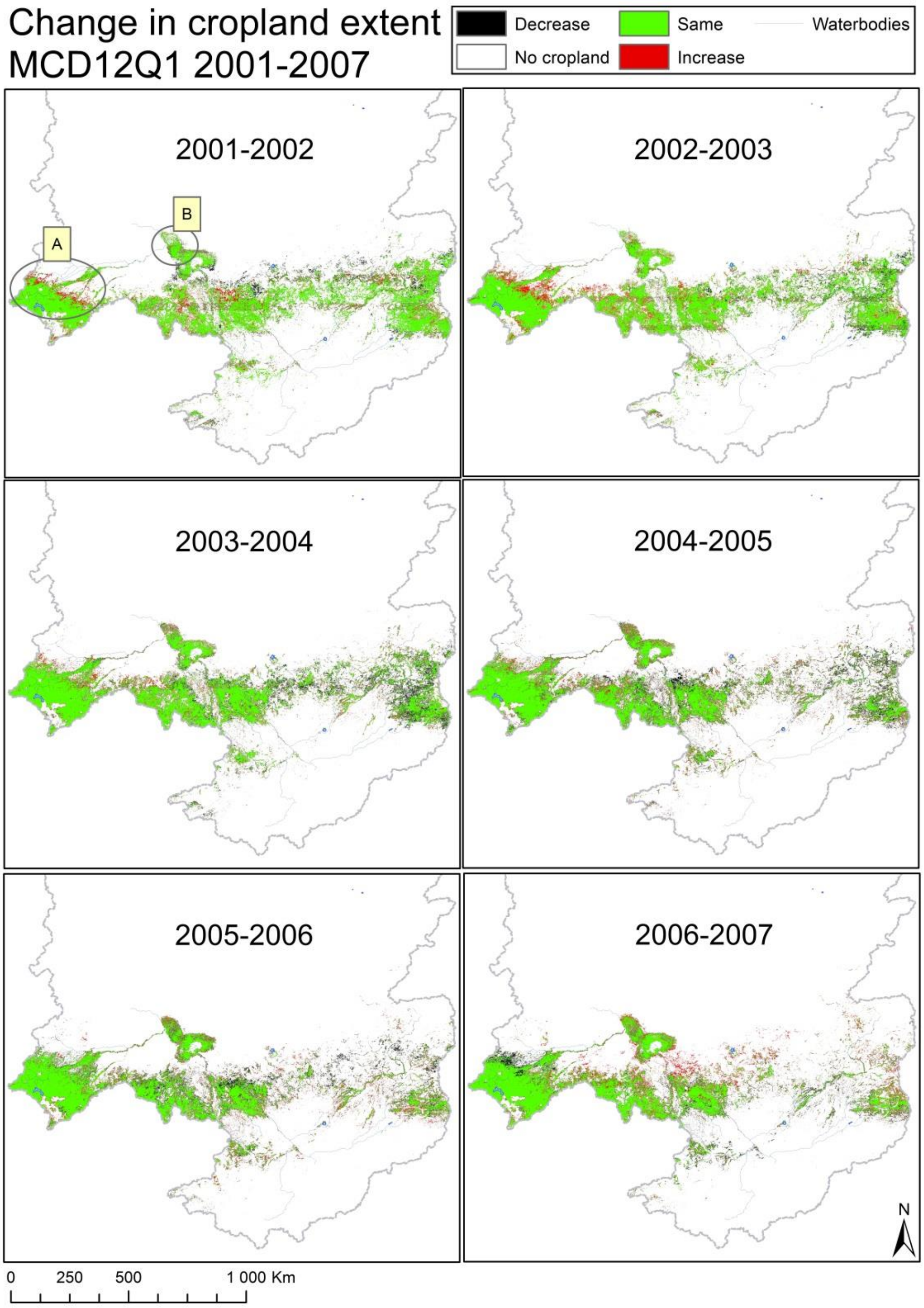

Figure 13 The annual change in cropland within the Lake Chad Basin from 2001 to 2007 according to the 500m resolution MCD12Q1 dataset. Areas of clear trends are labeled with A and B.

A. A steady trend of extending cropland downstream the KYB from 2001 to 2006. Between 2006 and 2007 a retraction of cropland occurs in this area.

B. An trend of intensification of cropland within the “former shoreline of Lake Chad” is evident thorugh out all the eigth years. This is especially evident near the northern pool of the lake.

The outcome of the multi-temporal analysis is comparied to the precipitaiton patterns in the Sahel area to find explanations to changes in the cropland extent.

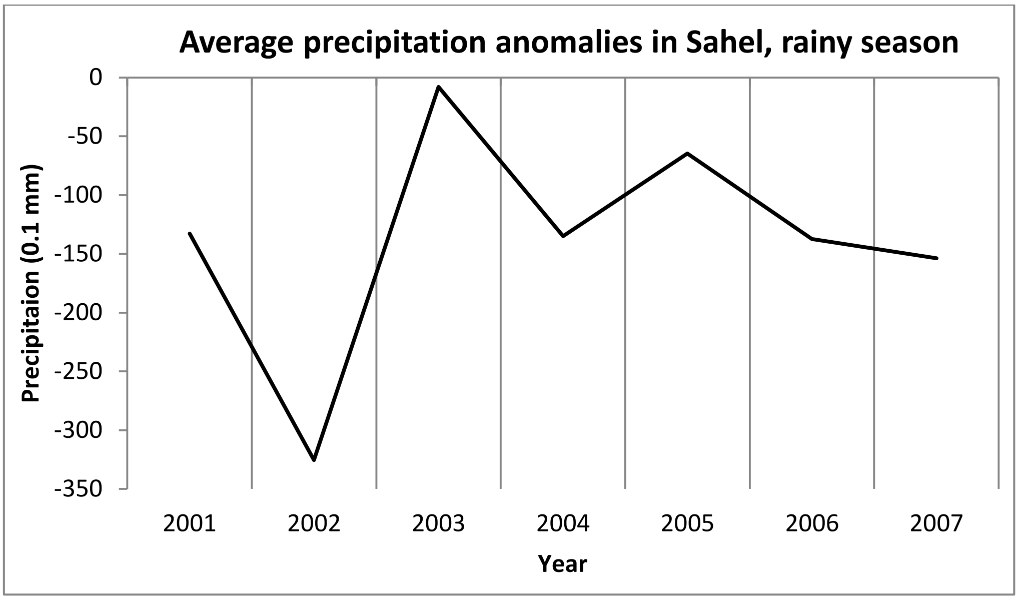

Figure 14 Precipitation anomalies (0 representing the average between 1950 and 1979) in the Sahel region during the rainy months of May to September. Source: Mitchell, 2013.

In 2002 precipitation levels were very low but recovered and reached a peak the subsequent year. The following years precipitation varied but with a rend of reduced rainfall in the Sahel region. The precipitation level was lower than the average precipitation in 1950-1979 during all the investigated years.

The following figures show areas where irrigaiton is likely be practiced and are therefore studied in detail to find trends in the change of cropland extent. The location of these regions (1-4) are presented in Figure 11.

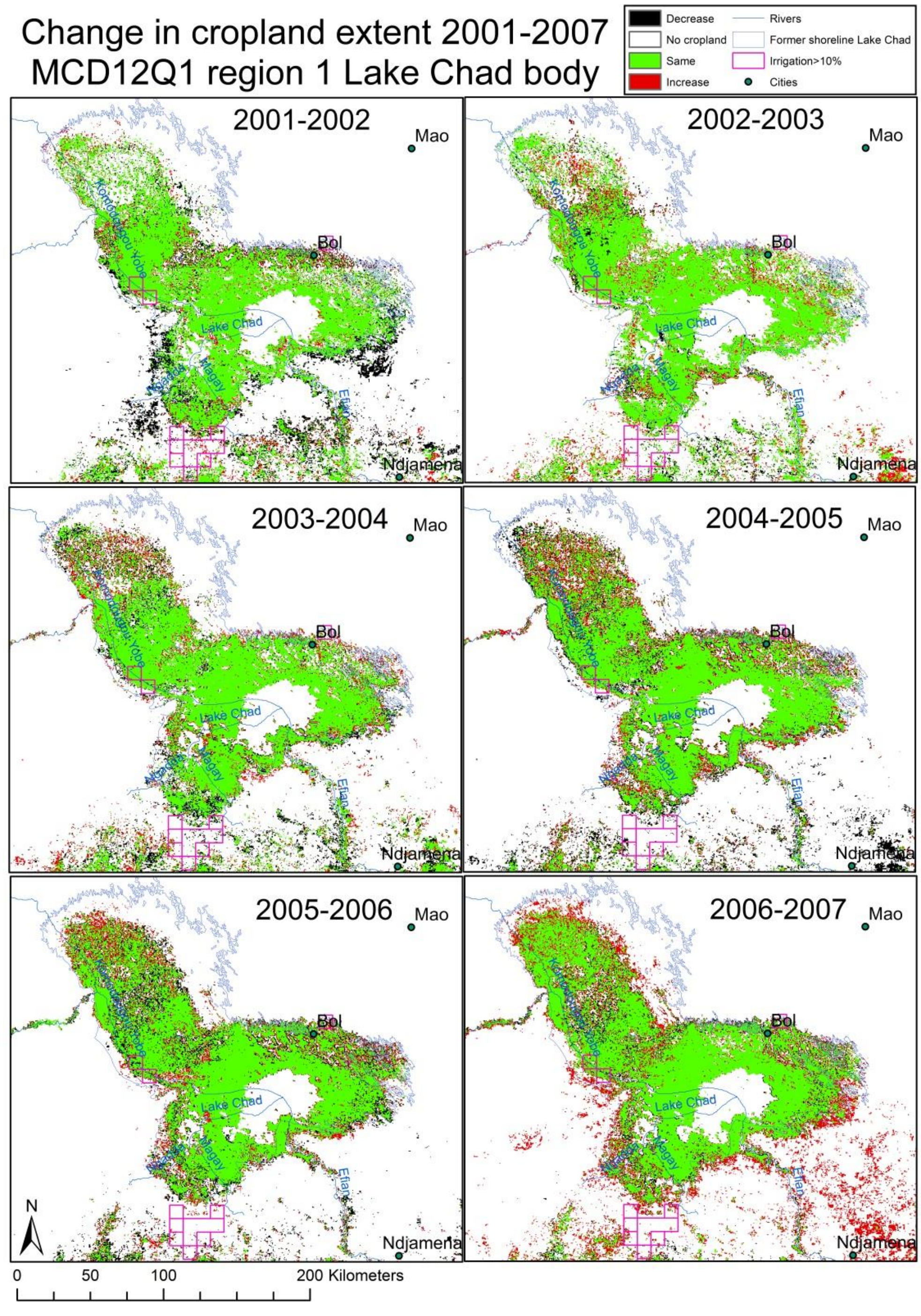

Figure 15 The annual change in cropland by Lake Chad (region 1) from 2001 to 2007 according to the 500m resolution MCD12Q1 dataset.

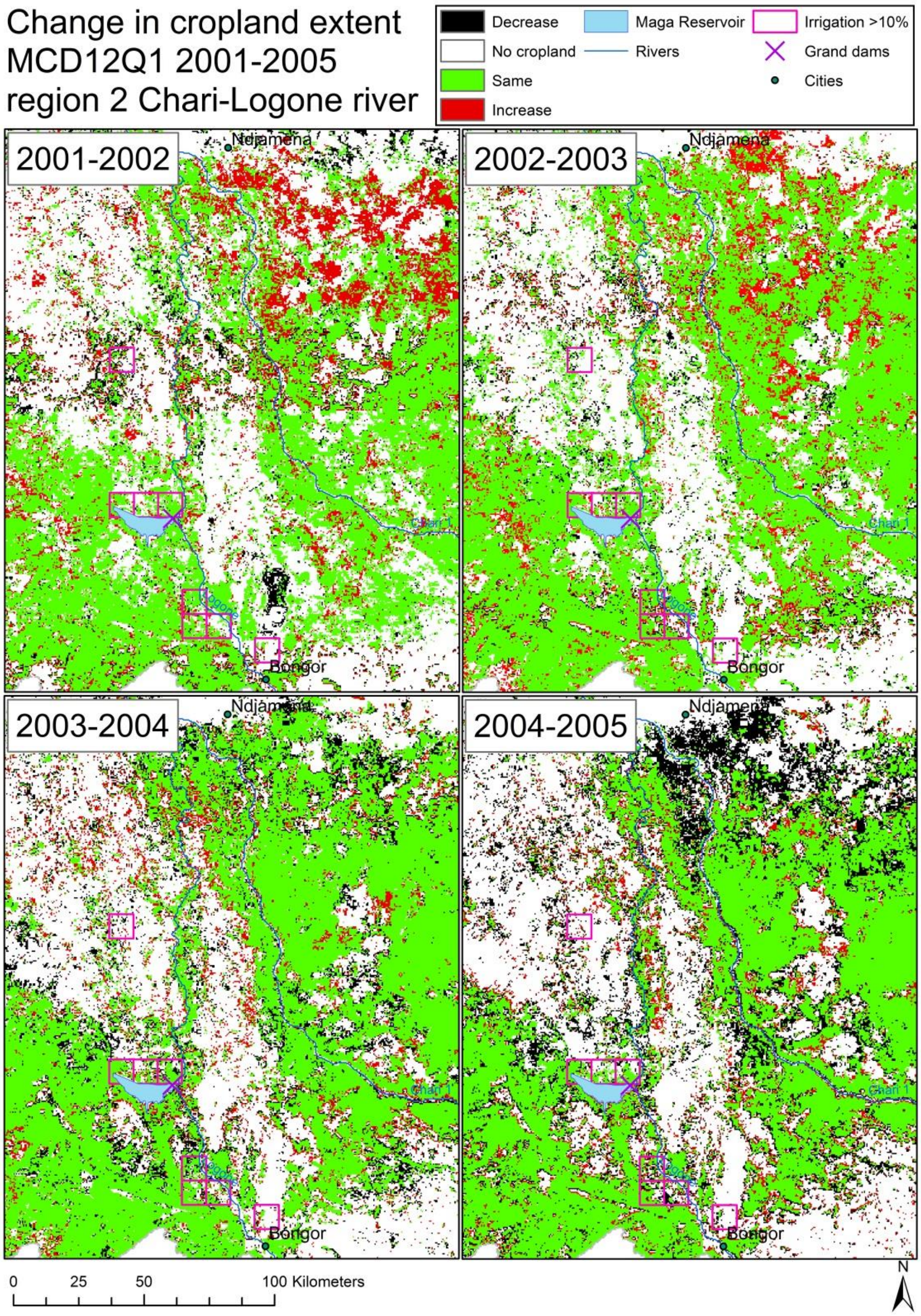

Figure 16 The annual change in cropland by the Chari-Logone River (region 2) from 2001 to 2005 according to the 500m resolution MCD12Q1 dataset.

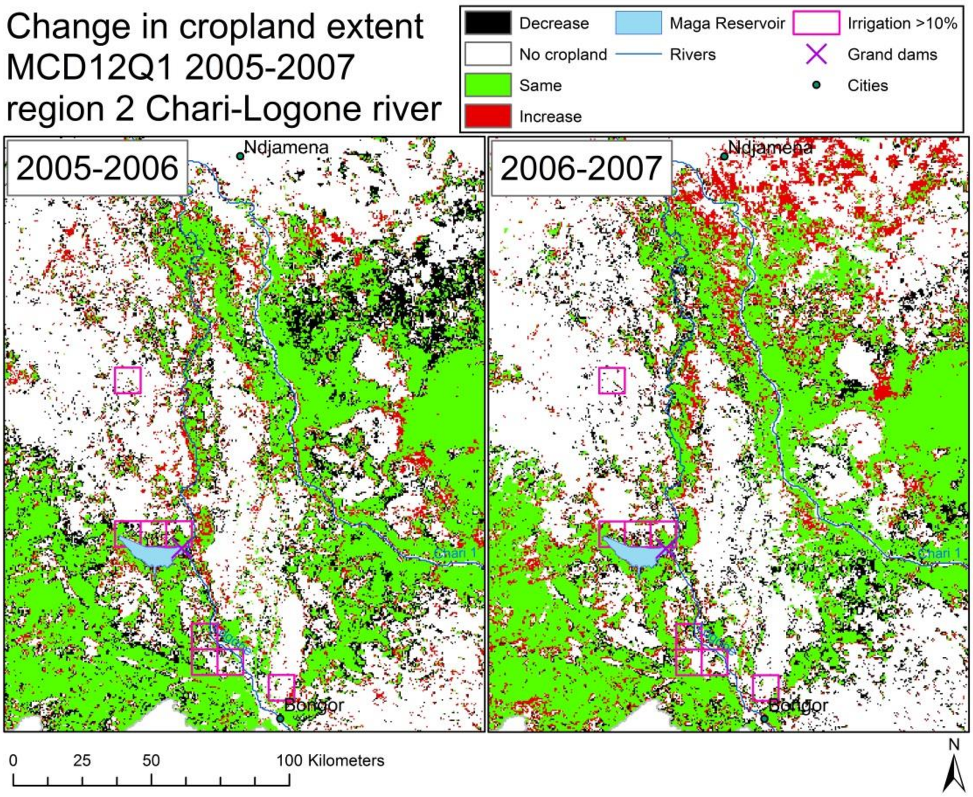

Figure 17 The annual change in cropland by the Chari-Logone River (region 2) from 2005 to 2007 according to the 500m resolution MCD12Q1 dataset.

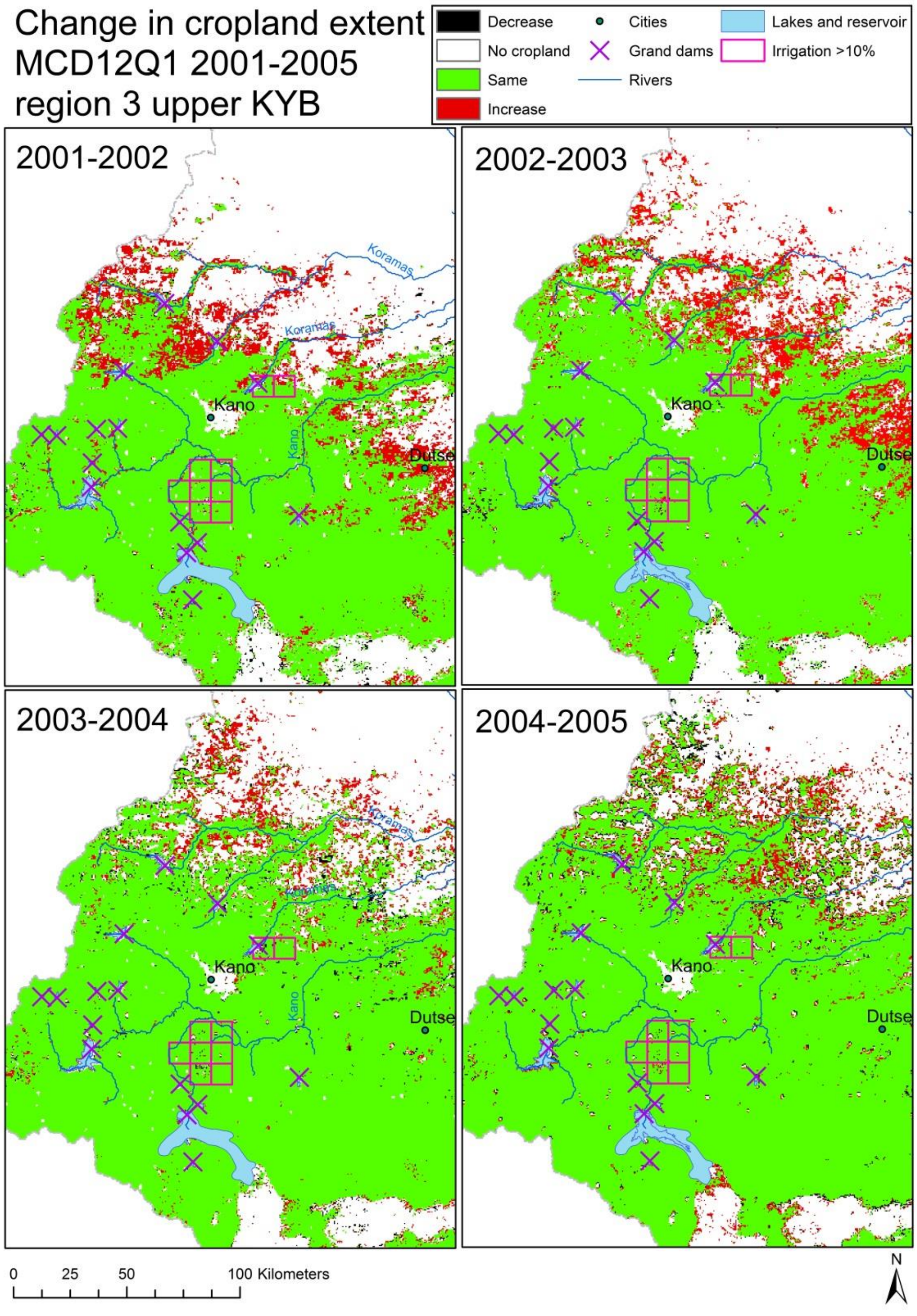

Figure 18 The annual change in cropland by the upper KYB (region 3) from 2001 to 2005 according to the 500m resolution MCD12Q1 dataset.

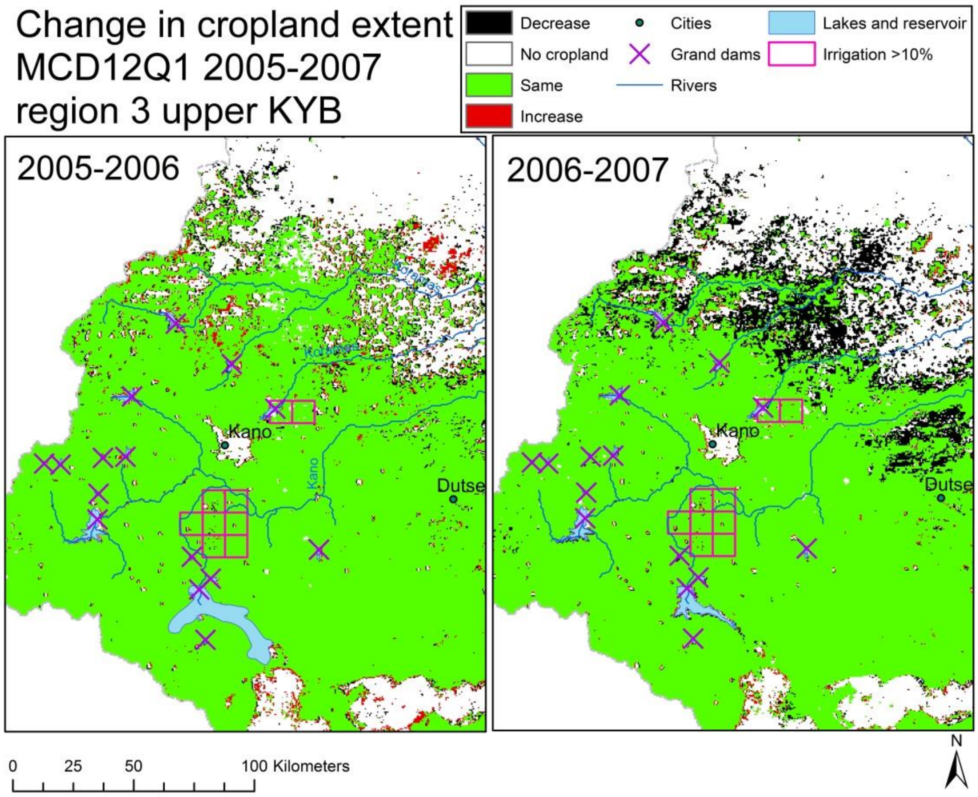

Figure 19 The annual change in cropland by the upper KYB (region 3) from 2005 to 2007 according to the 500m resolution MCD12Q1 dataset.

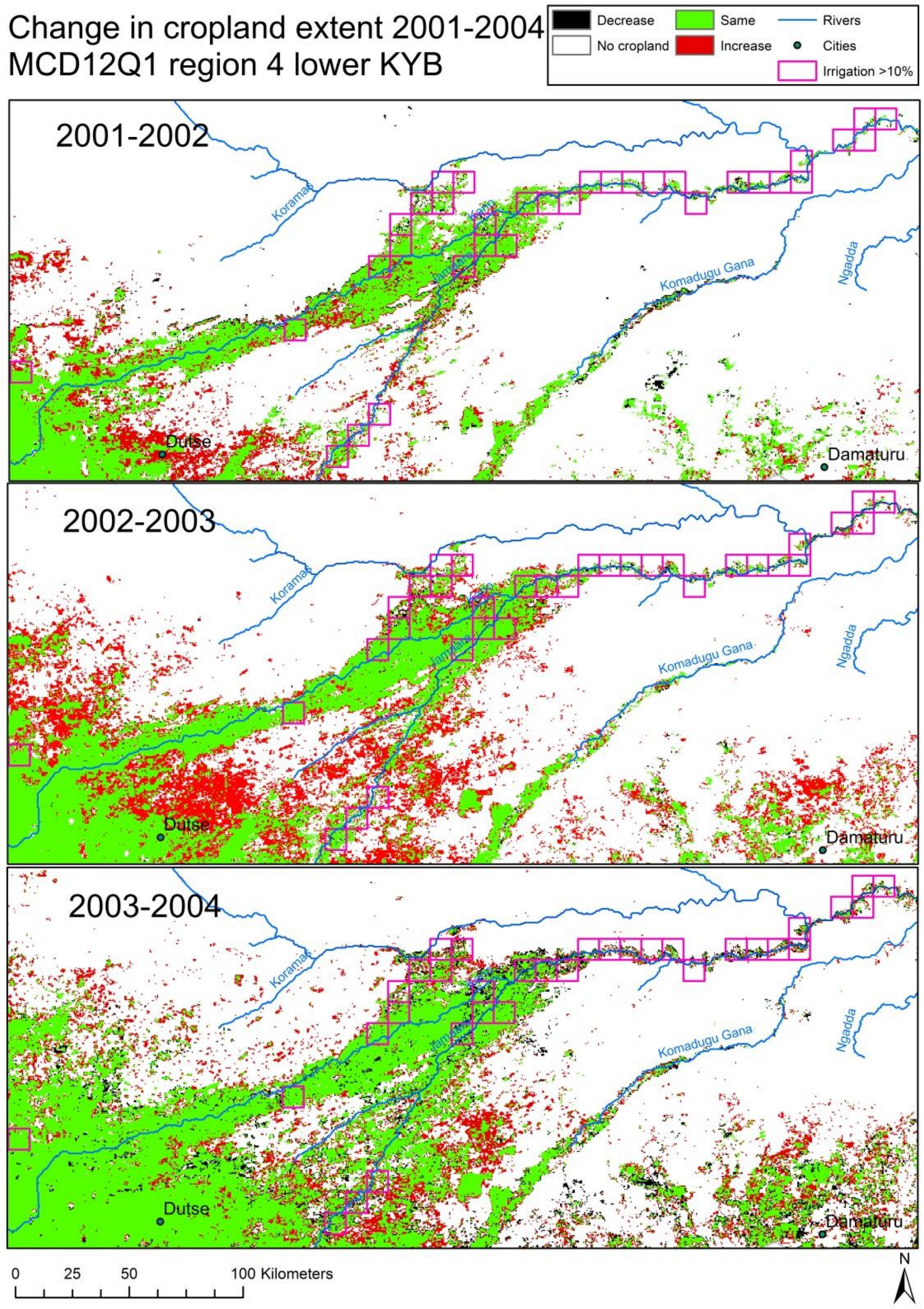

Figure 20 The annual change in cropland by the lower KYB (region 4) from 2001 to 2004 according to the 500m resolution MCD12Q1 dataset.

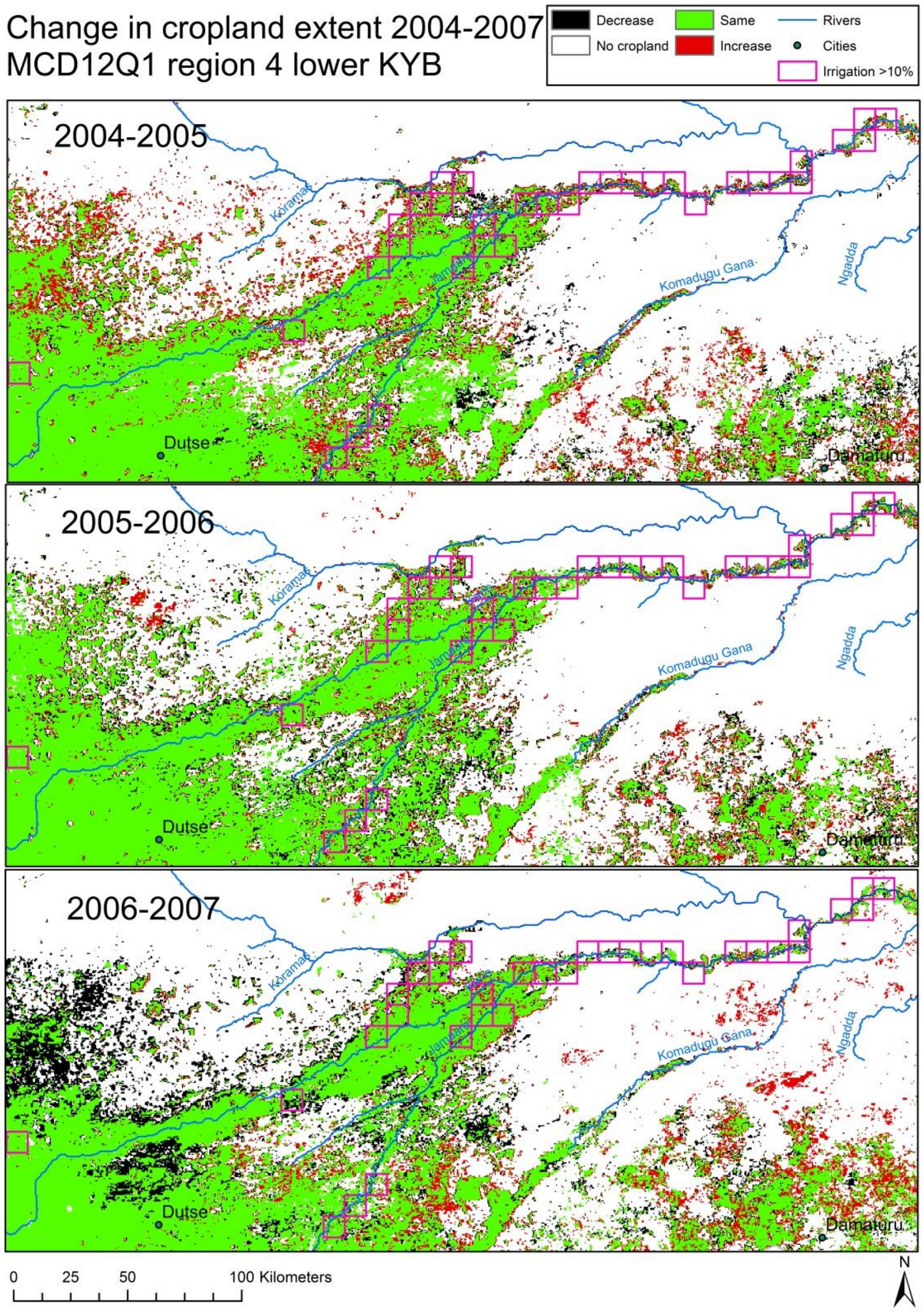

Figure 21 The annual change in cropland by the lower KYB (region 4) from 2004 to 2007 according to the 500m resolution MCD12Q1 dataset.

According to the temporal analysis of changes in cropland extent by the Lake Chad body (region 1) presented in figure 15, a decrease around Lake Chad's southern pool occurs between 2001 and 2002 that recovers between 2006 and 2007. The cropland around the northern pool is getting more intense each year and this is also occurring to some areas on the outskirts of the former shoreline of the lake. However, cropland extension is not occurring particularly close to the irrigation schemes.

In the northern part of region 2 (the Chari-Logone Basin, see figures 16 and 17) there is a large fluctuation of cropland extent. Between 2001 and 2003, cropland is extending but then retracting again between 2003 and 2005. This pattern is repeated again during the following years. The area of large fluctuations is not located particularly close to the Maga dam or the irrigation schemes.

In region 3, figures 18 and 19, there is a trend of cropland extension downstream the KY Rivers from 2001 to 2006. Most of the areas close to dams and irrigation schemes are already covered with cropland and no change is occurring in these regions.

The cropland area is expanding on the floodplains of the rivers in the lower KYB (see region 4 in figures 20 and 21). This area is labeled as being irrigated.

5.3 Bi-temporal change in cropland extent 2004-2006 to 2009

A comparison of the cropland extent within the Lake Chad Basin between 2004-2006 and 2009 was carried out based on the two 300 m resolution Globcover datasets. The result is presented in figure 22, together with dams and irrigated areas. According to figure 22, changes in cropland extent occurs in many regions within the basin, not particularly close to any irrigated land or dams.

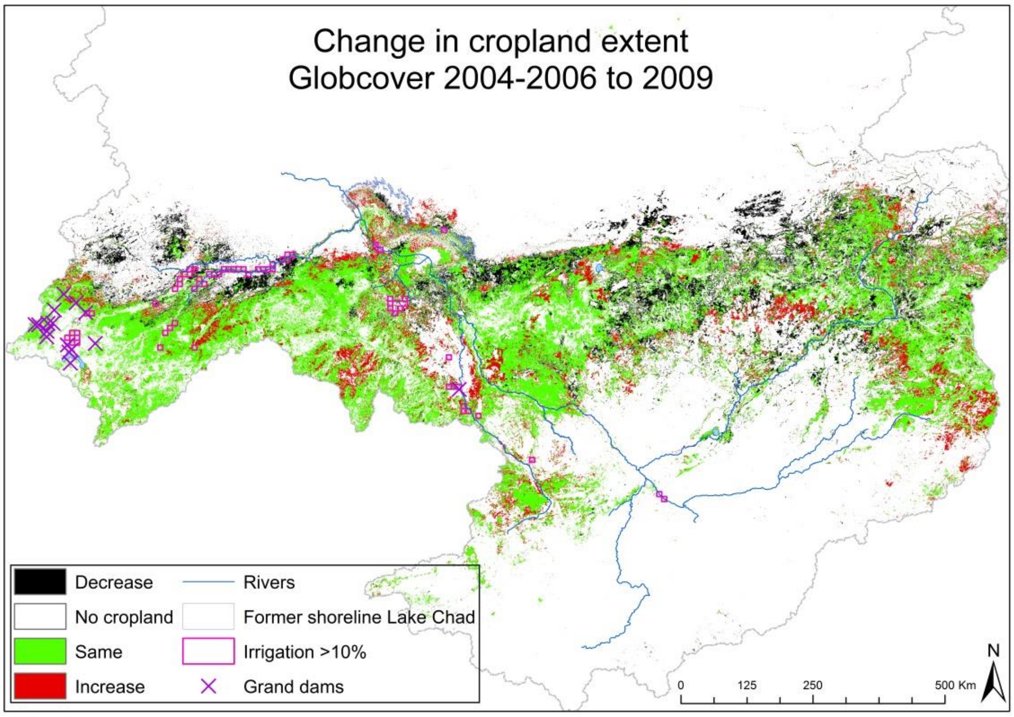

Figure 22 Change in cropland within the Lake Chad Basin from 2004-2006 to 2009 according to the 300m resolution Globcover datasets.

5.3 Long term bi-temporal change in cropland extent 1992-1993 to 2007

Figure 23 presents a temporal analysis between the cropland extent according to the GLCC (from 1992-1993) and MCD12Q1 (from 2007) datasets, together with the dams and irrigation datasets. The derived layer has a resolution of 1 km and large differences are visible in several regions within the area. However, change is not only occurring close to dams and irrigation schemes but within the whole basin.

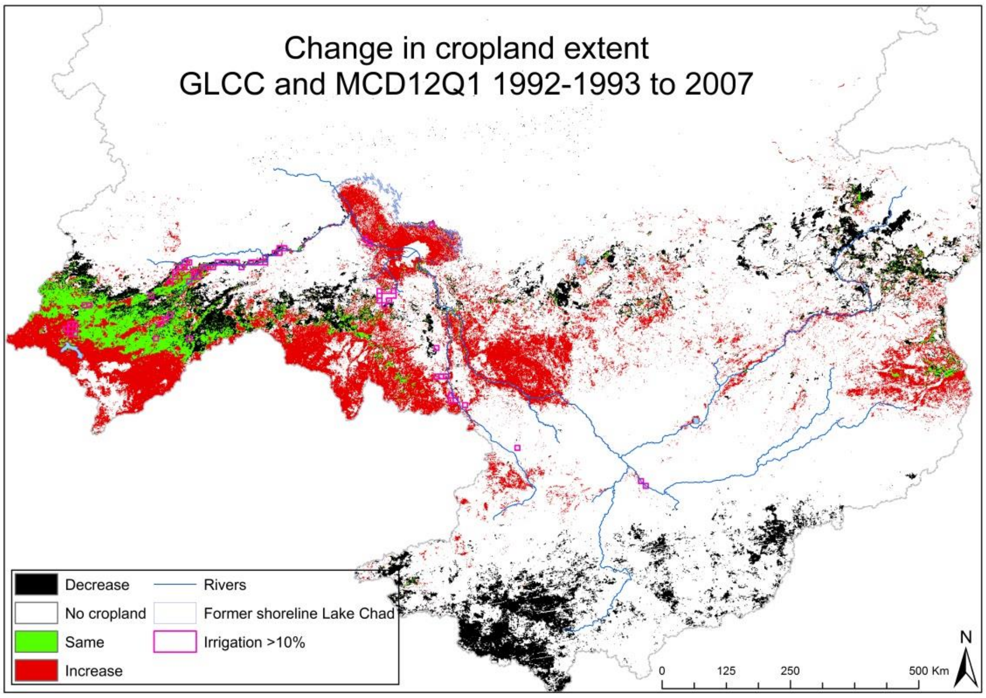

Figure 23 Change in cropland within the Lake Chad Basin from 1992-1993 to 2007 according to the 1km resolution GLCC and 500m resolution MODIS dataset. The generated layer has a resolution of km.

6 Discussion

Based on the temporal analysis of cropland extent represented by different land cover datasets, areas exposed to cropland extension can be delineated. The multi-temporal analysis based on the MCD12Q1 datasets (2001-2007) indicates a clear trend of intensified cultivation by the northern pool within the former shoreline of Lake Chad (region 1). A migration of cropland is detected from the headwaters by the dams in region 3 downstream the KY Rivers. Traditional recession farming also appears to be increasing on the floodplains of the KY Rivers (region 4). Other areas where irrigation is indicated, such as in the Chari-Logone river basin, do not seem to experience a consistent cropland extension but indicate instead a large annual variation. The purpose of comparing the result from the analysis of MCD12Q1 datasets with the precipitation anomalies data from the same time period was to detect regions that relied on irrigation during years of drought. However, the low level of precipitation in 2002, see figure 13 does not seem to have impacted the cropland in the region and it is therefore hard to deduce which areas are actually dependent on irrigation. Either this change in precipitation was not sufficient enough to make an impact on the cropland extent or more resistible land cover can be misinterpreted for cropland.

It is hard to draw any conclusions from the bi-temporal analysis carried out between the two Globcover datasets and the GLCC and MCD12Q1 (2007) datasets. Based on the Globcover datasets, changes in cropland extent occur in many regions within the Lake Chad Basin between 2004-2005 and 2009. No particular area is exposed to this change more than any another and it is therefore hard to know whether this difference is due to extreme weather conditions or if a trend in cropland extension actually occurs. The comparison between GLCC (1992-1993) and MCD12Q1 (2007) suffers the same limitations, in addition to differences in data sources and type of processing method used to derive the datasets. The impact this difference in data sources and type of processing method can have on the representation of cropland is large according to the comparison between two land cover products produced during almost the same time period, see figure 12.

The overall reliability in using land cover products in detecting changes in cropland extent is proven to be questionable. There are several factors that are unique to every dataset such as: atmospheric properties, sensor properties, illumination, type of indices and spectral values used in the classification process and legend. These conditions can even differ between the same types of datasets, which makes a change in cropland extent hard to discriminate from the data discrepancy. When detecting areas covered by cropland, there is a high risk of misinterpretation as agricultural land can easily be interpreted as natural grassland or scrubland. Clouds covering the tropical region and bottom part of the Lake Chad Basin also limit the data that is accessible within this part of the world.

The lack of data from 1960 to 1980, when Lake Chad began to shrink and most of the dams and irrigation schemes were put in place, limits the possibilities of finding factors that can explain the decreases in the water resource. The multi-temporal analysis between 2001 and 2007 indicates an extension in cropland in some regions. Whether this extension is substantially large in comparison to previous years is unknown. For this reason, analysis of the change in cropland extent between 2001 and 2007 might not be relevant to find reasons for the shrinkage of Lake Chad.

The characteristics of the KYB and the Chari-Logone River Basin are fairly different in terms of flow regulation. Only one major dam is located by the Chari-Logone Rivers and the remaining dams were constructed in the headwaters of the KYB. The two river basins have also been separated since the 1980's and should probably be treated as two separate systems. The fact that the results from the study only indicate changes in the KYB, which is contributing with a very small share of the water in the lake, makes the usefulness of the data between 2001 and 2007 questionable.

7 Conclusion

The purpose of this study was to use classified remote sensing data to detect areas exposed to extensions in cropland that could explain the increased water consumption in the Lake Chad Basin. Due to a lack of classified data further back in time, the analysis was only carried out using data from 1992 to 2009.

Comparisons between the MCD12Q1 datasets that were produced on an annual basis from 2001 to 2007 are found to be suitable for this type of study. They indicate an intensified cultivation by Lake Chad's northern pool and a cropland migration downstream the upper KYB. The flood and recession farming along the lower KYB also seem to have increased between 2001 and 2007. Based on these results, further investigations should be focused in regions 1, 3 and 4 in figure 11to improve water management and thereby reduce water consumption. However, whether or not this result can explain the increased water consumption in the Lake Chad Basin is questionable due to the fact that the largest retraction of the lake occurred between 1960 and 1980.

The study also aims to discuss the suitability and reliability of using classified land cover datasets to detect these changes. There are several drawbacks in using classified remote sensing data to detect changes in cropland extent such as differences in temporary conditions, data sources, processing methods as well as local conditions. This result should therefore rather be used as an indication and guidance for further studies than facts to base decisions on.

8 Recommendations

Previous studies have been carried out analyzing the causes of the reduced stream flow in the tributaries of Lake Chad (UNEP, 2004; Zilefac, 2010). However, due to the differences in the characteristics of the two tributaries and the separation of the lake into two pools, these analyses are probably more suitable to be done separately.

Trend analysis should also be carried out using recent statistics on stream flow and precipitations levels in order to find out whether the trend of unexplained flow decrese has continued since the 1980’s.

Figure 5 does not indicate any particular decrease in the surface area of Lake Chad during the last decades. For this reason, an analysis of the change in cropland extent between 2001 and 2007 might not be relevant for finding reasons for the shrinkage of Lake Chad. Thus Landsat multi-spectral images, with a resolution between 30 and 120m, should be used to delineate areas where change in cropland extent has occurred since 1972. This could possibly be a better indicator of the reasons to the increased water consumption since the 1960’s. The reason why this method has not yet been applied is the lack of knowledge and experience in the classification methodology that is needed to carry out such a study.

9 Dataset sources

The website from where datasets used in this study are accessed is presented below and all were available free of charge as of 2014-05-24.

9.1 Land cover datasets

- **MCD12Q1** dataset from year 2001, 2002, 2003, 2004, 2005, 2006 and 2007 with a resolution of 500m is available at: Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) (www.webmap.ornl.gov/wcsdown/dataset.jsp?ds_id=10004:)

- **GLCC** dataset from year 1992-1993 with a resolution of 1 km is available at: USGS's EarthExplorer (www.earthexplorer.usgs.gov)

- **GLC2000** dataset from year 1999-2001 with a resolution of 1 km is available at: European Union's Joint Research Center (JRC) (www.bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php)

- **Globcover** datasets from year 2004-2006 and 2009 with a resolution of 300m is available at: European Space Agency GlobCover Portal (www.due.esrin.esa.int/globcover/)

Other land cover and land use datasets that are reprocessed based on the main land cover datasets, as well as contacts to organizations that holds additional information about land cover maps, are accessible on the Geonetwork and the ORNL DAAC websites:

www.fao.org/geonetwork/
www.webmap.ornl.gov/wcsdown/index.jsp

9.2 Hydrological datasets

Geonetwork (www.fao.org/geonetwork)

- Digital Global Map of Irrigated Area version 5.
- Hydrological Basins and Africa Rivers produced by HydroSHEDS used to delineate the Lake Chad Basin and its tributaries.
- Inland water bodies in Africa originated from Digital Chart of the World and used to delineate the Lake Chad's former shoreline and other lakes in the Basin.

GWSP Digital Water Atlas (atlas.gwsp.org)

- Reservoirs, v1.01 used to delineate reservoirs within the Basin
- Dams, v1.01 used to delineate dams within the Basin

University of Washington, Precipitation anomalies in Sahel available from (http://jisao.washington.edu/data/sahel/)

Layers representing Cities, Country Boundaries and topography are all acquired from the Arc GIS library

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Appendix 1 Classification systems GLCC

Global Ecosystems Legend

Value	Description
1	Urban
2	Low Sparse Grassland
3	Coniferous Forest
4	Deciduous Conifer Forest
5	Deciduous Broadleaf Forest
6	Evergreen Broadleaf Forests
7	Tall Grasses and Shrubs
8	Bare Desert
9	Upland Tundra
10	Irrigated Grassland
11	Semi Desert
12	Glacier Ice
13	Wooded Wet Swamp
14	Inland Water
15	Sea Water
16	Shrub Evergreen
17	Shrub Deciduous
18	Mixed Forest and Field
19	Evergreen Forest and Fields
20	Cool Rain Forest
21	Conifer Boreal Forest
22	Cool Conifer Forest
23	Cool Mixed Forest
24	Mixed Forest
25	Cool Broadleaf Forest
26	Deciduous Broadleaf Forest
27	Conifer Forest
28	Montane Tropical Forests
29	Seasonal Tropical Forest
30	Cool Crops and Towns
31	Crops and Town
32	Dry Tropical Woods
33	Tropical Rainforest
34	Tropical Degraded Forest
35	Corn and Beans Cropland
36	Rice Paddy and Field
37	Hot Irrigated Cropland
38	Cool Irrigated Cropland
39	Cold Irrigated Cropland
40	Cool Grasses and Shrubs
41	Hot and Mild Grasses and Shrubs
42	Cold Grassland
43	Savanna (Woods)
44	Mire, Bog, Fen
45	Marsh Wetland
46	Mediterranean Scrub
47	Dry Woody Scrub
48	Dry Evergreen Woods
49	Volcanic Rock

IGBP Land Cover Legend

Value	Description
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
11	Permanent Wetlands
12	Croplands
13	Urban and Built-Up
14	Cropland/Natural Vegetation Mosaic
15	Snow and Ice
16	Barren or Sparsely Vegetated
17	Water Bodies
99	Interrupted Areas (Goodes Homolosine Projection)
100	Missing Data

USGS Land Use/Land Cover System Legend (Modified Level 2)

Value	Description
1	Urban and Built-Up Land
2	Dryland Cropland and Pasture
3	Irrigated Cropland and Pasture
4	Mixed Dryland/Irrigated Cropland and Pasture
5	Cropland/Grassland Mosaic
6	Cropland/Woodland Mosaic
7	Grassland
8	Shrubland
9	Mixed Shrubland/Grassland
10	Savanna
11	Deciduous Broadleaf Forest
12	Deciduous Needleleaf Forest
13	Evergreen Broadleaf Forest
14	Evergreen Needleleaf Forest
15	Mixed Forest
16	Water Bodies
17	Herbaceous Wetland
18	Wooded Wetland
19	Barren or Sparsely Vegetated
20	Herbaceous Tundra
21	Wooded Tundra
22	Mixed Tundra
23	Bare Ground Tundra
24	Snow or Ice
99	Interrupted Areas (Goodes Homolosine Projection)
100	Missing Data

Simple Biosphere Model Legend

Value	Description
1	Evergreen Broadleaf Trees
2	Broadleaf Deciduous Trees
3	Deciduous and Evergreen Trees
4	Evergreen Needleleaf Trees
5	Deciduous Needleleaf Trees
6	Ground Cover with Trees and Shrubs
7	Groundcover Only
8	Broadleaf Shrubs with Perennial Ground Cover
9	Broadleaf Shrubs with Bare Soil
10	Groundcover with Dwarf Trees and Shrubs
11	Bare Soil
12	Agriculture or C3 Grassland
17	Persistent Wetland
18	Dry Coastal Complexes
19	Water
20	Ice Cap and Glacier
99	Interrupted Areas (Goodes Homolosine Projection)
100	Missing Data

Source: USGS, 2008

Appendix 1 Classification systems GLCC

Global Ecosystems Legend-continue	
50	Sand Desert
51	Semi Desert Shrubs
52	Semi Desert Sage
53	Barren Tundra
54	Cool Southern Hemisphere Mixed Forests
55	Cool Fields and Woods
56	Forest and Field
57	Cool Forest and Field
58	Fields and Woody Savanna
59	Succulent and Thorn Scrub
60	Small Leaf Mixed Woods
61	Deciduous and Mixed Boreal Forest
62	Narrow Conifers
63	Wooded Tundra
64	Heath Scrub
65	Coastal Wetland, NW
66	Coastal Wetland, NE
67	Coastal Wetland, SE
68	Coastal Wetland, SW
69	Polar and Alpine Desert
70	Glacier Rock
71	Salt Playas
72	Mangrove
73	Water and Island Fringe
74	Land, Water, and Shore (see Note 1)
75	Land and Water, Rivers (see Note 1)
76	Crop and Water Mixtures
77	Southern Hemisphere Conifers
78	Southern Hemisphere Mixed Forest
79	Wet Sclerophylic Forest
80	Coastline Fringe
81	Beaches and Dunes
82	Sparse Dunes and Ridges
83	Bare Coastal Dunes
84	Residual Dunes and Beaches
85	Compound Coastlines
86	Rocky Cliffs and Slopes
87	Sandy Grassland and Shrubs
88	Bamboo
89	Moist Eucalyptus
90	Rain Green Tropical Forest
91	Woody Savanna
92	Broadleaf Crops
93	Grass Crops
94	Crops, Grass, Shrubs

Simple Biosphere 2 Model Legend	
Value	Description
1	Broadleaf Evergreen Trees
2	Broadleaf Deciduous Trees
3	Broadleaf and Needleleaf Trees
4	Needleleaf Evergreen Trees
5	Needleleaf Deciduous Trees
6	Short Vegetation/C4 Grassland
7	Shrubs with Bare Soil
8	Dwarf Trees and Shrubs
9	Agriculture or C3 Grassland
10	Water, Wetlands
11	Ice/Snow
99	Interrupted Areas (Goodes Homolosine Projection)
100	Missing Data

Biosphere Atmosphere Transfer Scheme Legend	
Value	Description
1	Crops, Mixed Farming
2	Short Grass
3	Evergreen Needleleaf Trees
4	Deciduous Needleleaf Tree
5	Deciduous Broadleaf Trees
6	Evergreen Broadleaf Trees
7	Tall Grass
8	Desert
9	Tundra
10	Irrigated Crops
11	Semidesert
12	Ice Caps and Glaciers
13	Bogs and Marshes
14	Inland Water
15	Ocean
16	Evergreen Shrubs
17	Deciduous Shrubs
18	Mixed Forest
19	Forest/Field Mosaic
20	Water and Land Mixtures
99	Interrupted Areas (Goodes Homolosine Projection)
100	Missing Data

Vegetation Lifeforms Legend	
Value	Description
1	Evergreen Needleleaf Vegetation
2	Evergreen Broadleaf Vegetation
3	Deciduous Needleleaf Vegetation
4	Dedicuous Broadleaf Vegetation
5	Annual Broadleaf Vegetation
6	Annual Grass Vegetation
7	Non-Vegetated Land
8	Water Bodies
99	Interrupted Areas (Goodes Homolosine Projection)
100	Missing Data

Source: USGS, 2008

Appendix 2 Classification systems MCD12Q1

IGBP		UMD	
Value	Description	Value	Description
0	Water Bodies	0	Water
1	Evergreen Needleleaf Forest	1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest	2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest	3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest	4	Deciduous Broadleaf Forest
5	Mixed Forest	5	Mixed Forest
6	Close Shrublands	6	Close Shrublands
7	Open Shrublands	7	Open Shrublands
8	Woody Savannas	8	Woody Savannas
9	Savannas	9	Savannas
10	Grasslands	10	Grasslands
11	Permanent Wetlands	12	Croplands
12	Croplands	13	Urban and Built-Up
13	Urban and Built-Up	16	Barren or Sparsely Vegetated
14	Cropland-Natural Vegetation Mosaics		
15	Snow and Ice		
16	Barren or Sparsely Vegetated		

LAI/fPAR		NPP	
Value	Description	Value	Description
0	Water	0	Water
1	Grasses/Cereal Crops	1	Evergreen Needleleaf Forest
2	Shrubs	2	Evergreen Broadleaf Forest
3	Broadleft Crops	3	Deciduous Needleleaf Forest
4	Savannah	4	Deciduous Broadleaf Forest
5	Evergreen Broadleaf Forest	5	Annual Broad leaf Vegetation
6	Deciduous Broadleaf Forest	6	Annual Grass Vegetation
7	Evergreen Needleleaf Forest	7	Non-Vegetated Land
8	Deciduous Needleleaf Forest	8	Urban
9	Unvegetated		
10	Urban		

PFT	
Value	Description
0	Water
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Shrub
6	Grass
7	Cereal crop
8	Broadleaf crop
9	Urban and built up
10	Snow and Ice
11	Barren or Sparsely Vegetated

Source: DAAC, 2014

Appendix 3

Classification systems
GLC200 and Globcover

GLC2000

Value	Description
1	Tree Cover, broadleaved, evergreen
2	Tree Cover, broadleaved, deciduous, closed
3	Tree Cover, broadleaved, deciduous, open
4	Tree Cover, needle-leaved, evergreen
5	Tree Cover, needle-leaved, deciduous
6	Tree Cover, mixed leaf type
7	Tree Cover, regularly flooded, fresh water (& brackish)
8	Tree Cover, regularly flooded, saline water,
9	Mosaic: Tree cover / Other natural vegetation
10	Tree Cover, burnt
11	Shrub Cover, closed-open, evergreen
12	Shrub Cover, closed-open, deciduous
13	Herbaceous Cover, closed-open
14	Sparse Herbaceous or sparse Shrub Cover
15	Regularly flooded Shrub and/or Herbaceous Cover
16	Cultivated and managed areas
17	Bare Areas
18	Water Bodies (natural & artificial)
19	Snow and Ice (natural & artificial)
20	Artificial surfaces and associated areas

Globcover

Value	Description
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,…)

Source: Mayaux, 2003 Bicheron, 2008