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Satellite-Based Assessment of Land Use and Land Cover (LULC) Changes around Lake Fitri, Republic of Chad

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Abstract

Lake Fitri, located northeast of the Republic of Chad's Capital, N'Djamena, and southeast of Lake Chad, is especially important because it serves as an alternative source to Lake Chad in supporting the livelihood of pastoralists and subsidence farmers displaced from the Lake Chad region. It therefore serves to relieve population pressures on Lake Chad, which has undergone drastic reduction in total water volume in the last few decades. The area has also been the epicenter of recent violent campaigns and devastating insurgency mounted by the so-called Boko Haram.

This study investigated the land use land cover around Lake Fitri from 1986 to 2003, and from 2003 to 2013 using Landsat 5 (TM), Landsat 7 (ETM+), and Landsat 8 (OLI_TIRS). The satellite imageries were retrieved from the Global Visualization (GloVis) web-based platform and analyzed using ERDAS Imagine 2014. Supervised classification of areas around the lake was performed into five land use land cover classes.

The results revealed significant changes in three land use types, namely Farmland and Grassland combined, Forest, Savanna, and Steppe combined, and Wetland. Farmland and Grassland combined increased from a mere 0.38% of the total study area in 1986 to 41.05% in 2013. At the same time, Forest, Savanna, and Steppe combined decreased from about 23% in 1986 to about 7.40% in 2013. This increase in farmlands and grasslands coverage and the concomitant decrease in trees and shrubs can be explained by the persistent pressures on land from increasing population and livestock in the area. The findings also show a major decline in Wetland, which decreased from about 14% of the total study area to 3% in the same time period. This loss in wetland coverage is regrettable because of the important environmental and ecological functions of wetlands.

Keywords: satellite-based, assessment, land use land cover, changes, Lake Fitri, Chad

1. Introduction

Lake Fitri is located northeast of the Capital of Chad, N'Djamena, and southeast of Lake Chad, in the Lake Chad Basin (LCB). Due to its closeness to Lake Chad, which has undergone drastic reduction in total water volume in the last few decades, Lake Fitri serves to relieve population pressures on Lake Chad. Lake Fitri is a particularly rich and important zone because it can be considered as an alternative source to Lake Chad in supporting the livelihood of pastoralists and subsidence farmers. In fact, there are always green pastures in and around the lake. Bdliya and Bloxom (n.d.) stated that agro-pastoralists are attracted to the region by wetland pastures in the hot dry season, recession pastures in the cold dry season, and dune pastures in the rainy season. Fisheries resources such as *Silurides* and *Pterocarpus* exist.

There are several studies addressing land use land cover (LULC) changes in Africa including many in the vicinity of Lake Chad. This study focused on Lake Fitri area specifically because very few LULC studies have been done in this area. One of the most recent LULC studies on the LCB was conducted by Policelli, Hubbard, Jung, Zaitchik, and Ichoku (2018) where total surface water area of Lake Chad was estimated using Land Surface Temperature (LST) measurements from three sources: (1) the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) Terra sensor, (2) the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Meteosat, and (3) the European Space Agency (ESA) Sentinel-1a mission radar data. Their findings revealed that, for the dry seasons of 1988-1989 to 2016-2017, the maximum total surface water area of the lake was about 16,800 km^2, the

minimum was about 6400 km^2 and the average was about 12,700 km^2. They also found that the total water area of the lake was highly variable during this time period, with an average rate of increase of about 143 km^2. Using Landsat and NigeriaSat-1 data, Babama'aji and Lee (2014) reported a 35% decrease in waterbodies in the LCB from the 1970s and 1991.

A study by Leblanc, Lemoallé, Bader, Tweed, and Mofor in 2011 used the Meteosat thermal maximum composite data (Tmax) to account for water covered by aquatic vegetation and provide a consistent monthly time series of the total inundated area estimates for Lake Chad. They reconstructed the total inundation patterns for a 15-year period (1986-2001). The findings were that Lake Chad remained below 16,400 km^2 and the variability of the inundated area observed in the northern pool is about 60% greater than that of the southern pool. Buma and Lee in 2016 used the Gravity Recovery and Climate Experiment (GRACE) and the Land Remote-Sensing Satellite (LANDSAT) imageries to investigate the changes within the Lake Chad Basin from 2003 to 2013. They found that GRACE terrestrial water storage within the basin had been somewhat stable with the highest averaged values of 0.69 cm per year occurring in 2012.

Pyke and Andelman (2007) argued that LULC interacted with atmospheric conditions to determine current climate conditions, as well as, the impact of climate change and environmental variability on ecological systems. That study also suggested that LULC has the possibility of being considered as a powerful tool capable of modifying local climate conditions and significantly contributing to the net global impact of climate change. According to Lambin, Geist, and Lepers (2003), LULC change is shown to be driven by synergetic factor combinations of resource scarcity leading to an increase in the pressure of production on resources, changing opportunities created by markets, outside policy intervention, loss of adaptive capacity, and changes in social organization and attitudes. A systematic analysis of local-scale LULC change studies conducted over a range of timescales can help to uncover general principles that provide an explanation and prediction of land use changes in the future.

Like many other sensitive natural ecosystems, Lake Fitri is also affected by climate change and pressure from overcrowded human population and livestock resulting in significant LULC changes. Data from the Earth Observatory (2012) indicated that Lake Fitri was significantly larger in the past, but may have also been completely dry on multiple occasions during past climatic phases. In addition to this, being located in a transition zone between the desert and the Sahel/savanna zones, Lake Fitri is also subject to the impact of the ever advancing desert. More indepth knowledge and a deeper understanding of its dynamics would help better assess the impact of increasing nomadism pressure on Sahelian ecosystems.

The general objective of this study is to analyze the LULC changes of Lake Fitri. Specifically, the goals are to (1) analyze the spatio-temporal scope of LULC around Lake Fitri using multi-temporal Landsat satellite data, (2) evaluate spatio-temporal changes of LULC around Lake Fitri from the 1980s to 2010s, and (3) determine the potential factors inducing the changes in LULC.

1.1 Description of the Study Area

Lake Fitri (Figure 1.a) is located in the Batha Region, a region in the center of Chad with geographic coordinates 12˚53'53'' N and 17˚25'44''E (National Geospatial-Intelligence Agency [NGA], 2012). Lake Fitri is about 300 km east of N'Djamena, the capital of Chad. Its extent is nearly 500 km^2 and can double or triple in wet years. Lake Fitri (Figure 1.b) is a shallow freshwater lake sustained by seasonal rainfall and run-off from a catchment area approximated at 70,000 km^2 (BirdLife International, 2014; Earth Observatory, 2012). According to Bdliya and Bloxom (n.d.), Lake Fitri is sometimes considered as a miniature of Lake Chad. It covered 420 km^2 in a median year with a depth between 1.5 and 2 m during normal periods, and a volume varying from 0.7 to 2 x 10^9 m^3. The lake supports vegetation characteristics of the sahelian wetlands with *Echinochloa stagnina*, *Vossia cuspidata*, and *Nympheae aquatica*, and woodlands with *Acacia nilotica* and *Mitragyna inermis*; it is also important for mammals such as the *Loxodonta africana* and *Gazella rufifrons.* Some of the main species of birds found in this site in the winter season are the *Anas acuta* (Northern Pintail), *Dendrocygna bicolor* (Fulvous Whistling-Duck), *Platalea alba* (African Spoonbill), and the *Balearica pavonina* (Black Crowned-Crane), etc. (BirdLife International, 2014). According to the Earth Observatory (2012), the Ramsar Convention of 1971 designated Lake Fitri, which is an endorheic or terminal lake of 23 km long fed by the Batha River, and its surroundings as wetland of international importance. Lévêque, as cited in Burgis and Symoens (1987), described Lake Fitri as a secondary and miniature relic basin of Lake Chad. According to Lemoallé, also cited in Burgis and Symoens (1987), Lake Fitri is fed by the flows from the Bather river from July to October as well as by Ouadis from Aboutelfan. At that time, the average annual rainfall was 450 mm/year and the input water from the tributaries varied from 0.7 to 2×10^9 m^3/ year. The evaporation was roughly greater than 2 m/year.

The study done by the Lake Chad Basin Commission (LCB) in 2006 revealed the economic and ecological importance of Lake Fitri. More than 50,000 seasonal grazers and their livestock spend the dry season in its vicinities. also, more than 30,000 tons of fish are produced per year. It is a wintering area for birds, a refuge for Afrotropical species, and an important place for elephants during the dry season. Lake Fitri's ecosystem, however, is under increasing pressure from conflicting herding, agriculture, and fishing activities that mostly occur during extended dry periods.

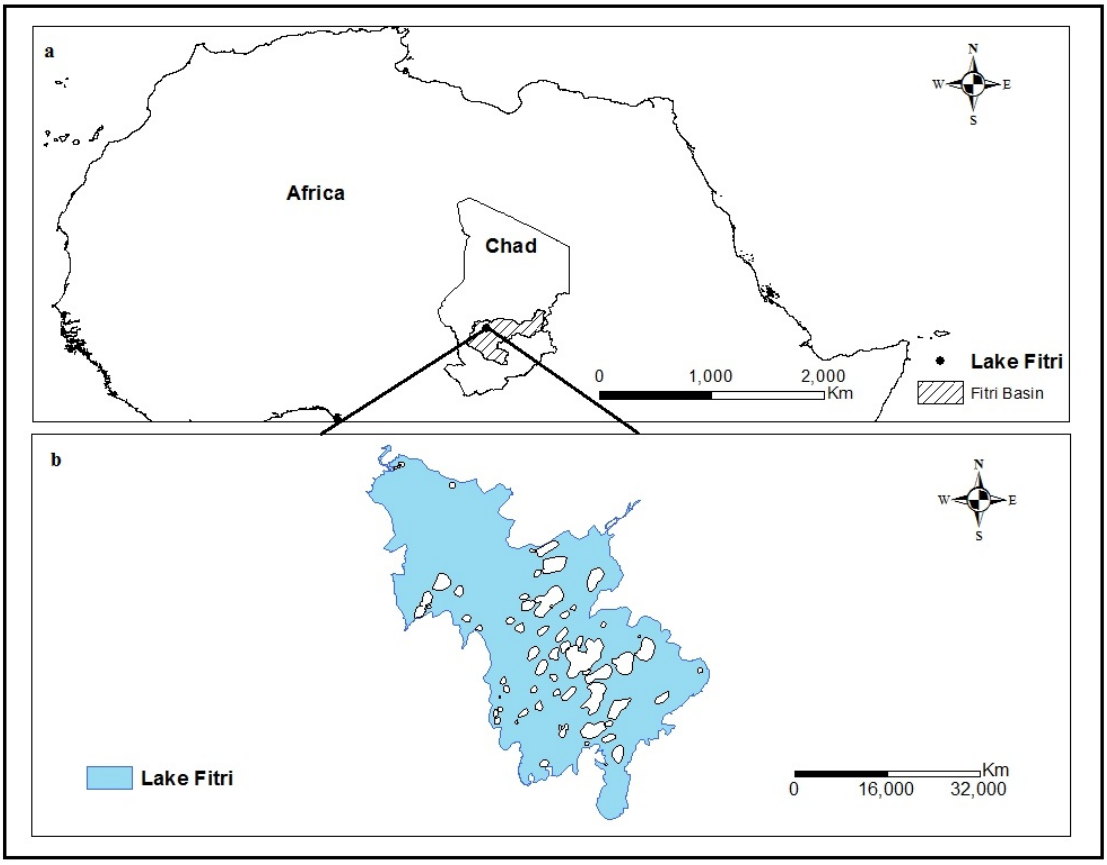

Figure 1. The Lake Fitri: (a) location in Chad; (b) map digitized from a photograph by the Earth Observatory, 2012

The Worldwide Reference System (WRS) for the Landsat satellite imagery of Lake Fitri's nominal scene is path 183 and row 51. The whole area covered by the scene is the focal point in this study.

2. Methodology

2.1 Data Sources

Using the Global Visualization (GloVis) web-based platform, we acquired Satellite images from Landsat 5 (TM), Landsat 7 (ETM+), and Landsat 8 (OLI_TIRS) for the years 1986, 2003, and 2013 to perform the LULC analysis in this study. Table 1 shows the specification of the data.

We initially used ERDAS Imagine 2014 to perform the supervised classification. We then made some adjustments using ERDAS Imagine 2016 and ArcGIS 10.2.2.

Table 1. Data specification

Data	Date
Landsat Thematic Mapper (Landsat 5 TM)	Nov. 14th, 1986
Landsat Enhanced Thematic Mapper Plus (Landsat 7 ETM+)	Jan. 5th, 2003
Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (Landsat 8)	Oct. 23rd, 2013

All of those images are from path 183 and row 51 and have the following characteristics. Projection: UTM Zone 33, Spheroid: WGS 84, Datum: WGS 84. We chose images from the end of the rainy season (October and November) and cold season (January) in order to better assess the impact of rainfall on vegetation and other human activities.

2.2 Data Preparation

Data layers were stacked and radiometric correction performed using the histogram Equalization Filter. The classes considered for classification (water bodies, wetlands, bare soil, forests-savannas-steppes, and grasslands-farmlands) were clear enough to be distinguished.

2.3 Classification

We conducted a supervised classification using the "Supervised Maximum Likelihood" method; five classes were identified: Bare Soil, Farmland and Grassland combined, Forest Savanna, and Steppe combined, Water Bodies, and Wetland. Bare Soil was identified as soil and sand not covered by vegetation; Farmland and Grassland combined were open land in which grasses were dominant and there was cultivated land; Forest, Savanna, and Steppe combined included all the vegetative forms other than grasses, from trees to shrubs; and Water Bodies referred to the lake itself, rivers, and the Wadi. Wetland were inundated or saturated areas at a frequency and duration sufficient to support a prevalence of vegetation and included swamps, marshes, bogs, and similar areas (Darden, 2011).

We used Google Earth, LULC maps of 2000 and 2013, and a vegetation map related to the soil as guides to achieve a more accurate classification.

2.4 Post Classification

After performing the supervised classification**,** we filtered the images and the unclassified pixels were eliminated. The following post-classification procedures were conducted:

i. Accuracy assessment: we reported the Accuracy Assessment (Error matrix, Accuracy Totals, and Kappa Statistics) with at least 256 random points.

ii. Area Table: we added an area table for the classes in the attribute table using the tool Table/Add Area. The areas were first in hectares; we then converted them in square kilometers. We computed the changes image by image.

iii. Rate of Change: we computed the rates of changes in LULC classes from 1986 to 2003 and 2003 to 2013 using the following equation (1) borrowed from FAO (1990):

$$R = \left[\left(\frac{A_2}{A_1}\right)^{\frac{1}{(t_2 - t_1)}} - 1\right] * 100 \quad (1)$$

where: R = rate of change; A_1 = area at time t_1; A_2 = area at time t_2; t_1 and t_2 are the starting and ending times, respectively.

3. Results and Discussion

3.1 Land Use Land Cover Analysis of Lake Fitri from a 1986 Classified Image

Figure 2 shows the LULC map from the supervised classification of Lake Fitri and its vicinity for the year 1986. The corresponding area coverage and percentages for each LULC is shown in Table 2. In the year 1986, Bare Soil around Lake Fitri covered 19437.99 km^2. Forest, Savanna, and Steppe combined covered 7202.50 km^2. Farmland and Grassland combined represented 118.14 km^2 while Wetland (marshes and swamps) covered 4410.52 km^2. Lastly, Water Bodies, including lakes and rivers covered only 57.45 km^2.

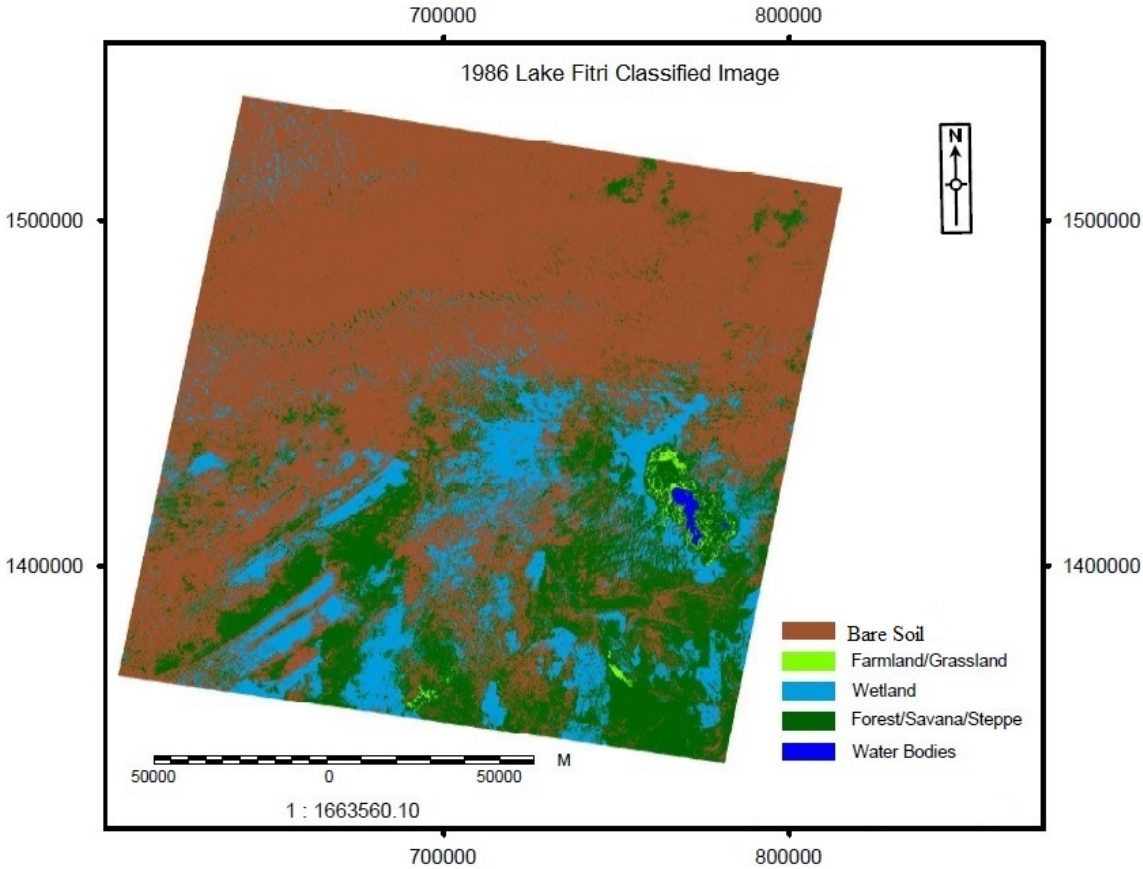

Figure 2. Land Use Land Cover map of Lake Fitri and its vicinity for the year 1986

It is obvious from Table 2 that the major LULC around Lake Fitri in 1986 were, in decreasing order, (1) Bare Soil (62.25%); (2) Forest, Savanna, and Steppe combined (23.06%); (3) Wetland (14%); (4) Farmland and Grassland (0.38%); and (5) Water Bodies (0.18%).

Table 2. The area coverage and percentages for different LULC in 1986

Class	No. of pixels	Area coverage (km^2)	Percentage LULC (%)
Bare Soil	22756497	19437.99	62.25
Farmland-Grassland	1311299	118.14	0.38
Forest-Savanna-Steppe	8621082	7202.50	23.06
Water Bodies	63835	57.45	0.18
Wetland	5084861	4410.52	14.12
Total		31226.60	100.00

3.2 Land Use Land Cover Analysis of Lake Fitri from a 2003 Classified Image

Figure 3 shows the LULC map from the supervised classification of Lake Fitri and its vicinity for the year 2003. The corresponding area coverage for each LULC type and associated percentages are highlighted in Table 3. The area coverage of Bare Soil around Lake Fitri was 24937.54 km^2 while the area covered by Forest, Savanna, and Steppe combined represented 3766.10 km^2. Farmland and Grassland combined covered 2852.32 km^2. The area represented by Wetland and water Bodies were 280.50 km^2 and 198.80 km^2, respectively.

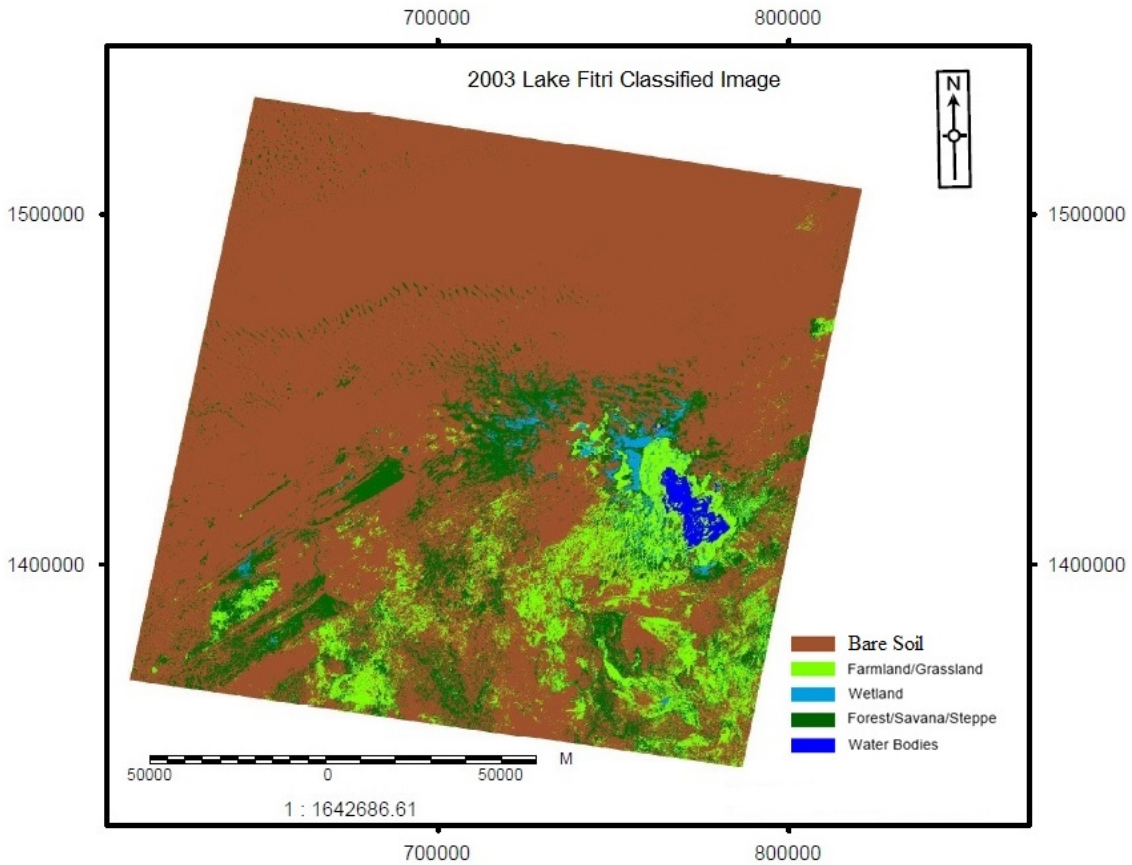

Figure 3. Land Use Land Cover map of Lake Fitri and its vicinity for the year 2003

The predominant LULC in Lake Fitri and its surroundings in 2003 were, in descending order: (1) Bare Soil (77.84%); (2) Forest, Savanna, and Steppe combined (11.75%); (3) Farmland and Grassland combined (8.90%); (4) Wetland (0.87%); and (5) Water Bodies (0.62%) [Table 3].

Table 3. The area coverage and percentages for different LULC in 2003

Class	No. of pixels	Area coverage (km^2)	Percentage LULC (%)
Bare Soil	114279521	24937.54	77.84
Farmland-Grassland	13686397	2852.32	8.90
Forest-Savanna-Steppe	17149806	3766.10	11.75
Water bodies	883597	198.80	0.62
Wetlands	1246709	280.50	0.87
Total		32035.26	100.00

3.3 Land Use Land Cover Analysis of Lake Fitri from a 2013 Classified Image

The last period for which we carried out supervised LULC classification for Lake Fitri and its vicinity was 2013. The map is shown in Figure 4 while Table 5 contains the area corresponding to each LULC type and associated percentages. The area covered by Bare Soil around Lake Fitri was 18053.38 km^2. Farmland and Grassland combined covered 15349.54 km^2 while Forest, Savanna, and Steppe combined coverage was 2764.00 km^2. Wetland and Water Bodies represented 1039.05 km^2 and 182.70 km^2, respectively.

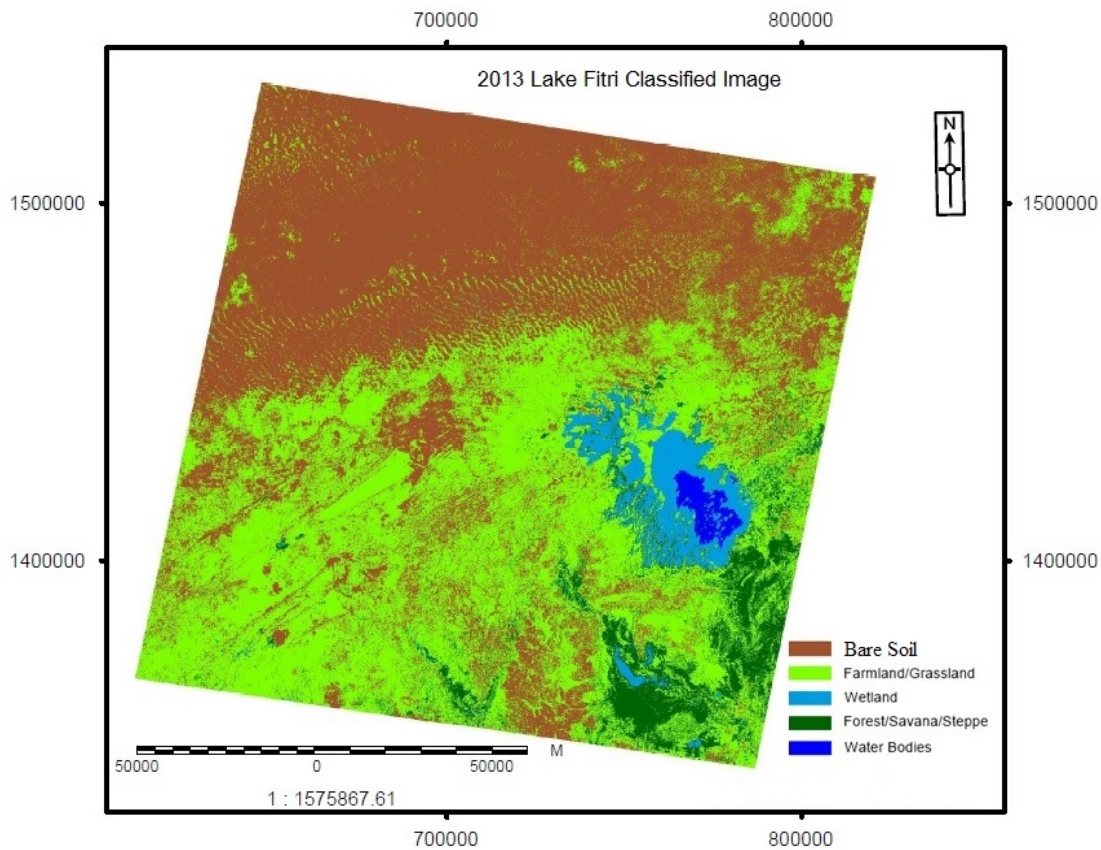

Figure 4. Land Use Land Cover map of Lake Fitri and its vicinity for the year 2013

Table 4 shows that in 2013, the predominant LULC in Lake Fitri and its surroundings were as follows, in a descending order of importance: (1) Bare Soil (48.30%); (2) Farmland and Grassland combined (41%); (3) Forest, Savanna, and Steppe combined (7.39%); (4) Wetland (2.78%); and (5) Water Bodies (0.49%).

Table 4. The area coverage and percentages for different LULC in 2013

Class	**No. of pixels**	**Area coverage (km^2)**	**Percentage LULC (%)**
Bare Soil	20059309	18053.38	48.30
Farmland-Grassland	17055035	15349.54	41.05
Forest-Savanna-Steppe	3072193	2764.00	7.39
Water Bodies	203050	182.70	0.49
Wetland	1154508	1039.05	2.78
Total		37388.67	100.00

The percentages of the LULC types for the years 1986, 2003, and 2013 are shown in Table 5. It is clear that the Bare Soil and Water Bodies increased from 1986 to 2003, then decreased in 2013. Farmland and Grassland combined continually increased while Forest, Savanna, and Steppe combined continually decreased from 1986 to 2013. Wetland decreased drastically from 1986 to 2003 before recovering slightly in 2013.

Table 5. Land Use Land Cover coverage in Lake Fitri in 1986, 2003, and 2013 in percentage

Class	Year 1986 (%)	Year 2003 (%)	Year 2013 (%)
Bare Soil	62.25	77.84	48.30
Farmland-Grassland	0.38	8.90	41.05
Forest-Savanna-Steppe	23.06	11.75	7.39
Water Bodies	0.18	0.62	0.49
Wetland	14.12	0.87	2.78
Total	100.00	100.00	100.00

The percent changes during the time periods 1986 - 2003, 2003 - 2013, and 1986 – 2013 were computed. Table 6 contains the percent changes from the respective years of reference. The analyses show the following results: bare soil coverage had a percentage increase from 1986 to 2003 and a percentage decrease from 2003 to 2013; overall, there was a decrease from 1986 to 2013. The water bodies' coverage had a percentage increase from 1986 to 2003, a percentage decrease in the 2003 – 2013 period; the overall percentage from 1986 to 2013 increased. Wetland coverage had a percentage decrease in the first period, then a slight percentage increase in the second period; the general trend from 1986 to 2013 was a percentage decrease. Farmlands and grasslands had a percentage increase for all three periods whereas forests, savannas, and steppes coverage had a percentage decrease.

Table 6. Lake Fitri's land Use Land Cover percent changes

Class	1986 to 2003 (%)	2003 to 2013 (%)	1986 to 2013 (%)
Bare Soil	28.29	-27.60	-7.12
Farmland-Grassland	2314.35	438.14	12892.67
Forest-Savanna-Steppe	-47.71	-26.60	-61.62
Water Bodies	246.04	-8.09	218.01
Wetland	-93.64	270.42	-76.44

Figure 5 shows the pictorial views of the different LULC types and their respective percentages for the years 1986, 2013, and 2013.

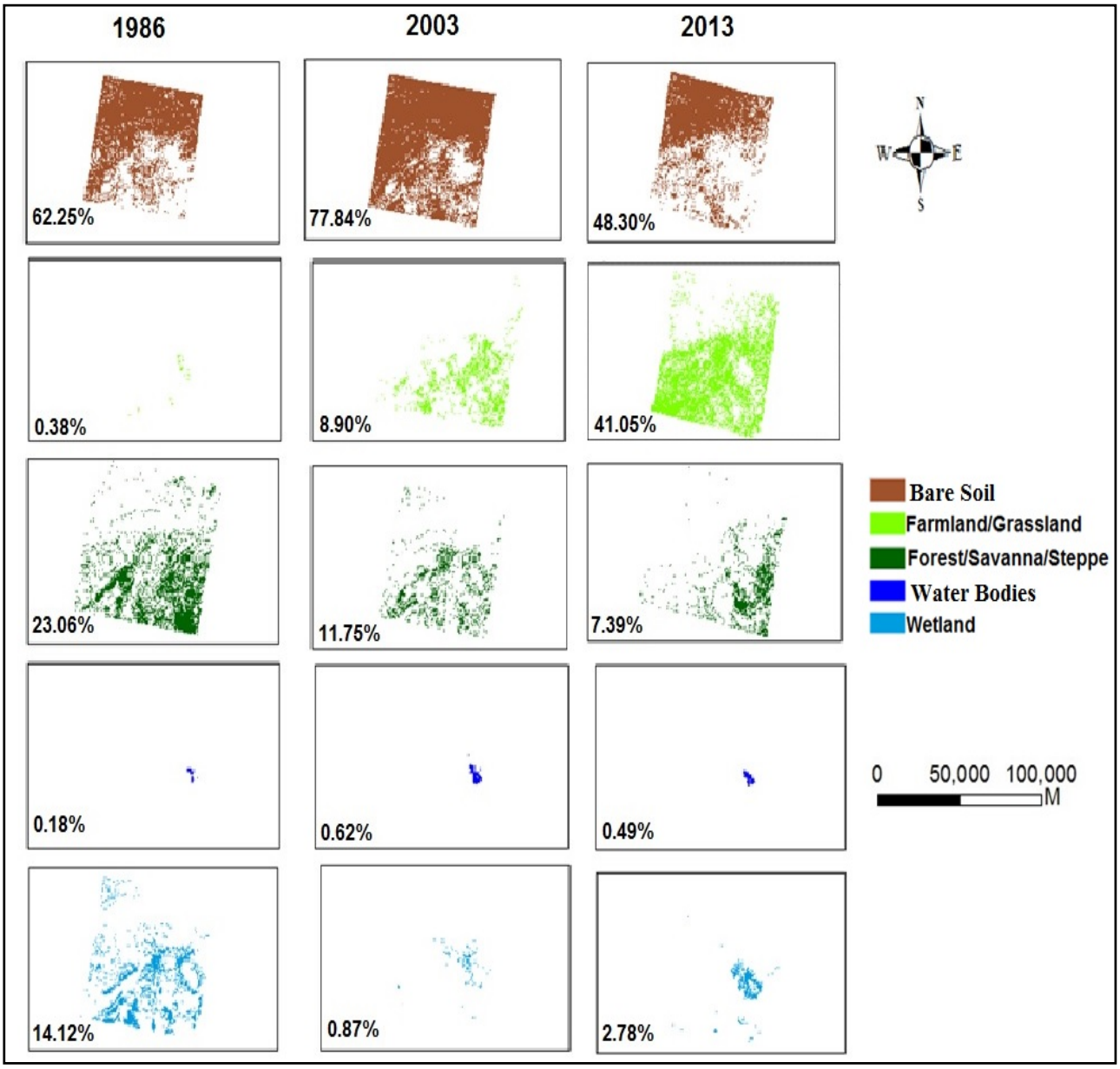

Figure 5. Pictorial and percentage views of Lake Fitri's LULC trend from 1986 to 2013

4. Discussion

In the preceding section, we presented results of LULC changes within Lake Fitri and its vicinity for the period 1986 to 2013, a 27-year-period beginning in 1986 and ending in 2013. The results indicated that the region has undergone significant LULC changes in several respects. The most significant of these changes appears to be the expansion of farmlands as well as grasslands used for livestock grazing. In 1986, these two LULC types combined covered only 0.38% of the entire area. By 2013, they accounted for 41% while wooded areas such as forest, savanna, and steppe combined decreased in the same time period from 23% to about 7.40%. We also noted a major decline in wetland areas, which accounted for 14% of the total land in 1986, but less than 3% in 2013. Below, we discuss these changes in greater detail for each land use type.

4.1 Bare Soil

Bare Soil is the designation given to areas representing soil and sand not covered by vegetation. This land cover type increased from 19437.99 km^2 in 1986 to 24937.54 km^2 in 2003, and then decreased to 18053.38 km^2 in 2013. The percentages of the total land area represented by Bare Soil were 62.25, 77.84, and 48.30% for the time period, respectively. The increase in land not covered by vegetation could be due to the drought of 1984 that the

Sahel region experienced, the continuing process of desertification, and the pressing anthropogenic activities such as farming and grazing. In fact, data from FAOSTAT in 2012 showed that Chad's population grew almost exponentially between 1980 and 2012 and that livestock (cattle, sheep, and goats), also increased in number from 1980 to 2012, with the exception in the drought years of 1984 and 1986. It is not clear why there was a significant drop in the percentage of areas identified as bare ground in 2013, but that period coincided with a return of wetter conditions to the region (Jury, 2013).

4.2 Farmland-Grassland

Farmland and Grassland combined increased from 18.14 km^2 in 1986 to 2852.32 km^2 in 2003 and 15349.54 km^2 in 2013. They were 0.38%, 8.90%, and 41.05%, respectively, in the same time period.

The increasing coverage by farmlands and grasslands and the decreasing coverage of trees and shrubs could be highly correlated and might be the results of forest degradation due to anthropogenic activities such as farming, herding, and wood energy. More space could be used to meet food security needs for increasing population and livestock. The analysis of data from FAOSTAT in 2012 shows that the population of Chad increased from 4,554,000 million in 1980 to 11,525,000 million in 2011. The Pearson correlation between population and agricultural land is positive and moderately strong (0.412). This appears to confirm that increasing population is one of the major driving forces of the expansion in the agricultural land area in Chad during the period of study. Interestingly, Bourn and Wint (1994) found a close association between livestock biomass and the presence of people. They concluded that cultivation and rural habitation were the primary predictors of livestock distribution. Taylor et al. (2002) observed that cropland coverage in the Sahel had risen from 5% to 14% in the 35 years prior to 1996.

4.3 Forest-Savanna-Steppe

Forest, Savanna, and Steppe combined represent all the vegetative forms from trees to shrubs. Together, they accounted for 7202.50 km^2 in 1986, 3766.10 km^2 in 2003, and 2764.00 km^2 in 2013. In effect, this represented a decrease from 23.06% in 1986 to 11.75% in 2003, and 7.39% in 2013, respectively. Again, the decrease of this land use type is most likely due to the anthropogenic factors mentioned earlier. It is plausible that this decrease is also related to the increase of farmlands for agricultural and grazing purposes. In 2012, the United Nations Environmental Programme (UNEP) indicated that vegetation has not recovered to its full potential despite the increase in rainfall following the droughts of 1980s.This result is corroborated by a recent study (Keenan et al., 2015) which found that Africa is among the sub-regions of the world where forest areas continued to decline from 1990 t0 2015. The study also reported that the net forest loss was mainly in the tropics with highest rates of loss in the low-income countries. According to Funk et al. (2012), human and animal pressure on a degraded ecosystem, combined with limited agricultural development, lead to low levels of national food production. The study by Taylor, Lambin, Stephenne, Harding, and Essery (2002) concluded that the process of agricultural intensification, coupled with deforestation and other land use changes, translated to a conversion of 4% of the land from tree to bare soil over that period.

4.4 Water Bodies

Water Bodies in the classified image included Lake Fitri itself, rivers, and Wadis. Together, they covered 57.45 km^2 in 1986, 198.80 km^2 in 2003, and 182.70 km^2 in 2013 representing 0.18%, 0.62%, and 0.49% of the total area in those time-periods, respectively.

The results indicate a slight increase (0.18 – 0.49%) in the water body in the areas classified as Water Bodies in the classified image. These changes probably reflect changes in rainfall patterns in the region.

4.5 Wetland

Wetland, which generally refers to areas inundated or saturated and supporting a prevalence of vegetation, covered 4410.52 km^2 in 1986, 280.50 km^2 in 2003, and 1039.05 km^2 in 2013. This represented a significant decrease in the total area identified as wetland from 14.12% in 1986 to 0.87% in 2003 and 2.78% in 2013. This is an important land use change that deserves attention because of the great ecological value of wetlands. The loss of wetlands in this region as identified in the classified images will likely have an adverse effect on the biodiversity of the region as well.

5. Conclusions

This study focused on the LULC analysis of Lake Fitri and its vicinity between 1986 and 2013. We found significant changes in three land use types, namely Farmland and Grassland combined, Forest, Savanna, and Steppe combined, and Wetland. Farmland and Grassland combined increased from a mere 0.38% of the total

study area in 1986 to 41.05% in 2013. At the same time, Forest, Savanna, and Steppe combined decreased from about 23% in 1986 to about 7.40% in 2013. This increase in farmlands and grasslands coverage and the concomitant decrease in trees and shrubs can be explained by the persistent pressures on land from increasing population and livestock in the area. Notably, the population of Chad increased from 4.5 million in 1950 to about 11.5 million in 2011, according to the United Nations Food and Agricultural Organization (FAOSTAT, 2013). The findings also indicate a loss of Wetland, which decreased from about 14% of the total study area to 3% in the same time period. This loss in wetland coverage is regrettable because of the important environmental and ecological functions of wetlands. The loss in wetland areas is probably associated with the decline of surface water in the area due to changing climate and environmental conditions.

The results are especially significant because they shed some light on the larger implications of environmental degradation within the Lake Chad region and the resulting effects of the population migrations into the adjacent sub-basins. Clearly, the LULC changes in the Lake Fitri area documented in this study are linked to the economic and social pressures produced by the well-documented large-scale decrease in the water surface of Lake Chad. These findings suggest that for the current efforts to address the environmental problems to be successful, they also have to address the changes occurring in the neighboring sub-basins. However, we recommend that additional studies, including ground truth data collection, participatory, observational or semi-structured interview be conducted in order to complete these results.

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