Agricultural Trend Analysis Using Earth Observation Data

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1 Introduction

Under the framework of the Global Land Cover Network (GLCN) activities, a study was conducted in 2005 to assess agricultural changes in Kenya for the last 30 years (1970-2000). The results achieved from this study can help quantify the pressures associated to agricultural land-use. Change detection analysis can indicate trends in agricultural change and allow forecasting for the future. Together with GIS technology and local expert knowledge, causes and consequences of these changes can be identified.

This study will show the structure of the GLCN database and how it can be used for change detection. The database will be used to assess the intensity of agriculture in the Kisumu district between the 1970s and 2000. Therefore we will use the extent of cultivated land and field density as two indicators to quantify agricultural intensity, where extent of cultivated land spans the overall area used for agricultural purposes and field density specifies the amount of agricultural fields per cultivated area in percentage.

2 Study area

In 2005 the GLCN group conducted a study to map the agricultural development in Kenya for the last 30 years. This particular case study focuses on the Kisumu District within the Nile basin and illustrates the applied techniques and analyses the development of agricultural practice in the area.

2.1 Kisumu District

The Kisumu district is one of 70 Kenyan districts and is located at the eastern shores of Lake Victoria.The main population centre in the district is Kisumu town, which is the third largest city in Kenya and a growing commercial, fishing, industrial and communication centre in the Lake Victoria basin.

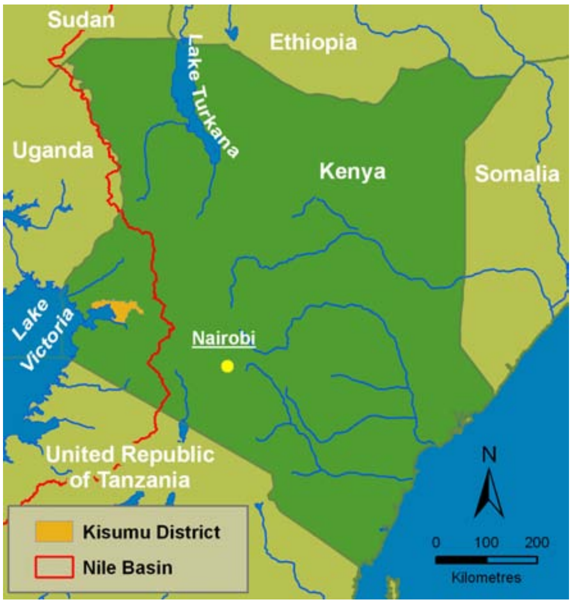
Geographically, the district lies in a depression that is part of the larger Nyanzana gulf. The district is divided into two zones, the midland areas in the west and the Kano plains in the east, broken occasionally by low ridges and rivers. There are also escarpments to the north, east and south of the district.

The climate of the district is humid with an average annual rainfall between 560 and 1630 mm. There are two rainy seasons with approximately 70% of the precipitation falling during the first rainy season from March until May. Shorter rains follow in September and October.

Land in Kisumu district is used for crops and animal production. In addition, there are sand harvesting, brick making, industrial development and waste dumping activities. Lake Victoria itself is used for fishing. The district currently encounters several environmental issues because of solid waste disposal, water pollution, wetland encroachment and brick making.

FIGURE 1

Map of Kenya with the location of the Kisumu district



3 Change detection principles

Change detection of environmental factors has become a major application of satellite imagery (Zhan *et al.*, 2000) and can be defined as the measurement of environmental changes utilizing two or more Earth Observation (EO) scenes covering the same geographic area acquired at different times. EO provides repetitive coverage of terrestrial features at short intervals and consistent image quality (Mas, 1999). Using these EO sources, information about land cover and changes in land cover can be updated efficiently and cheaply. Numerous change detection approaches have been developed and are used in a wide range of applications including monitoring of shifting cultivation, assessment of deforestation, study of changes in vegetation phenology and disaster monitoring (see e.g. Hame *et al.*, 1998; Colwell and Weber, 1981; Lambin, 1996; Roy *et al.*, 2002).

Detecting changes is influenced by several factors, namely:

- the selection of the change detection technique,
- the selection of the multi-temporal dataset,
- the spatial co-registration and, if necessary, the radiometric normalization of the satellite images.

3.1 Change detection techniques

The broad variety of existing change detection methods are grouped into two basic classes (Singh, 1989) based on:

- simultaneous analysis of multi-temporal data,

- post-comparison of independently produced classifications for different dates.

The first class comprise of methods such as image differencing / ratioing, multi-date classification, principle component analysis and change vector analysis. Each approach differs in their complexity of computation, resulting qualitative and quantitative change information and accuracy of the change detection result (Jensen, 1996).

Another way of discriminating changes between two image dates is the comparison of independently produced classifications for different dates (post-classification comparison). In this approach, imagery from two different dates are classified independently before an algorithm is applied to determine the areas that have changed between dates. In addition, statistics and change maps can be generated to express the specific nature of change (Lillesand and Kiefer, 2000). In comparison to other change detection techniques this presents the advantage of indicating the nature of change. A post-classification methodology was used for this study.

3.2 Multi-temporal datasets

Multi-temporal satellite images as well as existing land cover maps can be sources of data for change detection analyses. Remotely sensed images from numerous satellite platforms, each differing in their spatial and spectral characteristics, are available to the user community. While the spatial resolution defines the smallest size of recognizable change, the spectral properties of the image affect the kind of change that is detectable. The same is valid for the use of already existing land cover maps. Scale and the classification system used to produce the maps must be comparable to the spatial resolution and spectral characteristics of the satellite images if the process is to be successful.

When compiling multi-temporal datasets, selection of appropriate seasonal imagery is essential. Many land cover features (specifically different types of vegetation) follow characteristic annual cycles. Thus, selected imagery should depict actual change, opposed to seasonal change. Often anniversary dates are used for detecting changes to minimize sun angle and seasonal differences (Lillesand and Kiefer, 2000).

3.3 Spatial co-registration and radiometric normalization

When analysing multi-temporal datasets, accurate co-registration of imagery is essential so that changes in the pixel values represent actual changes on the ground rather than changes in the sensor, sun, target geometry and atmospheric conditions (Du *et al.*, 2002).

If a simultaneous change detection technique is applied it is also necessary to normalize the images radiometrically. Radiometric normalization of images aims at minimizing radiometric differences between multi-temporal images that are caused by different atmospheric conditions, sensor calibrations and sun-target constellations at the times of image acquisition (Heo and FitzHugh, 2000). Different normalization methods have been evaluated by Du *et al.* (2002), Heo and FitzHugh (2000), Yang and Lo (2000).

4 Datasets

This study uses 4 spatial datasets to establish a land cover database that monitors the agricultural practice for the last three decades. They comprise of satellite imagery for three different time periods (2000, 1980s and 1970s) and a land cover map focusing on agricultural practice.

TABLE 1

Characteristics of the used satellite images and land cover map

Spatial Dataset	Date	Scale / Resolution
(1) Landsat ETM+	2000-2001	30 m (15 m PAN)
(2) Landsat TM	1984-1987	30 m
(3) Landsat MMS	1972-1976	80 m
(4) Africover Land Cover Database	2000	1 : 200,000

4.1 Landsat images

Landsat satellite imagery over three decades were selected to recognize agricultural changes occurring between 1970 and 2000 and to create three datasets representing agriculture status for the 1970s, 1980s and 2000 respectively.

Landsat ETM+ images were used to determine agriculture development for the year 2000. For the two preceding decades, Landsat TM (1980s) and Landsat MSS (1970s) images were used to assess agricultural development for the 1980s and 1970s respectively.

All selected images represent similar time periods over the years to avoid differences between images that might result from different vegetation phenology.

4.2 Africover database

The interpretation process was supported by the existing Africover dataset for Kenya (www.africover.org). As a database represening the status of land cover for the year 2000, it was generated by visual interpretation of Landsat imagery and represents a homogenous and up-to-date land cover dataset at a map scale of 1:200,000.

The categorization of classes follows the standardized Land Cover Classification System (LCCS). LCCS is a classification system that uses specific criteria to uniquely identify different land cover classes. These criteria describe an agricultural class by attributes, like the life form of the main crop, the crop type, the crop combination, the spatial aspect, cover related cultivation practices.

The Africover dataset for Kenya includes around 160 classes describing different land cover types and land use practices in the country. There are 41 different classes in the Kisumu district.

5 Implementation

Three agricultural datasets were generated for the 1970s, 1980s and 2000. They were based on the Africover dataset and the Landsat imagery. GeoVis software was used to support the classification process and a post-classification comparison of the datasets was carried out to detect changes in the intensity of agricultural practices in the Kisumu district.

5.1 Generating the agricultural datasets

The Africover database (year 2000) was the starting point for the study. Initial steps involved the extraction of all agricultural classes from the comprehensive Africover database. This agricultural dataset contains information about the LCCS code, the field density and the field size.

Secondly, Landsat images from each decade were visualized simultaneously with the agricultural dataset overlain. The images were then visually analysed, polygon by polygon, to determine any agricultural land use change. For cases where change between two image dates occured, the corresponding agricultural dataset was updated spatially and/or thematically to represent the feature identified in the image. No change was applied to the dataset if no agricultural differences was detected. This method resulted in three agricultural datasets, each representing the agricultural status for one of the three decades.

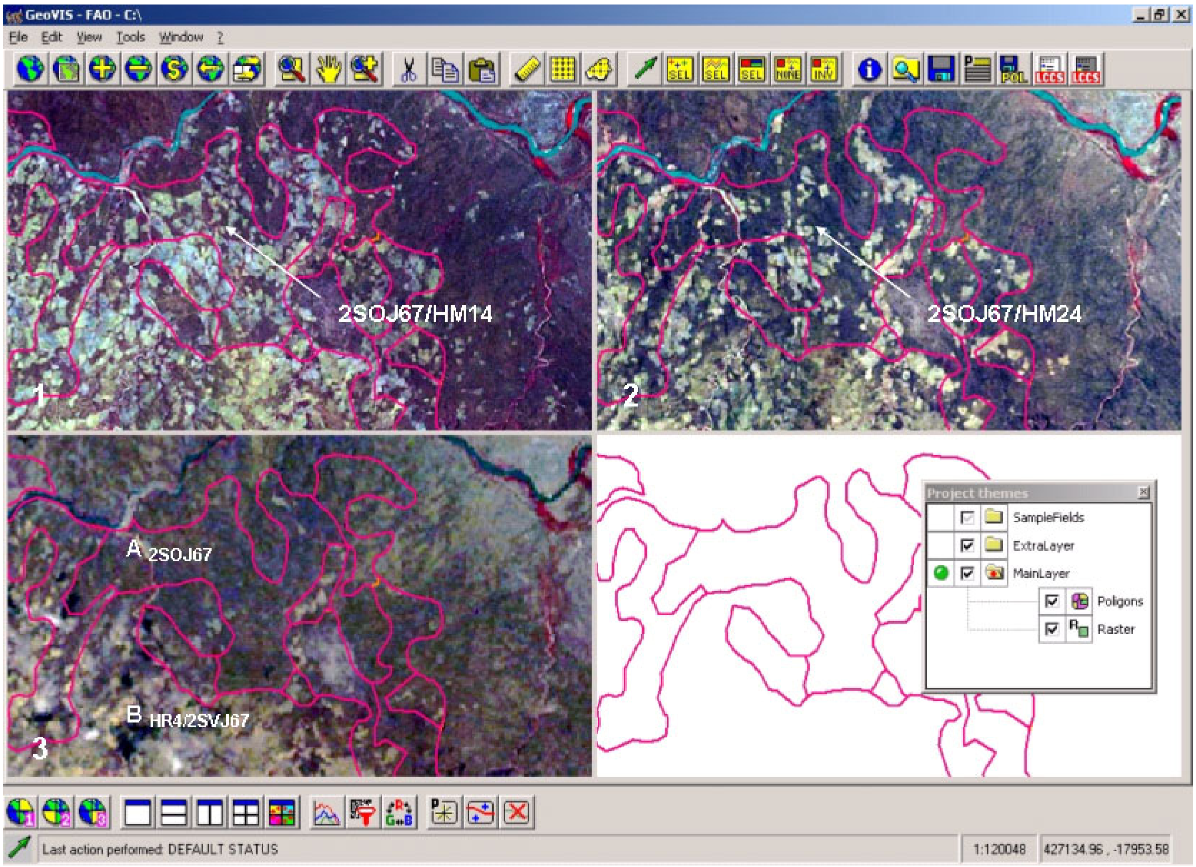
The agricultural datasets were updated accordingly to following criteria:

- Spatial change: The polygon extent changed if feature outlines did not correspond to the border visible on the satellite image. This type of change comprised of modifying polygon borders, splitting of polygons or the merging of several polygons.
- Thematic change: The polygon class has changed if the assigned class does not correspond to the class evident from the image. The polygon has to be reclassified for this type of change. Thematic changes affect the LCCS code, the field density and the field size.

The GeoVis software package (www.africover.com) was used as the tool to generate these three agricultural datasets. The ability of GeoVis to simultaneously display different Landsat images and superimpose vector datasets allowed for greater efficiency in the analysis. Furthermore the LCCS classification system is fully intergrated in GeoVis and can assist the user in the (re-)classification process.

FIGURE 2

This screenshot shows the set up of satellite images and vector dataset in the GeoVis software. Landsat images are displayed simultaneously with the 2000 image in the upper left (1), the 1980s image in the upper right (2) and the 1970s image in the lower left (3) quarter. The agricultural dataset is also overlain on the images.



The agricultural datasets were generated by simultaneously displaying three Landsat images in GeoVis (Figure 2). These images were visualized as false color composite (FCC) with the near-infrared, the red and the green channel of the satellite image in the red, green and blue display channels. The agricultural dataset was then superimposed on these images to determine changes in land cover and updated if necessary.

The above figure (Figure 2) indicates a sample area where changes in agricultural activities continuously emerge. The central polygon had been completely covered by natural vegetation in the 1970s. However, the 1980s image indicates clear evidence of agriculture land use in this area. Approximately 20% of the polygon is occupied by agriculture. Field density increased further and reached approximately 50% in 2000. To represent these changes the LCCS code was updated, using GeoVis.

5.2 Change analysis

The three generated datasets represent the agricultural status for 1970s, 1980s and 2000 and were used in the change detection analysis. The change detection analysis allowed for the identification of change, the extent and the nature of change.

The change detection analysis was carried out to monitor the cultivation intensity for the Kisumu district within the Nile basin. This was assessed by the two indicators mentioned earlier. Firstly, the extent of cultivated land spans the overal area used for agriculture. Secondly, the field density quantifies per cultivated land the percentage covered by agricultural fields. Change of these two indicators are used as a measure for the intensification of agriculture between 1970s and 2000.

6 Results

Three agricultural datasets were generated and analysed in respect of the two indicators:

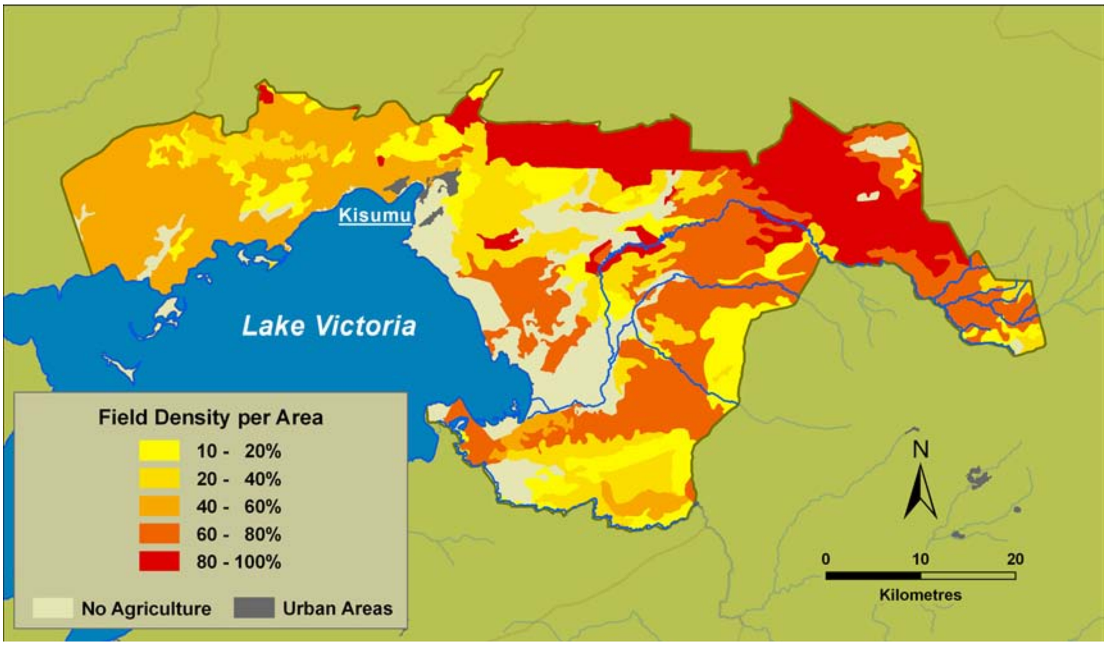
- Extent of cultivated area: For each decade the total area covered by agricultural activities was quantified.
- Field density: Field density for each cultivated land was quantified and given as a percentage.

The following section presents the results of the analysis. It shows status and change of the extent and the field density of cultivated areas for the Kisumu district from 1970 till 2000.

6.1 Status of cultivated areas and field density

FIGURE 3

Status of field density in the Kisumu district, Kenya, 1970s



For the 1970's, Figure 3 illustrates that large areas of intense agriculture are found in the north and east of the district. Instead, the area surrounding Kisumu town is characterized by a medium and low field density per area.

FIGURE 4

Status of field density in the Kisumu district, Kenya, 1980s

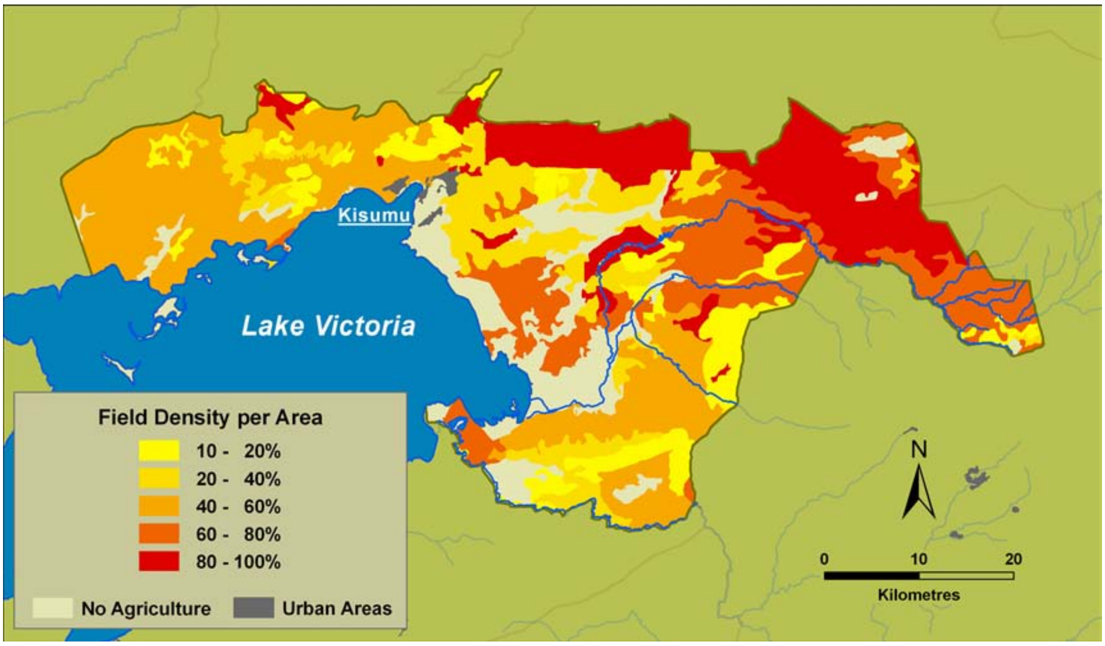
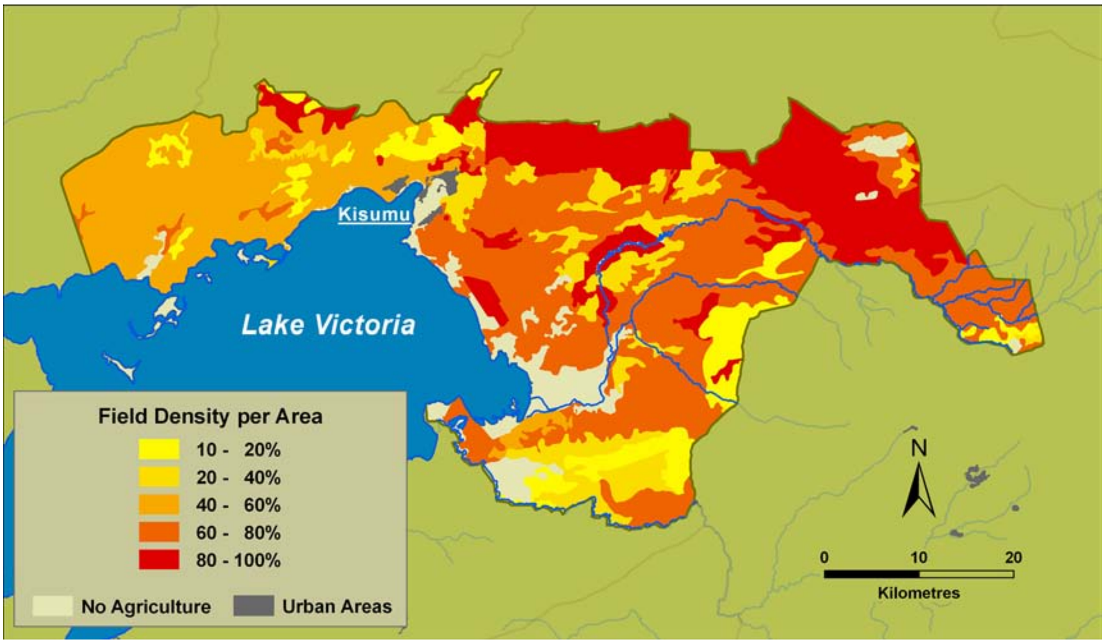


Figure 4 for the Kisumu district in the 1980s shows a similar picture as in the previous decade. Intense agriculture can be found in the north part of the district. Other parts of the district are covered by a medium to low field density. It is noteworthy that the field density in the south decreased slightly during the last decade.

FIGURE 5

Status of field density in the Kisumu district, Kenya, 2000



In 2000, most areas of the Kisumu district are covered by a high density of agricultural fields (Figure 5). There is not only evidence of high agricultural activities in the northern and eastern parts of the district but also in the central Kisumu district and close to shores of Lake Victoria.

TABLE 2
Field density and cultivated areas between 1970s and 2000 for Kisumu district

Field Density	1970	1980	2000
10 - 20%	12,9%	10,1%	8,2%
20 - 40%	13,8%	13,6%	9,9%
40 - 60%	19,6%	26,3%	19,5%
60 - 80%	22,0%	17,9%	34,5%
80 - 100%	16,8%	18,0%	19,7%
Cultivated Areas (total)	**85,1%**	**85,9%**	**91,8%**

6.2 Expansion of cultivated areas

Agricultural activities can be found in almost all parts of the district. In respect to the observed time period, land used by agriculture expanded steadily since the 1970s (from 85% in 1970s to 92% in 2000, Table 2).

FIGURE 6
Cultivated areas in the Kisumu district, Kenya, between 1970s and 2000

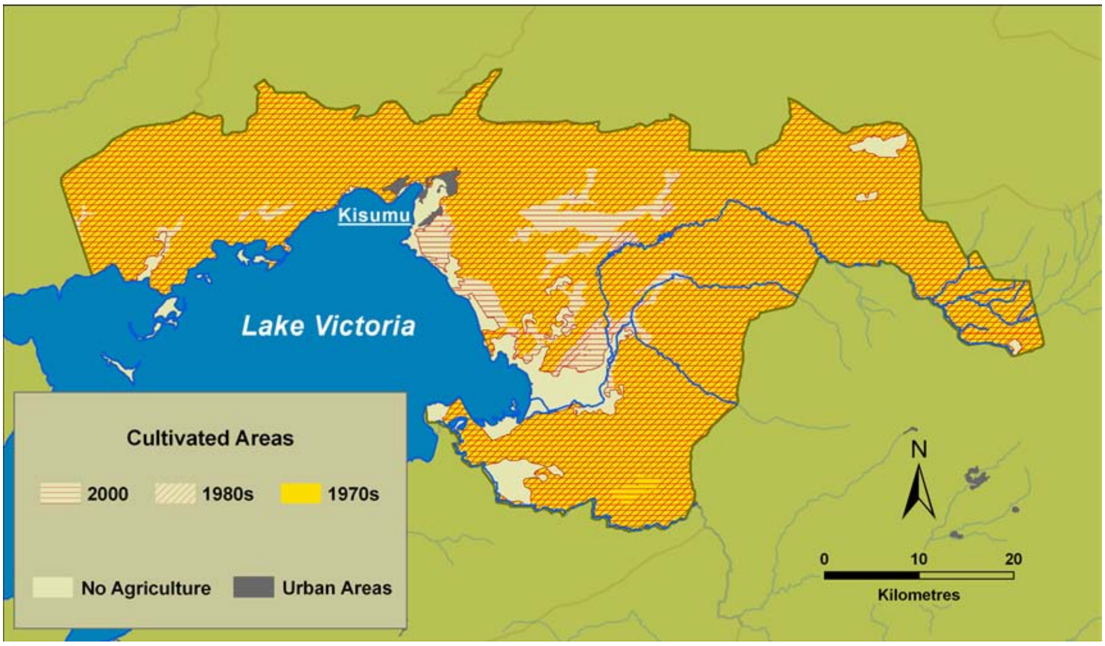


Figure 6 shows the development of cultivated areas from the 1970s to 2000. It is evident in the 1970s large parts of the Kisumu district had been covered by agricultural already.

Between 1970s and 1980s the cultivated land expanded moderately. These areas can be found especially close to the course of the rivers. But we can recognize a distinct expansion after the 1980s. Large areas were converted in 2000 to agricultural use in central Kisumu district and southern of Kisumu town along the shores of the Lake Victoria.

While between the 1970s and the 1980s this expansion occurred moderately (Table 2) by ca. 1% in the larger surroundings of the riverbanks, the increase of cultivated land is noticable in the subsequent decade (almost 6%). After the 1980s wide areas of central Kisumu district have been reassigned for agricultural purposes and this can also be seen in large parts along and close to the Victoria Lake shoreline in the south of Kisumu town.

6.3 Increase of field density

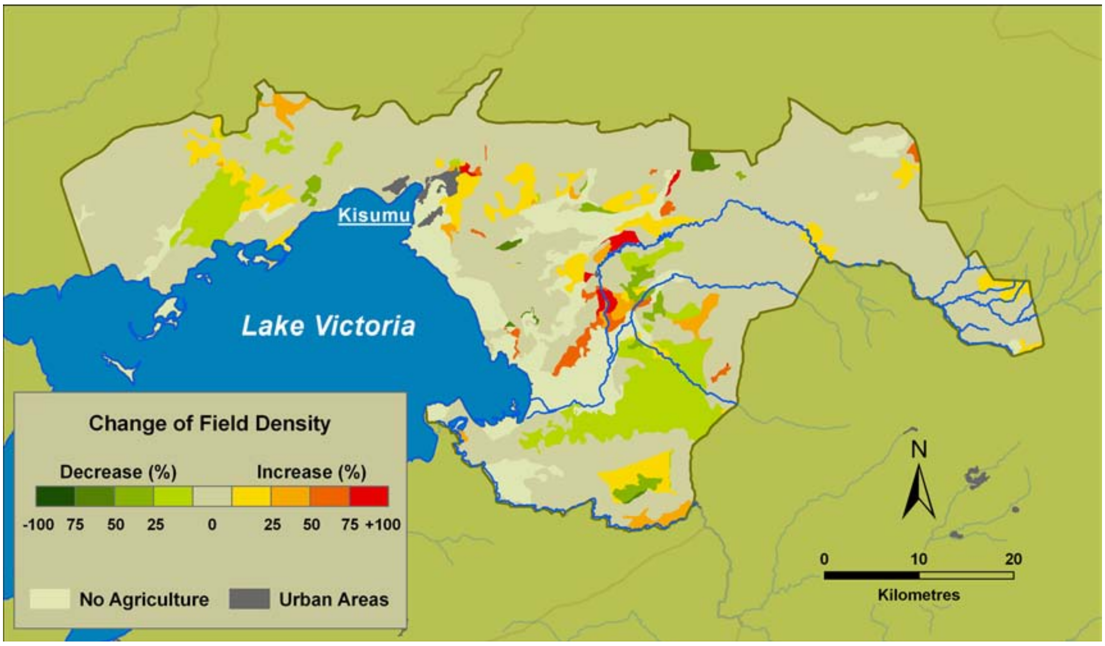
The change analysis of the agricultural datasets depicts a mixed pattern of decreased and increased field density for the period between 1970s and 1980s (Figure 7). In the western and the southern parts of the district, large areas were found to be less intensively used in the 1980s than they had been in the 1970s. However, field density increased in many other parts throughout the district. A strong intensification of field density was found close to the rivers caused by newly gained agricultural land rights.

In the following period, between 1980 and 2000, the density of agricultural fields increased considerably in large parts of the district (Figure 8). This affected not only newly converted agricultural areas in the central Kisumu district but also land that had been used for cultivation previously. It is noticeable in the southern district that after a less intense agricultural period between the 1970s and 1980s, the period from 1980 to 2000 saw a significant rise in field density.

In general it can be said that the density of agricultural fields increased between 1970s and the year 2000. There is a trend to a higher field density per area. While in the 1970s circa 39% of the cultivated areas were covered by at least 60% with agricultural fields, it increased to 54% in the year 2000 (Table 2).

FIGURE 7

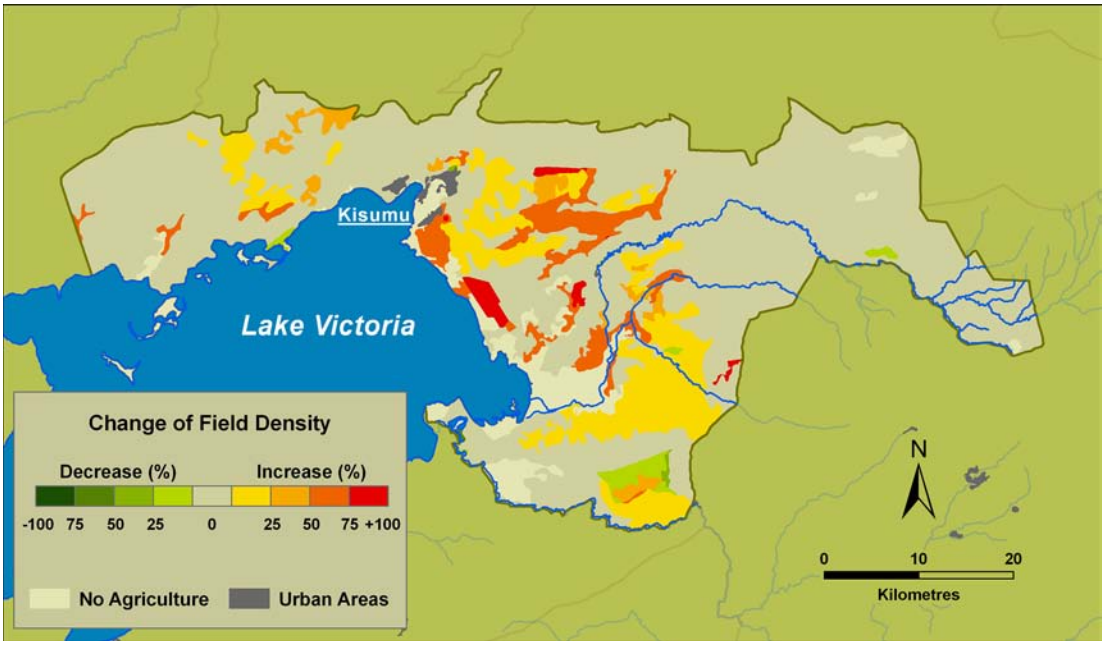
Change of field density in the Kisumu district, Kenya, between 1970s and 1980s



The change map (Figure 7) shows a mixed pattern of decreased and increased field density between 1970s and 1980s. A slight reduction of field density occurred especially in the southern and western parts of the district. The orange and red areas along the river indicate areas where field density increased considerably during the previous decade. They may have resulted from recently cultivated areas. However, field density remained unchanged for large parts of the cultivated area.

FIGURE 8

Change of field density in the Kisumu district, Kenya, between 1980s and 2000



The period from 1980 to 2000 is striking, with agricultural field density increasing considerably in most parts of the Kisumu district (Figure 8). In the central parts of the district and along the Lake Victoria this increase results mainly from newly cultivated land.

7 Conclusions

An agricultural database was generated to assist in assessing the agricultural development in Kenya for the last 30 years. This database comprised of three datasets that mapped the agricultural status for three decades, the 1970s, the 1980s and 2000. This database was used to assess the changes in the cultivation intensity for the Kisumu district (Kenya) within the Nile basin. This was achieved by undertaking a post-classification comparison of the three agricultural datasets and it was determined that there had been an increase in extent and intensity of agricultural land use in Kisumu district over the past 30 years.

The study took advantage of EO datasets that allow for a holistic view and repetitive coverage of the earth surface. A semi-automated classification procedure was used to create the agricultural datasets using Landsat images as the source of information. The interpretation process was supported by the use of GeoVis software, which allowed the interpreter to manage and process vector and raster data, to compare several images simultaneously and to link the agricultural datasets to the Land Cover Classification System (LCCS).

The derived database of agricultural practice and its changes could form part of a geographical information system (GIS). Using GIS technology in combination with additional environmental databases and expert knowledge can assist in the identification of land use change causes and their consequences. These integrated databases can provide vital information about the environmental implications of agricultural practices on the hydrological cycle, quality of groundwater, soil productivity, and superficial erosion/runoff (Rosati, 2005).

Glossary

The Global Land Cover Network (GLCN) is a global alliance for standard multi-purpose land cover data production. The overall objective of GLCN is to increase the availability of reliable and standardized information on land cover and its changes at the global level. Such information is urgently needed by policy-makers and planners responsible for food security activities, mitigation of natural and human-induced disasters, and environmental protection. GLCN provides a neutral international clearinghouse for land cover mapping and monitoring projects. It develops effective communication links with relevant organizations, advises on harmonization of land cover mapping methodologies and widely disseminates information on their products and services. In the Global Land Cover Network framework, FAO and UNEP set up in Rome and in Florence a Land Cover Topic Centre (GLCN-LCTC), to provide updated information, technical support, products (LCCS, GEOVIS and MAP software) in the field of land cover mapping. (http://www.glcn.org/)

The **Africover** project is part of the Global Land Cover Network (GLCN) initiative for the assessment and the monitoring of land cover. For the whole of Africa, it seeks in the establishment of a homogeneous, geographic reference including a digital database on land cover, geodetically referential, toponomy, roads and hydrography. It is Africover's core strategy to reinforce national and sub-national capacities for the establishment, update, and use of these geographical databases.

In the period between 1995 and 2002 the Eastern African Module as been implemented as part of the Africover project and FAO's assistance to the Nile Basin countries. In this period the land cover of ten east African countries have been mapped based on the interpretation of remote sensing data. Land cover classes follow the standardized Land Cover Classification System (LCCS), which has been developed during the implementation of the module. Africover can now provide a homogeneous land cover database for Burundi, Democratic Republic of Congo, Egypt, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda. (http://www.africover.org/)

The **Land Cover Classification System** (LCCS) can be considered as one of the most significant attempts for the establishment of a standardized, systematic, multi-purpose land cover classification. It has been developed by the Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP) to meet the need for improved access to reliable and standardized information on land cover and land cover change.

LCCS is a comprehensive, standardized a priori classification system designed to meet specific user requirements, and created for mapping exercises, independent of the scale or means used to map. It enables a comparison of land cover classes regardless of data source, thematic discipline or country. The LCCS system enhances the standardization process and minimizes the problem of dealing with a large amount of pre-defined classes.

To facilitate the complex classification process and ensure standardization, innovative software has been developed to guide the user to select the appropriate class (Di Gregorio, 2005).

LCCS is now adopted by FAO and UNEP as the standard land cover classification system.

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