

LONG TERM MONITORING AND ASSESSMENT OF NATURAL RESOURCES: REMOTE SENSING AS A COMPONENT OF AN INTEGRATED APPROACH – THE CASE STUDY OF THE LAKE VICTORIA BASIN IN KENYA

Ambrose Oroda¹, Stephen Anyango², Charles Situma³ and
Anne Branthomme⁴

¹INRA National Consultant – Remote Sensing and Mapping

²INRA Overall National Consultant – Kenyatta University

³INRA National Project Coordinator – Department of Resource Surveys and Remote Sensing (DRSRS)

⁴INRA Kenya Project Manager – FAO, Rome

ABSTRACT

Human well-being and progress are vitally dependent upon the ecosystems goods and services such as food, freshwater, wood-fuel, fibre and medicines. Other services include meeting man's spiritual, recreational and educational needs, and stabilizing soils and climate. The demands for these goods and services have been on the increase due to population pressure, in some cases resulted in over-exploitation and negative alteration of the ecosystems hence modifying their basic physical properties and disrupting the complex interactions that typified the original ecosystems. The Kenyan economy is principally natural resources based, the main sources of livelihoods being agriculture, livestock production, exploitation of forest resources, and tourism. Land and the resources thereon are, therefore, very critical for Kenya. Degradation of these resources threatens the economic, social, political and the physical well-being of the country and results into increased levels of poverty and food insecurity. The need for current and accurate information on land resources to formulate sound policies cannot be overemphasised. However, there remains limited knowledge and awareness on the impacts and severity of environmental degradation issues in Kenya. Periodic spatial land cover and land use assessments are important generators of information on the state of the environment and the conditions of natural resources. It has also been recognised that various components and resources in an ecosystem are closely interrelated and as such there is need to assess and manage them in an integrated and holistic manner to enhance the knowledge and understanding of how they interact. In Kenya, assessments of natural resources have been mainly sector based, usually driven by narrow information needs by policy makers or institutions that target one particular aspect or a particular resource. As such the concept of the **Integrated Natural Resource Assessment (INRA)**, an ecosystem based approach to address biodiversity and ecosystems functions and services in a more holistic way, was conceived. INRA aimed at establishing a monitoring system that can generate information on the state of the environment and natural resources for policy formulation, land use planning, and conservation and sustainable utilization of natural resources. The INRA started with a pilot supported under the FAO-Netherlands Partnership Programme (FNPP) and covered forest, agriculture, wildlife and water resources. Remote Sensing (RS) is an efficient tool to track and monitor both spatial and temporal transformations on land landscape through land cover and land use mapping. When combined with *in situ* ecosystems assessments and other biophysical and socio-economic data, land cover and land use maps provide very important information that allows various analyses of ecosystem conditions and can show linkages between various human management practices and uses of natural resources. The integration and manipulation of spatial data into Geographical Information System (GIS) makes it possible to carry out analyses that help in understanding land use change processes and dynamics. This paper describes how, within the INRA concept, high-resolution satellite remote sensing was used to monitor the status of land cover and land use between 2000 and 2008 within the Lake Victoria basin in Kenya. The region is one of the most densely populated (300 persons per km²) and has one of the highest poverty rates globally. The area was found to be predominantly agricultural (about 95%).

1. INTRODUCTION

Human well-being and progress are vitally dependent upon the ecosystems that provide various goods and services including food, freshwater, wood-fuel, fibre and medicines (WRI, 2003). The ecosystems also meet man's spiritual, recreational and educational needs while stabilizing soils and climate as well. The demands for ecosystems goods and services are on the increase due to population pressure, in some cases resulting in over-exploitation and altering of the ecosystems negatively (Hare and Ogallo, 1993, UNEP, 2005, Husle, 2007). The increased utilisation has led to changes in the ecosystems structures and how they function and, consequently, to modification in their basic physical properties and to disruption of the complex interactions that typified the original ecosystems.

The Kenyan economy is principally natural resources based, the main source of livelihood for the majority of Kenyans being agriculture, livestock production, and forestry. Tourism, based on wildlife viewing within protected areas, is Kenya's greatest foreign exchange earner, and one of the largest employers. Land and the resources thereon are, therefore, very critical for Kenya, and constitute the basis for survival. However, like in many other African and developing countries, their degradation (through accelerated deforestation, desertification, soil degradation, accelerated industrial pollution, decrease in biodiversity, increase in invasive non-palatable species, decrease in the quality and quantity of water, depletion of mineral and wildlife resources) threatens the economic, social, political and the physical well-being of the country, and the resources integrity. This, increasingly, diminishes the population's ability to obtain their basic needs and subsequently results into increased levels of poverty and food insecurity. This scenario is worsened by climatic variability that negatively impacts the environment as well as natural resources (UNEP and GoK, 2000; 2006).

While the need for current and accurate information on land resources to build sound policies is being more and more recognized, there is still a lack of knowledge, understanding and awareness on the severity of these environmental issues in Kenya at both the local and national levels. Periodic spatial land cover and land use assessments are important generators of information on the state of environment as well as on the conditions and trends of the natural resources. These assessments can also provide information on environmental hotspots resulting from unsustainable utilisation of the natural resources such as deforestation, degraded wildlife habitats, diminishing biodiversity, loss of wetlands as well as water degradation sites.

The various components and resources in an ecosystem are closely interrelated and there is need to manage, and assess them in an integrated manner. Therefore, a holistic approach of assessment of natural resource is desirable to enhance the knowledge and understanding of the interactions between, for example, land use management practices and the natural resources and ecosystems functions and services they provide. However assessments of natural resources in Kenya have been mainly sector based, usually driven by limited information needs by policy makers or institutions that target one particular aspect or a particular resource. As such the concept of the Integrated Natural Resource Assessment (INRA) in Kenya, to address biodiversity and ecosystems functions and services in a more holistic way through an ecosystem approach, was conceived. INRA aims at establishing a monitoring system that can generate information on the state and changes of the environment and natural resources for policy formulation, land use planning, conservation and sustainable utilization of natural resources.

The INRA started with a pilot supported under the FAO-Netherlands Partnership Programme (FNPP) and covered, in particular, forest, agriculture, wildlife and water resources with a particular focus on agro-biodiversity and

ecosystems services and integrity (FAO & GoK, 2009). INRA was piloted in three areas, including the Lake Victoria Region, Coastal Region and Eastern Region (Figure 1) and included both comprehensive field data collection and remote sensing analysis of land cover and land use changes.

Remote Sensing (RS) has emerged as an efficient tool to track and monitor both spatial and temporal transformations of land landscape. Land cover and land use maps provide very important information that, in combination with *in situ* and other biophysical or socio-economic data allows various analyses and assessment of ecosystem conditions, as well as showing the linkages between various human management practices and uses and natural resources status. The integration and manipulation of spatial data into Geographical Information System (GIS) makes it possible to make analysis that help in understanding land use changes processes and dynamics in a particular area.

This paper describes how, within the INRA, high-resolution satellite remote sensing has been used to monitor the status and changes of land cover and land use from 2000 to 2008 in the Lake Victoria Region. The study, based on Africover 2000 Land cover map and recently acquired ASTER imagery for 2008 covering eleven districts touching Lake Victoria shows how a spatio-temporal study of landscape patterns can contribute to a better comprehension of human impacts on natural resources as well as to provide a tool for raising awareness on environmental degradation and support intersectoral policy dialogue.

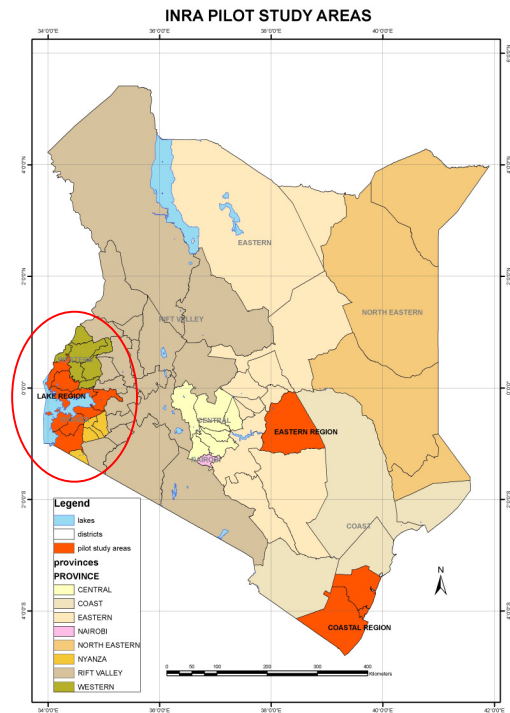


Figure 1: Map showing INRA pilot study sites in Kenya

Study area

The Lake Victoria basin in Kenya covers an area of about 38,900 km², approximately 22% of the entire Lake Victoria Basin. The basin constitutes one of the most densely populated areas of the world, the Kenyan side having a density of about 300 persons per km² (UNEP, 2006), and one of the poorest rural population in the world (UNEP, 2006) average poverty level of over 55% (WRI et al 2007). Major basic livelihoods are crop farming, livestock production and fishing. Majority of people are small scale peasant farmers practising subsistence mixed farming. The communities in the Lake Victoria basin are vulnerable to environmental changes due to significantly relying on land and water based resources for their livelihoods.

2. MATERIALS AND METHODS

2.1 Remote sensing data used

Two sets of Landsat Satellite images of the years 2000-2001 and 2006-2008 and a selection of ASTER images of varying dates between 2006 and 2008 covering the eleven districts of the Lake Victoria Region were acquired. The two sets of satellite imageries were used to track temporal changes on the resources in the study area. On-line selection of the satellite images was done based on the date of images, seasonality and percentage of cloud cover. The most recent Landsat ETM+ images were downloaded free of charge from the Global Land Cover Facility (GLCF) web site <http://www.landcover.org/>. ASTER images were purchased from the United States Geological Survey (USGS). All the images acquired were single band digital and pre-processed (radiometrically corrected, terrain corrected and geometrically corrected) and in GEOTIFF format. The ASTER images were acquired at level - 1B, calibrated radiance images for each band. The images were projected to Universal Transverse Mercator (UTM) WGS84 zone 36 South.

AFRICOVER land cover dataset served as a basis for the classification and analysis of satellite images.

2.2 Image processing procedures

Image processing procedures carried out included creating image composites to form multi-band images. The images were imported into ERDAS Imagine (ERDAS format, .img). The Landsat composite images were made by using three bands of the Enhanced Thematic Mapper (ETM+) sensor forming the false colour image where bands were red represents the Near Infrared (ETM+ band 4), green represents Red (ETM+ band 3) and blue represents green (ETM+ band 2). This results into RGB where it is equated to NRG. ASTER composites images were

made from bands 1, 2 and 3N in the VNIR bands.

The .img images were re-exported back to GEOTIFF format. All the images and the AFRICOVER shapefiles were re-projected to UTM WGS 84 Zone 36 South.

Each of the images was georeferenced using the “*Transform using links*” in GeoVis software based on the AFRICOVER layers to ensure they perfectly overlaid before the interpretation exercise. The images were enhanced using linear stretching using Image Works, a module of the PCI image processing software in order to improve their clarity during interpretation. Some of the images were enhanced using photoshop software and re-exported into ERDAS Imagine for georeferencing and projection. The Landsat and ASTER images were geocoded using ERDAS software. The ASTER images were mosaicked so that they could cover the study area. The Landsat and the mosaics of ASTER were used for change detection.

2.3. Classification scheme

The classification legend used in this study is based on a dichotomous approach and defines land cover and land use classes based on four levels of classification (see Figure 2). These classes are defined in details in the INRA Field Manual (FAO & GoK, 2007). The first level is composed of the global classes designed for the assessment of resources at global level and is based on the classification system developed by the FAO global Forest Resources Assessment (FRA) to ensure harmonisation between countries for regional or global assessments. The global classes include Forests, Other wooded land, Other land and Inland water. The second, third and fourth levels are country specific, and include additional classes designed to meet specific national and sub-national information needs. The second level applies to all classes and differentiates between land use/cover types; the third level only applies to forest and describes naturalness of forests; while the fourth level

mainly refers to vegetation canopy cover and is applicable only to natural forests, shrubs and natural grassland.

Not all INRA classes could be differentiated using Remote Sensing so there were grouped into broader RS classes.

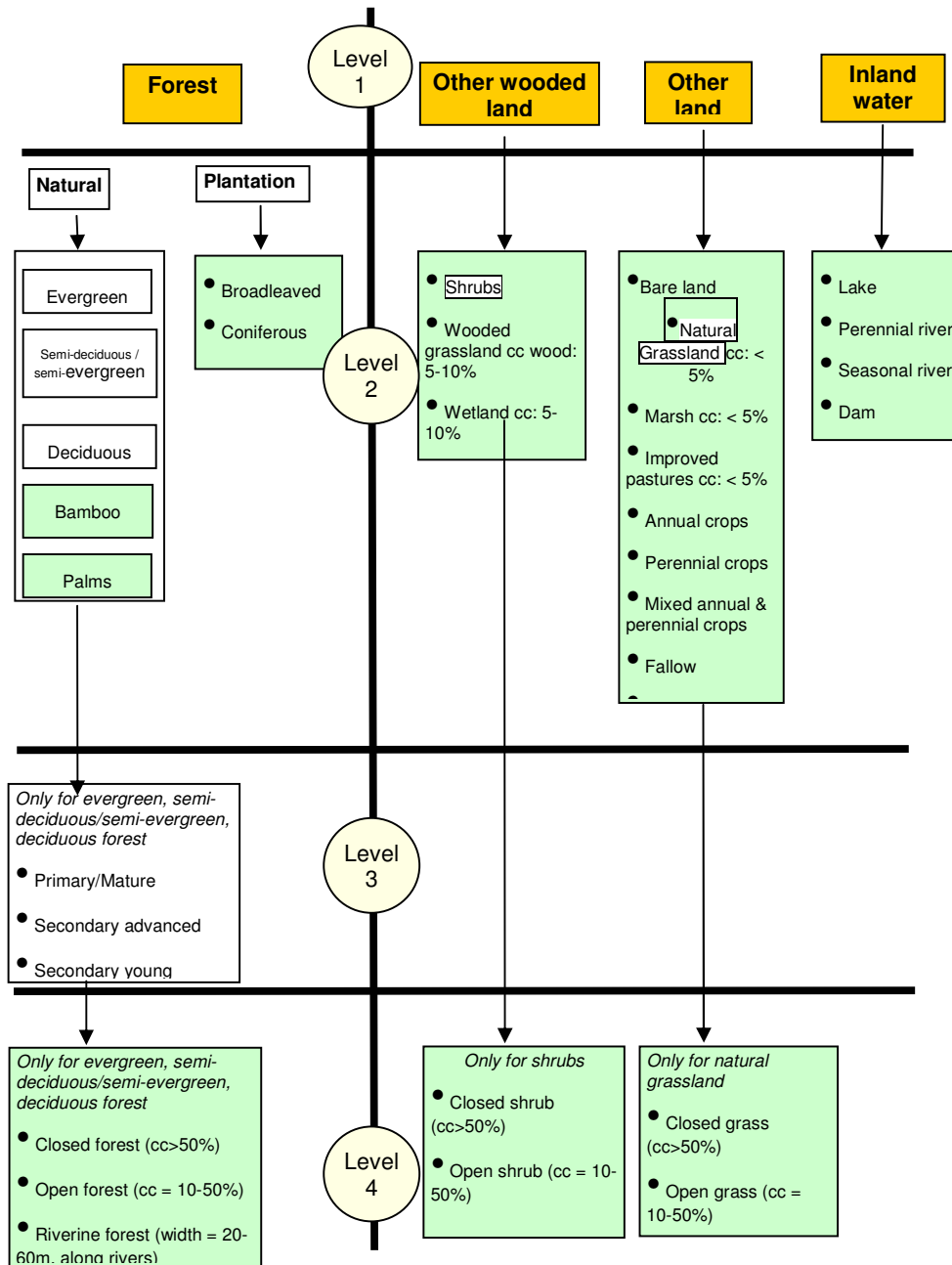


Figure 2: Classification system used in INRA

2.3. Classification and change detection procedures

2.3.1 *Reclassification and review of Africover dataset for 2000/2000:*

The AFRICOVER land cover layers (initially derived from Landsat satellite images of 2000/2001) were reclassified based on the INRA Remote Sensing classes. These AFRICOVER data was reclassified according to INRA land use/ land cover classification based on the Land Cover Classification System (LCCS). The polygons/classes of the dataset were adjusted using the 2000 Landsat imagery, experience and field knowledge. The polygons were produced using GEOVIS, a vector-based editing system specifically designed for thematic interpretation. It also has a direct link with the Land Cover Classification System (LCCS), which enables immediate assignment of specific land cover and land use classes to the interpretation polygons.

2.3.2 *Interclass Change Detection between Landsat imagery for 2000/2001 and Aster imagery from 2006/2008:*

Detailed interclass changes/trends detection between 2000 and 2008 was carried out on-screen using the prepared datasets of ASTER images (2007/2008) and Landsat (2000/2001). The swipe module in ERDAS Imagine Software was applied.

The temporal changes were mapped out using the land cover and land use layers generated from 2000 and 2008 datasets. The changes were mapped using the Geographical Vector Interpretation Software (GeoVIS). The interpretation scale ranged between 1:25000 and 1:50000.

The resulting classified vector maps were exported into a Geographical Information System (GIS) environment using appropriate softwares including: ArcInfo, and ArcGIS and Arcview to facilitate further GIS based manipulations, analysis and modelling.

Further analysis of the results was carried out using Microsoft Excel to generate graphics for interpretation of the changes and presentation of the results.

3. RESULTS AND DISCUSSION

3.1 Land cover and land use maps and changes

Figures 3 and 4 show the final land cover and land use maps of the study area, representing the different land based resources in the Lake Victoria basin in 2000 and 2008. Figure 5 identifies changes that occurred between 2000 and 2008.

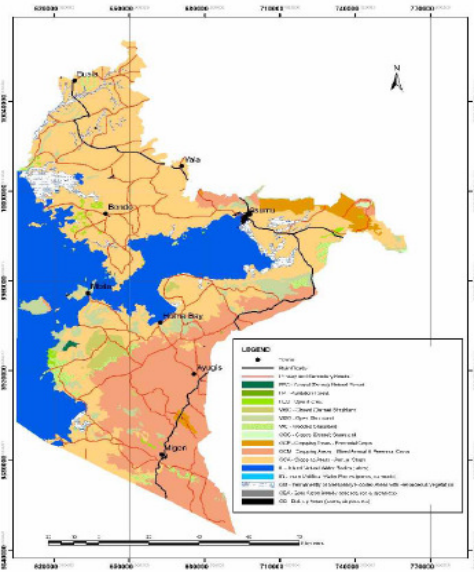


Figure 3a: Land cover/land use 2000

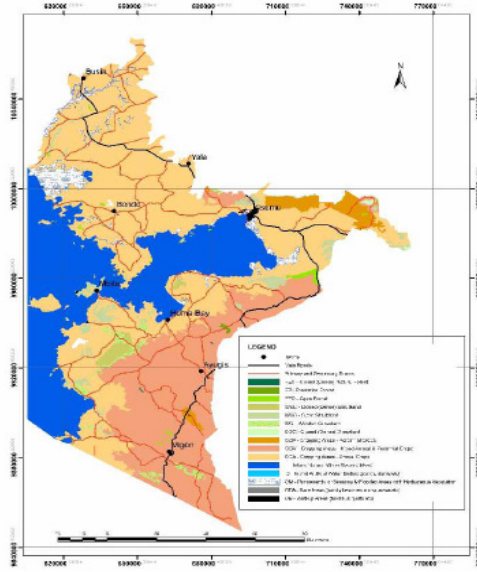


Figure 3b: Land cover/land use 2008

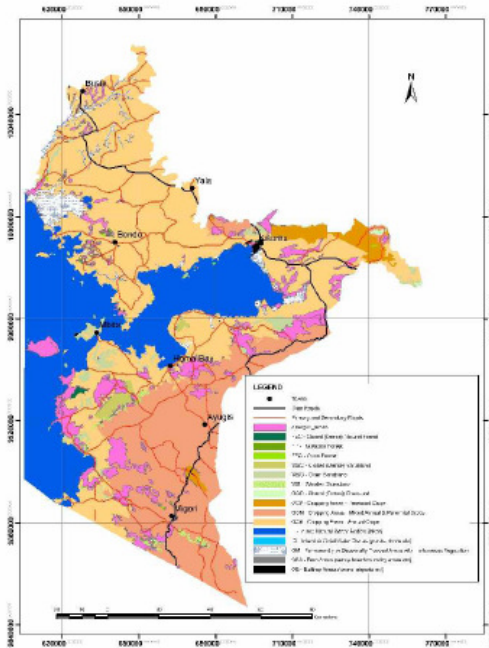


Figure 4: Changes in land cover and land use 2000-2008 (*change areas are in pink*)

Figures 3, 4, 5 and Table 1 below show the various land cover and land use classes found in the study.

In the study area the results of the level 1 classes are shown in Figures 5a and 5b below.

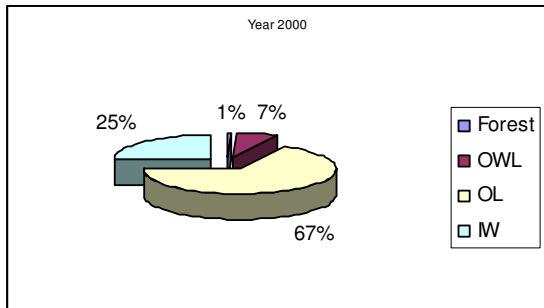


Figure 5a: Main land cover classes in 2000

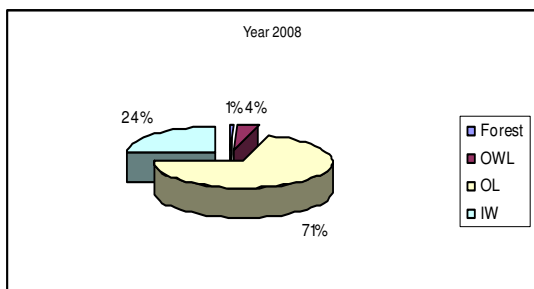


Figure 5b: Main land cover classes in 2008

The most dominant class is the Other Lands (OL) occupying 67% and 71% in 2000 and 2008 respectively. Inland Water (IW) class occupies 25% and 24% in 2000 and 2008 respectively. The Forest class occupies 1% of the study area.

The OL class comprises 7 level 2 classes including annual crops (OCA), mixed crops (OCM), perennial crops (OCP), marshlands (OM) and grasslands (OG).

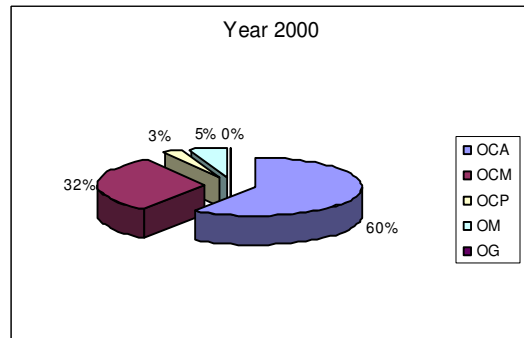


Figure 6a: Main Level 2 classes of OL class in the study area - 2000

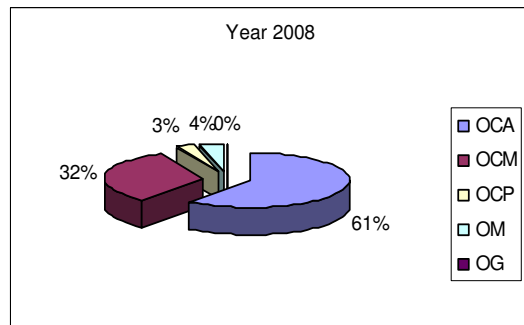


Figure 6b: Main Level 2 classes of OL class in the study area - 2008

The results show that the area is predominantly agricultural, agriculture occupying about 95% of the terrestrial system (Figures 6a and 6b): annual crops – 60%, mixed crops – 32% and perennial crops – 3%. Between 2000 and 2008, there was a general increase in cropping areas, about 6%. Area under annual crops increased by about 451 km² from 6027 to 6478 km² or by 7% while area under mixed crops increased by about 204 km² from 3250 to 3454 km² or by 6%. This signifies increase in agricultural activities generally associated with land degradation.

In general, changes in land cover and land use within the study area were mostly experienced in wooded vegetation that included open forest, shrublands, wooded grassland and woodland classes. The greatest changes were experienced in the open shrubland – 50%, closed shrubland – 42%, wooded grassland – 39%, while open forest and wetland (marshland) classes decreased by 27%, and 23% respectively. In absolute terms, for example, open shrubs decreased from 662 km² in 2000 to 327 km² in

2008. The changes were mainly conversions into agricultural lands. Such changes, unless accompanied by proper land husbandry systems and appropriate land use policies, are likely to result into extensive land degradation and massive loss of biodiversity, both floral and faunal as well as altering the lake basin ecosystems significantly.

Table 1 and Figures 7a and 7b summarise changes in land cover and land use within the study area. Table 2 shows the change matrix and gives details of the changes from which classes to which ones.

Table 1: Land cover and land use classes and databases

INRA Land use/Cover Class		Year 2000 (km ²)	Year 2008 (km ²)	Net land use/ cover change area (km ²)	Change in percent
Forest	Closed Forest (evergreen) (FEC)	13	15	2	+14%
	Open forest (evergreen) (FEO)	77	56	- 21	-27%
	Forest Plantation (FP)	1	8	7	+1045%
	Total forest	91	79	-12	-13%
Other wooded land (OWL)	Wooded grasslands (WG)	225	138	-87	-39%
	Closed Shrubs(WSC)	201	116	-85	-42%
	Open Shrubs (WSO)	662	327	-335	-50%
	Total OWL	1088	581	-507	-46%
Other lands (OL)	Bare lands (OB)	32	30	-2	-6
	Built up areas (OBA)	6	6	0	0%
	Annual Crops (OCA)	6027	6478	451	+7%
	Mixed annual/perennial crops (OCM)	3250	3454	204	+6%
	Perennial crops (OCP)	321	320	0	0%
	Grasslands (OG)	13	13	0	0%
	Marshlands (OM)	545	422	-123	-23%
	Total OL	10194	10723	529	5%
Inland water	Dam (ID)	0.2	0.2	0	0%
	Lakes (IL)	3710	3689	-21	-1%
	Total IW	3710	3689	-21	-1%
TOTAL		15086	15073	-13	
Total Area under water		3710	3689	-21	-1%
Total Land surface		11376	11384	8	7%
Land under agriculture (crops)		9598	10252	654	7%
Land under agriculture as a % of total area		63%	68%		

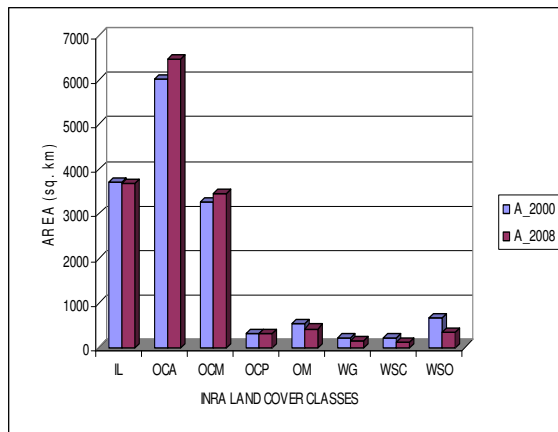


Figure 7a: Areas of major land cover and land use classes in the Lake Victoria basin of Kenya in 2000 and 2008

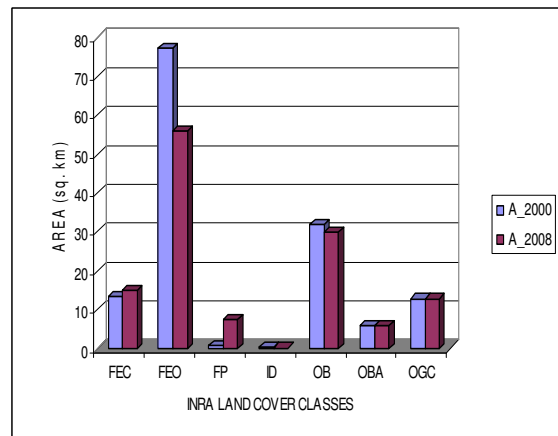


Figure 7b: Areas of minor land cover and land use classes in the Lake Victoria basin of Kenya in 2000 and 2008

Table 2: Land cover and land use change matrix – details of changes in 2000-2008

		Classes in 2008														Total of the class in 2000 (ha)	
Land use/cover classes	FEC	FEO	FP	WSC	WSO	WG	OGC	OM	OCP	OCM	OCA	OBA	OB	ID	IL		
FEC	1345															1345	
FEO		1316						9		404	6010					7730	
FP			66							0						66	
WSC	148			11192		3331				204	5242					20117	
WSO		3588			28869	1195	0	0	0	11720	20852		23		2	66249	
WG			7	376	2884	6894		1		2316	10056					6	22542
OGC							1280									1280	
OM						223		39453			14207				663	54546	
OCP					62	0			31874	200	8					32144	
OCM	9	252	690		503	910	0		127	311657	10671		208		0	325027	
OCA		435		18	347	1302		1389	2	18826	580337		2		30	602688	
OBA											0	589			0	589	
OB								11		116	300		2756		0	3183	
ID											14			18		32	
IL					1			1305			60				368181	369547	
Total of the class in 2008	1493	5598	756	11586	32666	13855	1280	32168	32003	345443	647757	589	2989	18	368882		

3.2 Detailed inter-class and Intra-class change detections

Despite the changes between land cover and land use classes in the study area, a lot of intra-class changes could be observed. Figure 8a, 8b, 9a and 9b show examples of intra-class changes within the study area.

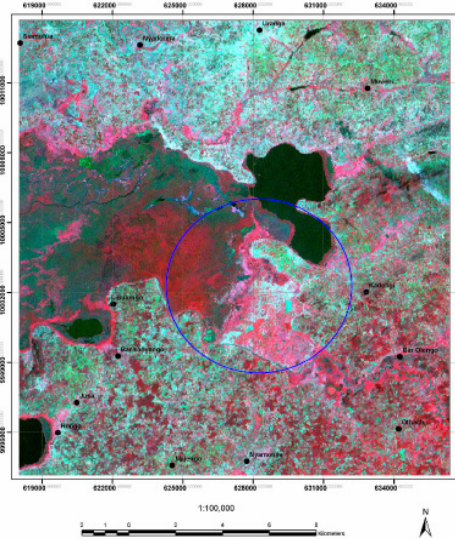


Figure 8a: Neglected Bunyala Irrigation Scheme

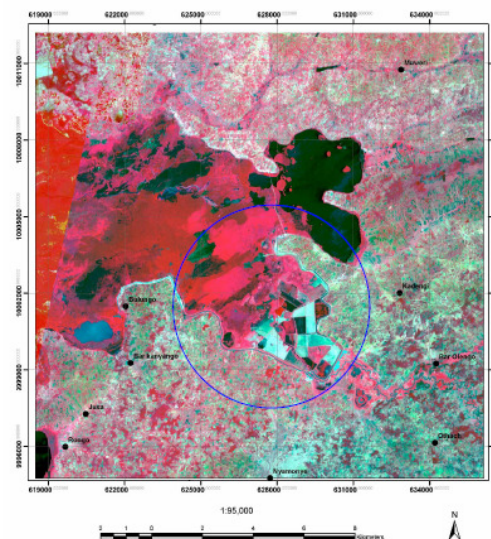


Figure 8b: Rehabilitated Bunyala Irrigation Scheme

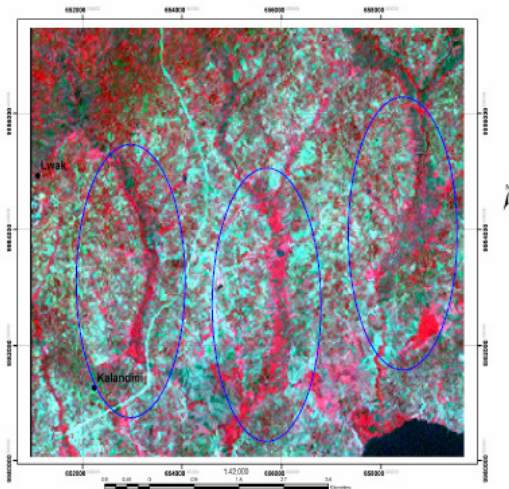


Figure 9a: Slightly disturbed riverine system (2000)

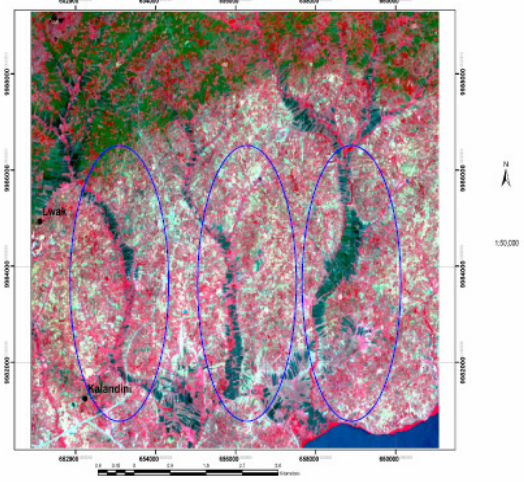


Figure 9b: Intensively cultivated riverine system (2008)

3.4 Impacts of changes in land cover and land use

The reclaiming of Yala swamp (FAO, 2005) and the rehabilitation of the Bunyala Irrigation Scheme as noted in the satellite images are some of the major notable ecological changes within the study area. These represent wetland conversion into agricultural purposes. However, it is important to note that some changes that are taking place outside the study area such as the clearing of the Mau Forest complex (UNEP *et al*, 2005) has negative impacts within the Lake Victoria basin. Such changes, for example, change the water regime of the basin resulting

into increased flooding during the wet season and reduced flow during the dry periods. Other impacts of such changes have been manifested in land degradation through increased sediment load into the water system, agro-biodiversity loss by for example interfering with the fish producing sites, and inadequate food security due to poor food production as a result of land degradation. The Lake Victoria basin is, therefore, typified with various challenges and environmentally fragile landscape due to these changes

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

From the results obtained, the area is predominantly agricultural. Agriculture is mainly subsistence farming although a few commercial agricultural activities were identified from the satellite images. Woody vegetation has generally been decreasing, presumably being cleared for agriculture and other land uses. Wetlands have also greatly decreased, and this may be attributed to wetlands being reclaimed for agriculture, for example, the Yala Swamp Irrigation Scheme and the revival of the Bunyala Irrigation Scheme. Decrease in rainfall quantities may be as well resulting in drying up of wetlands. Remote Sensing technique and methodology and the subsequent integration of the resultant databases into a GIS are very important in rapid assessment, monitoring and mapping of natural resources through land cover and land use assessments.

4.2. Recommendations

From the study it has been realised that woody vegetation areas are on the decline while agricultural activities have been on the increase. It was also realised that there are intra-class land cover changes.

It is recommended that further studies be carried out on the impacts of increased agricultural activities, particularly on land degradation, linkages between areas under agriculture and land productivity, and on possibilities of pollution due to possible increase in the use of inorganic fertilizers due to increased agricultural activities. The study also recommends studies to find out the impact of changes in land cover and land use on biodiversity, both floral and faunal biodiversity. Finally, the study recommends a greater integration of remote sensing information with field data in order to produce more precise thematic maps necessary for decision making and long term planning.

REFERENCES

- Baldyga, T. J. *et al*, 2007: Tracy J. Baldyga, Scott N. Miller, Kenneth L. Driese and Charles M. Gichaba, 2007: Assessing land cover change in Kenya's Mau Forest region using remotely sensed data.
- FAO, 2005: Land Cover Classification System: Environment and Natural Resources Series
- FAO & GoK, 2007: Integrated Natural Resources Assessment in Kenya: *Field Manual, 7th Edition*.
- FAO & GoK, 2009: Integrated Natural Resources Assessment in Kenya: *Result from the pilot phase, Draft*.
- Hare F. K. and L. A. J. Ogallo, 1993: *Climate Variations, Drought and Desertification*: World Meteorological Organization – WMO – No. 653, 1993.
- Husle, J. H., 2007: Sustainable Development at Risk: Ignoring the past. Cambridge University Press, India Pvt. Ltd, India and International Development Research Centre (IDRC), Canada
- UNEP, 2006: Lake Victoria Basin Environment Outlook: Environment and Development. UNEP, Nairobi.
- UNEP, 2005: *One Planet Many People: Atlas of Our Changing Environment*, UNEP, Nairobi, Kenya, pp 1-229
- UNEP, 2005: *One Planet Many People: Atlas of Our Changing Environment*, UNEP, Nairobi, Kenya, pp 1-229
- UNEP and GoK, 2006: Kenya Drought – Impacts on agriculture, livestock and wildlife. pp 33 – 38
- UNEP and GoK, 2000: Devastating Drought in Kenya: Environmental impacts and response. pp 19 – 21
- UNEP *et al* 2005: Maasai Mau Forest status report 2005
- USA-Forest Service, 1996: *Guidelines for the use of digital imagery for vegetation mapping*. United States Department of Agriculture – Forest Service, Washington DC, July, 1996, pp 7 – 54.
- Von Hagen, 2002: *Using GEOVIS and LCCS manual GCP/RAF/287/ITA*: FAO-AFRICOVER, Food and Agriculture Organisation of the United Nations, Rome, pp 1 - 2.
- WRI, 2003: Millennium Ecosystem Assessment: *Ecosystems and Human Well-Being, A Framework for Assessment*: World Resources Institute, Washington DC, pp 26 - 106
- WRI, 2000: World Resources 2000-2001: *People and Ecosystems: The Fraying Web of Life*. World Resources Institute, Washington DC, pp 3-145.
- WRI *et al*, 2007: World Resources Institute; Department of Resource Surveys and Remote Sensing, Ministry of Environment and Natural Resources, Kenya; Central Bureau of Statistics, Ministry of Planning and National Development, Kenya; and International Livestock Research Institute, 2007. *Nature's Benefits in Kenya, An Atlas of Ecosystems and Human Well-Being*. Washington, D.C. and Nairobi: World Resources Institute. Map 2.2. pp 15.