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Monitoring Water Quality and Land Cover Changes in Lake Victoria & Wetland Ecosystems using Earth Observation

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Abstract: ***Use of remote sensing in assessing water quality has expanded due to increased scanning of water bodies within a short time. The main parameters examined in this study are chlorophyll concentration, water turbidity due to erosion and water pollution as well as total suspended materials (TSM). All these cause changes in the color of the water bodies on the various wave lengthens of the electromagnetic spectrum. Assessing regional water quality is necessary but limited by scarcity of data. In this study, we have compared land cover changes and resulting water quality of Lake Victoria and relationship of resulting water quality due to changes within wetlands. We did mapping to provide ability to identify turbid and clear water with focus of producing water quality and substrate land cover type maps after comparison of Landsat and MERIS images. We also analyzed vegetation health over the period by comparing the NDVI results over the periods selected for investigation. We have compared the changes in land cover as well as destruction of wetlands and established that there is positive correlation of destruction of land cover and resulting poor water quality. It has been demonstrated that remote sensing is useful technique in mapping spatial distribution parameters such chlorophyll. The algorithm used on BEAM Visat has provided useful information that additional parameters are used to estimate suspended sediment concentration (SSC) through extraction of open water covered areas. Results of the analysis have shown that chlorophyll concentration on Lake Victoria increased over time from the year 2002 to year 2013. For instance between year 2002 and 2007, the Chlorophyll concentration has increased from 37.41 to 40.8 mg m^3 representing 9.16% increase in chlorophyll concentration within the lake.***

Keywords: Water quality, NDVI, Land cover, Wetlands, Earth observation, spatial ecosystem assessment tool.

1. Introduction

Wetlands are vital and complex ecosystems critical for water quality and biodiversity integrity. Sustainable use of wetlands at both local and international level is a leading step towards addressing challenges faced by government and non-government agencies tasked with management and conservation of wetlands [1]. Human activities have expanded around wetlands, which has led to farming activities within the wetlands such as finger ponds [2], Papyrus are harvested and used for making crafts mats, chairs, tables [3]; some are cleared to create space for wetland farming, sand harvesting, and shrubs (wetland trees) are used for fuel [4]. These activities among others contribute to destruction of wetlands to unprecedented level over a long period of time.

Wetlands transitions are very evident in small wetlands due to anthropogenic pressure [5]; since human activities can be very diverse over their small acreage such as use of fire during dry season to clear the vegetation, digging and leaving open fields in case of sand harvesting and use of pesticide on seasonal crops normally grown in wetlands such as tomatoes, vegetables and maize. The economic consequence of degradation of major wetlands in Africa such as Zambezi basin in Southern Africa, Lake Chilwa wetlands in Malawi, The Hadejia-Nguru wetlands in Nigeria, Nakivubo wetlands in Uganda and Yala Wetland in Kenya have led to long term destruction of safety and welfare of many communities [6]. The negative impacts on wetlands are exacerbated by current patterns of climate change. Extreme drier seasons makes wetlands attractive for farming due to their wetness, wetlands vegetation can easily be burn during dry season [7].

The current problems on wetlands around Lake Victoria are mainly indiscriminate papyrus overharvesting, land reclamation for farming agriculture, sand harvesting and at times overgrazing [8] . Studies carried out between year 1969 to year 2000 on wetlands, estimated that papyrus has been approximately lost in Dunga (50%), Koguta (47%) and Kusa (34%) [9]. These destruction affects other organisms that depends on the ecosystem diversity for survival and impairs documented wetlands ecological functions such water purifications and sediments trapping [10]. Additionally income from wetland tourism activities such birds watching, hippopotamus viewing and other wildlife such as snakes are compromised.

Wetlands play invaluable role in movement of people and terrestrial species[11], hence the need for spatial ecosystem assessment to determine changes in trends and acreage. Buffering functions of wetlands is useful in filtering various surface run offs as well as important in controlling siltation and reducing water turbidity [12]. In this study, we examine time series images of wetlands in Kenya to show change detection within the wetlands in terms of spatial acreage increase or decline, biomass change through NDVI, and finally examine water quality of Lake Victoria by analyzing information on chlorophyll concentration, turbidity and total suspended materials from year 2002 to 2013. Our study focus on relationship between changes in water quality and degradation of ecosystem within the wetlands.

2. Study Area and Research Context

Wetlands management in Kenya is informed by legal and policy instruments diffused in other sectors such as water, agriculture and environment in general; EMCA[1] 1999, Water Act, 2002 KWS[2] is the focal point for Ramsar Convention on Wetlands of International Importance hence critical in Wetlands Management especially those designated as Ramsar Sites, National Parks and Reserves. Local Civil Society are also critical in management of wetlands especially those having informal protection status such as Important Bird Areas (IBA), or offer critical ecosystem goods and services to locals hence co-management initiatives through by-laws or local conservation agreements and plans [13]. The wetlands in Kenya fall within the broad categories of wetlands used within East Africa categorized as marine, estuarine, man-made, saline water and fresh water as shown in Table 1

Table 1: East Africa Wetland classification system [13]

1	**Marine**			
1.1.	Subtidal		i.	sea grass beds
			ii.	coral reefs
1.2.	Intertidal		i.	rocky marine shores, reefs
			ii.	mud flats, sand flats, salt flats
			iii.	intertidal vegetated sediments: slat marshes, mangroves
2	**Estuarine**			
2.1.	Subtidal		i.	estuaries and marine deltas
2.2.	Intertidal		i.	mud flats, sand flats, salt flats
			ii.	estuarine marshes, salt marshes
			iii.	estuarine swamps, mangrove swamps
3	**Sodic and/or slaine water**			
3.1.	Lacustrine[a]	Permanent	i.	sodic lakes, salt lakes
		Temporary	ii	seasonally/occasionally inundated depressions, salt pans
3.2.	Palustrine[b]	Permanent	i.	sodic and salt marshes and swamps
			ii.	springs, soaks and resultant pools
4	**Freshwater**			
4.1.	Riverine[c]	Permanent	i.	edges of perennial rivers, streams and waterfalls
			ii.	inland deltas (including deltas in lakes)
		Temporary	i.	seasonal/occasional rivers, streams and waterfalls
			ii.	riverine floodplains, river flats, deltaic plains, riverine grass lands, mbugas[d]
4.2.	Lacustrine	Permanent	i.	freshwater lakes (> 10 ha) including shores subject to seasonal or irregular inundation (drawdown floodplains)
			ii.	freshwater ponds, pools (< 10 ha)
		Temporary	i.	seasonal lakes (> 10 ha)
			ii.	seasonal ponds, pools (< 10 ha)
4.3.	Palustrine	Herbaceous	i.	permanent swamps, marshes, dambos[e]
			ii.	seasonal/occasional swamps, marshes, dambos
			iii.	peatlands, fens
			iv.	montane wetlands (including bogs)
			v.	springs, soaks
		Woody	i.	shrub swamps, thicket wetlands
			ii.	swamp forests
5	**Man-made wetlands**			
5.1.	Aquaculture / mariculture		i.	fish ponds, prawn farms
5.2.	Agriculture		i.	farm ponds and dams
			ii.	irrigated lands, rice paddy, channels, canals, dithces
			iii.	seasonally flooded arable land
5.3.	Salt production		i.	salt evaporation pans
5.4.	Urban/ industrial		i.	borrow pits, brick pits, mining pools, road impoundments, quarries
			ii.	wastewater treatment facilities
5.5.	Water storage		i.	ponds, dams, reservoirs

Wetlands are associated with water bodies and river networks. The river networks form part of watershed that contributes to improving or degrading water quality of Lake Victoria. It is therefore imperative that all development projects within wetlands should be subjected to environmental impact assessment with more focus on wetlands [14, 15]. Furthermore, destruction of wetlands affect the food chain of various organism which eventually lead to reduction of their populations especially vertebrates [16].

[1] National Environmental Management and Coordination Act
[2] Kenya Wildlife Service

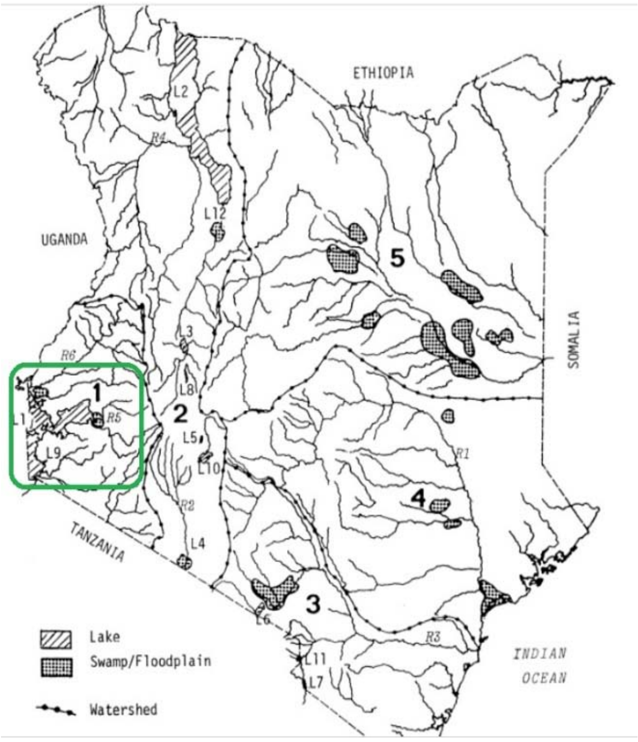

Figure 1: Lake Victoria and drainage rivers (Vanden Bossche et al., 1990)

Lake Victoria has surface area of 68,800 square kilometers (26,600 sq mi) and is Africa's largest lake by area, as well as the largest tropical lake in the world. Lake Victoria is the world's Second largest freshwater lake by surface area; after Lake Superior in North America. It's the world's ninth largest continental lake by volume, and it contains about 2,750 cubic kilometers (2.2 billion acre-feet) of water. It receives its water primarily from direct precipitation and thousands of small streams. The largest stream flowing into this lake is the Kagera River, the mouth of which lies on the lake's western shore. Lake Victoria is drained solely by the Nile River near Jinja, Uganda, on the lake's northern shore. It occupies a shallow depression in Africa and has a maximum depth of 84 m (276 ft) and an average depth of 40 m (130 ft).[5] Its catchment area covers 184,000 square kilometers (71,040 sq mi). [17]. The geographical location of the lake is shown in Figure 1.

Between the years 2000 to 2013, the water quality in Lake Victoria has undergone enormous changes due to increased urbanization, eutrophication and presence of aggressive weed "water hyacinth". The color of water has changed over time, although, it's difficult to monitor water color at every location with in situ measurements; through use of remote sensing, it's possible to study the whole lake. Analysis of trace metal contamination from sewer and industrial waste are better done through in situ measurements [18] to scaling of various metals. Spatial ecosystem assessment in this study has been carried out by comparing the vegetation vigor through NDVI; land use and land cover through supervised classification; and associated water quality in the lake focusing on chlorophyll concentration, total suspended mater and turbidity.

3. Methods and Data

In this study Landsat and MERIS images are used. Earth observation data from Landsat and MERIS images were selected at five year interval i.e. 2002, 2007and 2013. For each year, change detection, land use and land cover maps, and NDVI were generated from Landsat images. The images were subjected to supervised classification of five classes for each year from 2002 in the defined interval to subsequent years. The classes extracted were *water body, wetland vegetation, forests, other vegetation and unclassified.*

Change detection was done by subtraction one classified image from another of the of subsequent time stamp years as illustrated in Figure 2. From Landsat image, we generated land cover and land use information, NDVI and change detection information to enable us determine vegetation vigor, status of the land and water surface within wetlands and entire water body. Since satellite images collect brightness information in the form of digital number values (DN), the brightness was converted into reflectance to enable us determine the land cover spectral signature properties. The resulting information was compared with analysis of results from water quality information analysis of MERIS image.

Water quality information was defined from MERIS push broom imaging spectrometer satellite images full resolution.

The images were subjected to BEAM image processing software where digital number values were converted to reflectance. The resulting product was subjected to neural network tool to generate the threes water quality parameters.

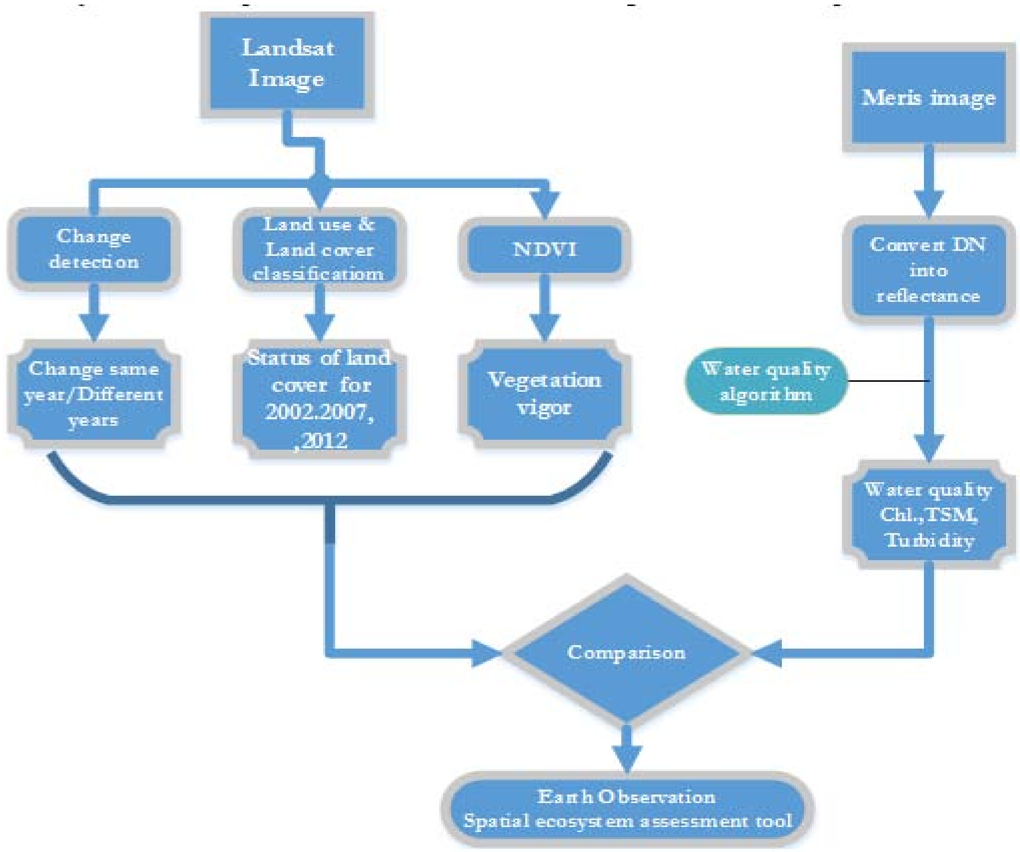

Figure 2: Earth Observation land cover and Water quality assessment model

The MERIS images were subjected to beam to generate water quality information on chlorophyll concentration on the lake, turbidity and total suspended materials. From the resulting information, comparison was carried out to determine the trend in changes of NDVI and corresponding water quality information in the lake.

In nutshell, Water quality was established through optimized optical domain method for mapping water quality parameters such as Secchi depth, Kd PAR, tripton and CDOM (colored dissolved organic matter). Substrate cover types could include algae, sea grass, sand, silt, or pollutes[19]. This approach involves the use of advanced land imager (ALI) together with in situ measurements of bio optical properties. The band ratio algorithm using band 2 and 3 developed was used to estimate CDOM content [20]. A series of preprocessing techniques such as radiometric correction and image rectification were applied on Landsat TM/ETM since the image of 2007 was full of strips, Landsat de-stripping was carried out. The open water covered areas were extracted from the images using the Modified Normalized Difference Water Index (MNDWI). Further, supervised classification was carried on false color composite of Landsat images and change detection method was used to detect spatial and temporal variations of the suspended sediment concentration (SSC).

4. Results

4.1. Land Cover Changes

The swath of Landsat image scene around Lake Victoria when classified reveals very broad classes at 30 meter pixels. However, comparing land use classification results reveals that there has been new classes of vegetation invading lake Victoria which was actually clear by year 2002, but five year later harbored by vegetation as shown in highlighted zones in Figure3 .

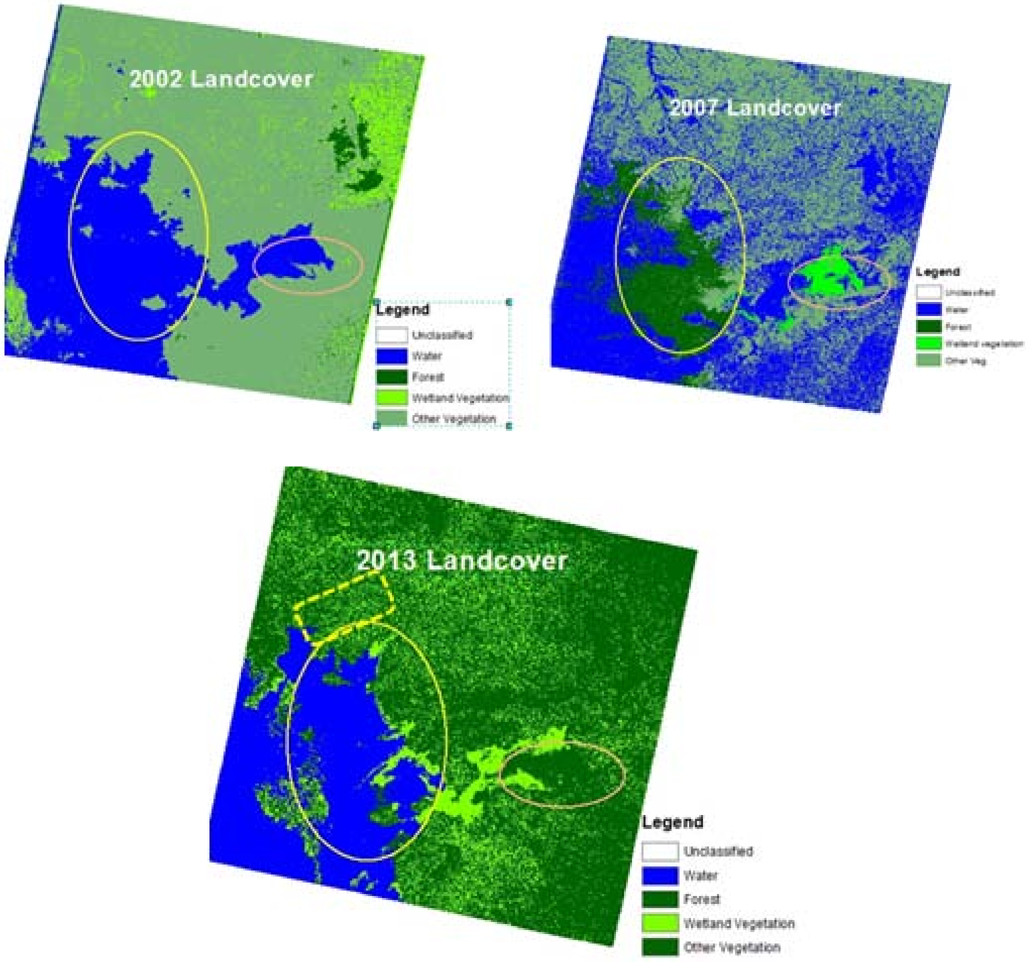

Figure 3: Land cover classification of lave Victoria

From the Land cover classification, it is clear that by the year 2002, there was little spread of green vegetation suspended on the water surface within Lake Victoria. Summary of area coverage by year 2002 is shown in Table 2.

Table 2: Land cover acreage by year 2002

Table

Sum_Output2002

OID	Class_Names	Count_Class_Names	Sum_Shape_Area
0	Forest	50333	773819499.848
1	Other Vegetation	41660	22354364814.799999
2	Unclassified	3	13663843759.1
3	Water	6881	10077257554.4
4	Wetland Vegetation	194347	2143617271.87

The trend changed in 2007, where the lake became very green like forest. The classification was done in false color composite and results of supervised classification revealed that, the Lake had green vegetation with spectral signatures similar to those of forest. This can be attributed to the green nature of Hyacinth weed, algae bloom, and other water vegetation during this period in time as shown in Table 3.

Table 3: Land cover acreage by year 2007

Table

Sum_Output2007

OID	Class_Names	Count_Class_Names	Sum_Shape_Area
0	Forest	153839	3529886083.48
1	Other Veg	334611	15821900972.200001
2	Unclassified	1	13812199381.4
3	Water	397644	15578207190.700001
4	Wetland vegetation	26460	670633272.126

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Table 4: Land cover acreage by year 2013

Table

Sum_Output

OBJECTID *	Class_Names	Count_Class_Names	Sum_Shape_Area
1	Forest	34106	572831507.598151
2	Other Vegetation	177418	22125384906.861755
3	Unclassified	1	14627189193.572533
4	Water	10678	6996880542.316276
5	Wetland Vegetation	1067491	5099342749.623189

However, by 2013, the dark green vegetation within the lake had reduced, but light green vegetation representing light and young vegetation increased in acreage as shown in Table 4 spreading wide within the lake (see dotted yellow line) in Figure 3. The area dotted yellow was actually clear water by the year 2002.

4.2. Change detection

The green color within the lake water body increased between the years 2002 to 2007 considerably. This is due to presence of water vegetation species like hyacinth, algae bloom, among others that was adversely capturing Winam gulf during this time. However, from 2007 to 2013, the greenness on the lake decreased over a good portion of the lake, but increased towards, the terminal end of the gulf as shown in Figure 4. This is due to activities going on the lake aimed at reducing the areal extent of the hyacinth within Lake Victoria and other efforts of conservation attributed to government parastern al, IGO[3] and NGOs. The gulf also suffered more of concentrated chlorophyll due to its hinterland nature caused by town built up, which blocks the East trade winds from spreading the hyacinth and other aquatic vegetation towards the western side of the lake.

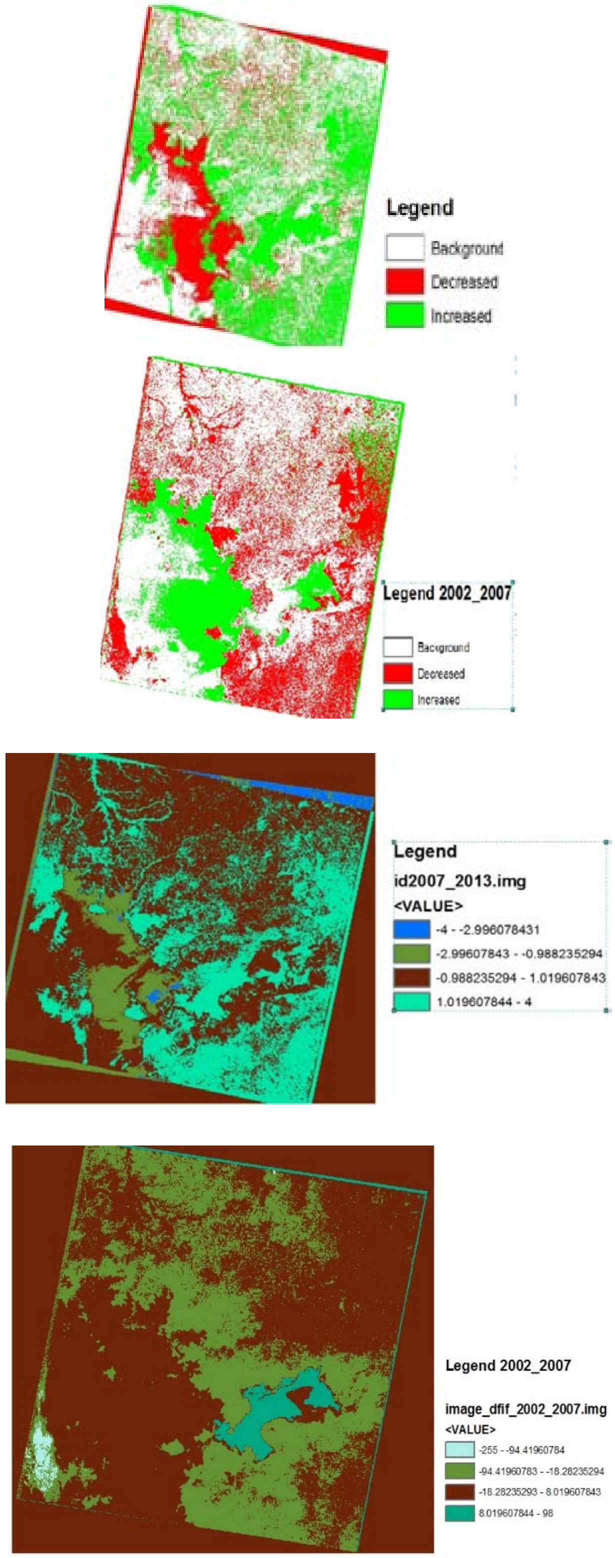

Figure 4: Change detection within Lake Victoria

4.3. Normalized Difference in Vegetation Index (NDVI)

The vegetation vigor was high during the year 2002, with higher portion of the region around the lake being green with NDVI values above 5.5 on average range values as shown in Figure5. During this period also, the wetland vegetation and vegetation values within the water body were less than 0.05.

[3] Inter-governmental organizations

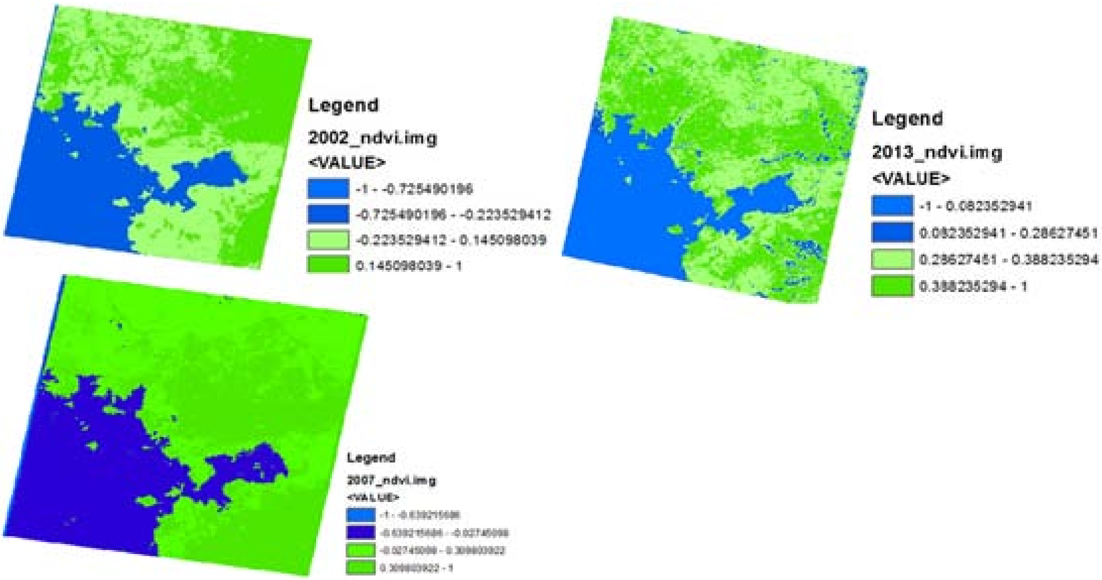

Figure 5: NDVI of vegetation within and around Lake Victoria

4.4. Water Quality

The chlorophyll concentration on Lake Victoria increased over time from the year 2002 to year 2013. For instance between year 2002 and 2007, the Chlorophyll concentration has increased from 37.41 to 40.8 mg m^3 representing 9.16% increase in chlorophyll concentration within the lake as shown in figure 6.

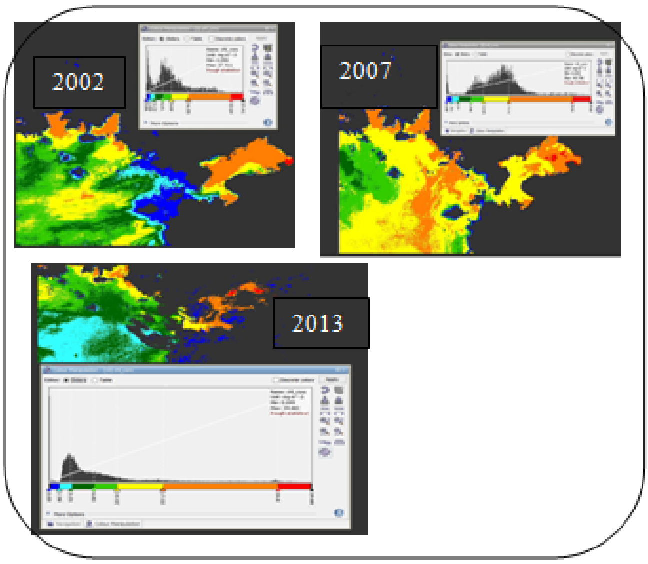

Figure 6: Water quality for lake from 2002- December 2012

However, between 2007 and year 2013, the chlorophyll concentration reduced from 40.8 to 39.88 mg m^3 small margin of 2.255%. On the other hand, TSM has increased over the years from 44.593 g m^3 in year 2002 to 51.58 g m^3 2007 representing 15.67% and consequently increased to 53.347 g m^3 from 2007 to 2013 representing increase of 3.43%. Moreover, turbidity over the lake has increased over the lake since the year 2002 with FNU of 22.21 in the year 2002, FNU 28.922 in 2007 and FNU of 29.16 FNU in year 2013. This represents increase of 30.22% between years 2002 to 2007 and consequently increases of 8.23% from the year 2007 to 2013 as summarized in Table5.

Table 5: Water quality comparison from 2002-2012

Water quality variable	2002	2007	2002-2007 % Change	2013	2007-20130 % Change
TSM	44.593	51.58	15.67	53.347	3.43
Chlorophyll	37.14	40.8	9.16	39.88	-2.255
Turbidity	22.21	28.922	30.22	29.16	8.23

The higher chlorophyll concentration on Lake Victoria results into reduced oxygen presence within the aquatic environment and hence compromised interaction of various activities of fauna and flora which would otherwise thrive very well in undisturbed ecosystem of Lake Victoria wetlands.

5. Discussion and Conclusions

The results of the study have shown that over the last thirteen years, water in lake Victoria has been invade by excess external vegetation resulting from poor management of wetlands and its surrounding. There is positive trend of increase of vegetation over the lake especially on Winam gulf. It has also emerged that vegetation vigor of wetland vegetation around the lake declined significantly between the years 2002 to 2007 than the year 2013. The water quality indices of the lake also illustrates that the water in the lake was of good quality in the year 2002, which deteriorated in subsequent years to contain more chlorophyll by year 2007 and 2013.

The model of spatial ecosystem assessment presented in this research provides a robust platform for carrying out comparison land cover information with resulting water quality information indices. Wetlands play vital role in controlling turbidity around a given water body, since turbidity increased by over 30% between 2002-2007 and 8% between 2007-20013, it evident that lake Victoria wetlands have deteriorated over this period and hence poor water quality.

6. Future Research

This study has investigated link between change in land cover and resulting water quality information on the whole of Lake Victoria. . However, future research should focus on link between water quality parameters time series and land cover changing trends on specific wetlands within the Lake Victoria basin.

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